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SolarPACES Task VI Report

SOLAR ENERGY & WATER PROCESSES AND APPLICATIONS

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SOLARPACES TASK VI PROJECT

First Phase (2010-2011): Assessment of CSP+D potential in the MENA area

Objective: technical assessment of possible configurations of CSP plants with Desalination facilities in the MENA region, considering specific coastal DNI potential and water and energy needs, using Egypt as reference country.

Partners: CIEMAT (Spain), DLR (Germany), NREA (Egypt)

SolarPACES budget: 25.000 Euros

Second Phase (2011-2012): Feasibility study of CSP+D integrated plant in Port Safaga (Egypt)

Objective: preliminary feasibility study of a integrated CSP+D plant at the Egyptian location selected within the previous study (Port Safaga, Red Sea) and over the selected configurations

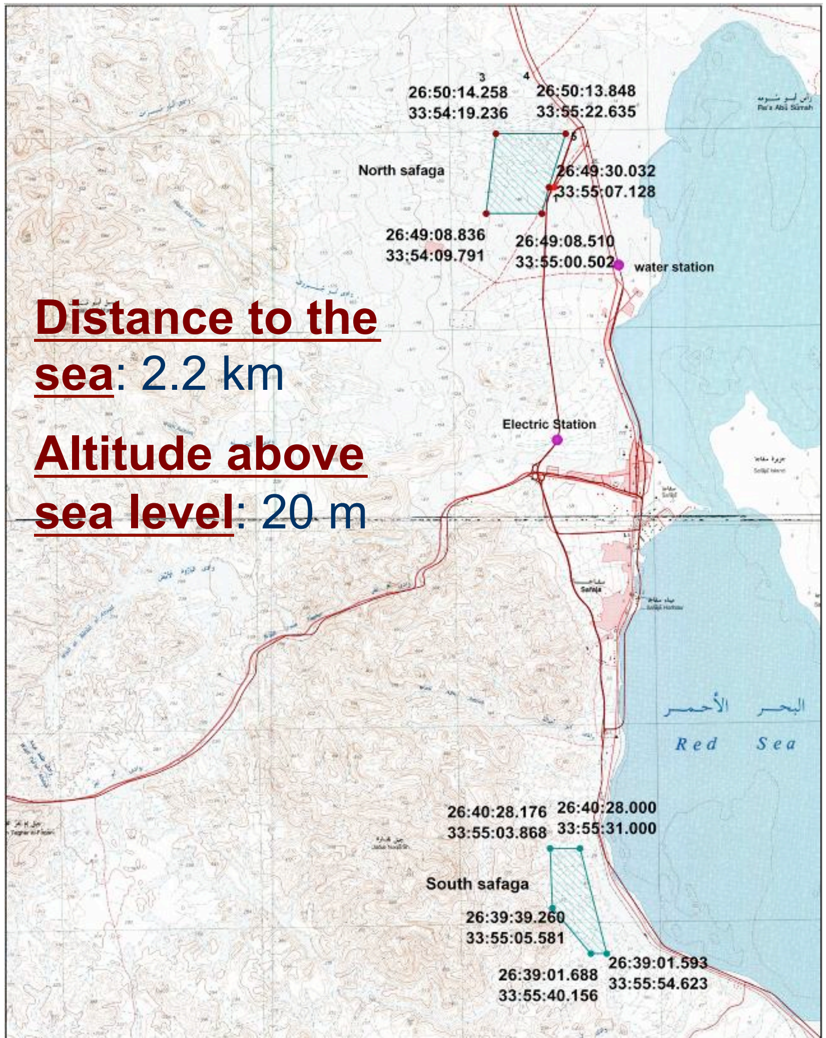
Partners: CIEMAT (Spain), DLR (Germany), NREA (Egypt)

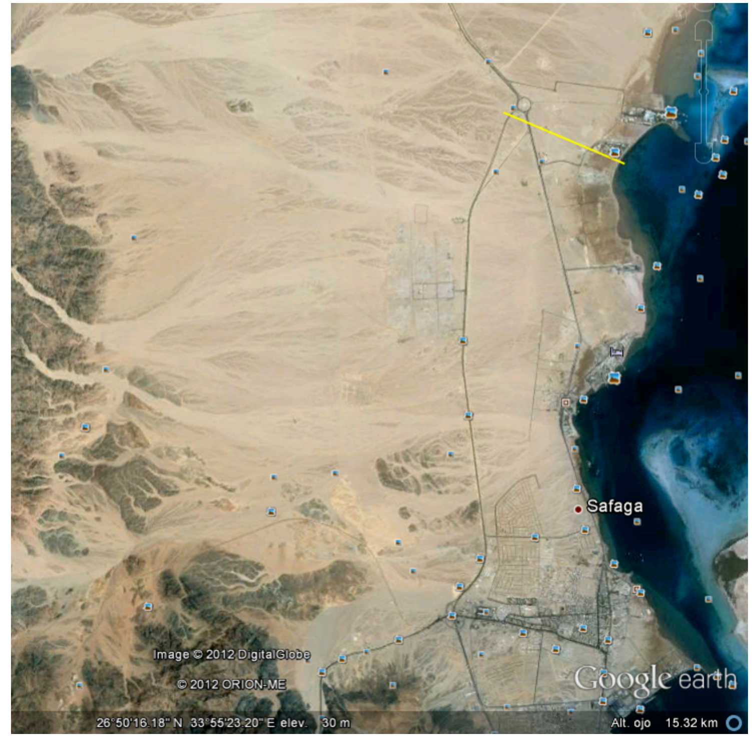
SolarPACES budget: 25.000 Euros

LOCATION SELECTION

Distance to the sea: 2.2 km

Altitude above sea level: 20 m





SECOND PHASE ASSUMPTIONS

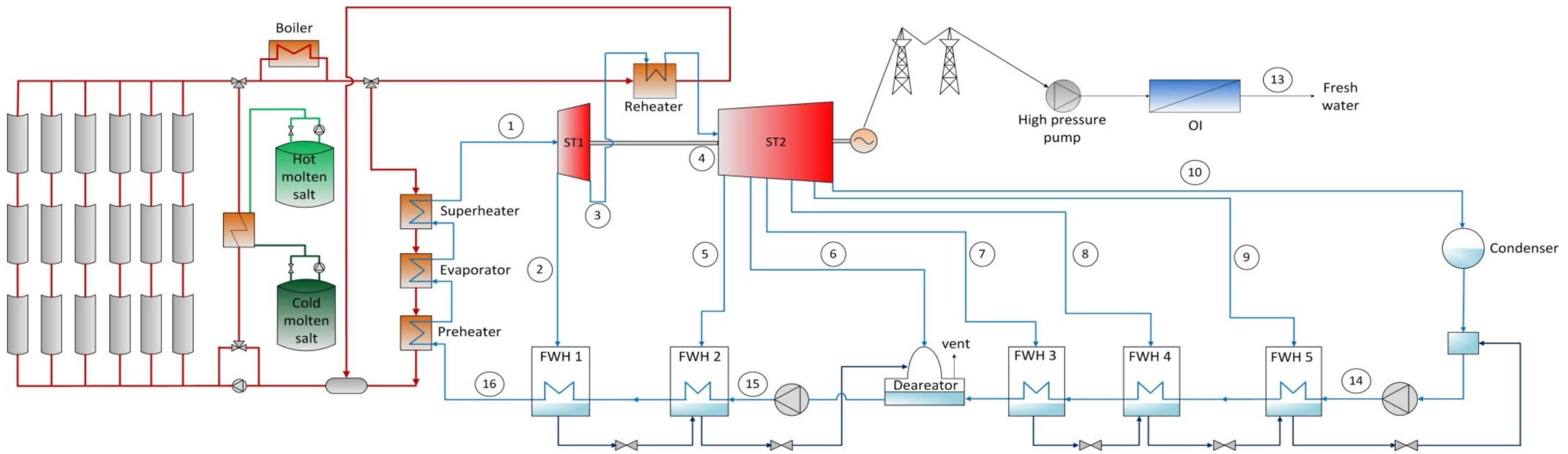
- Preliminary design and analysis of a CSP+D plant in Port Safaga, Egypt
- Plant Inputs: Turbine net capacity 50 MW (at design)
  Storage capacity 6.5 hours
- Analyzed cases:

Case	Cooling System	Desalination
1	Once-Through	RO
2	Evaporative Cooling	
3	Dry Cooling	
4	MED	

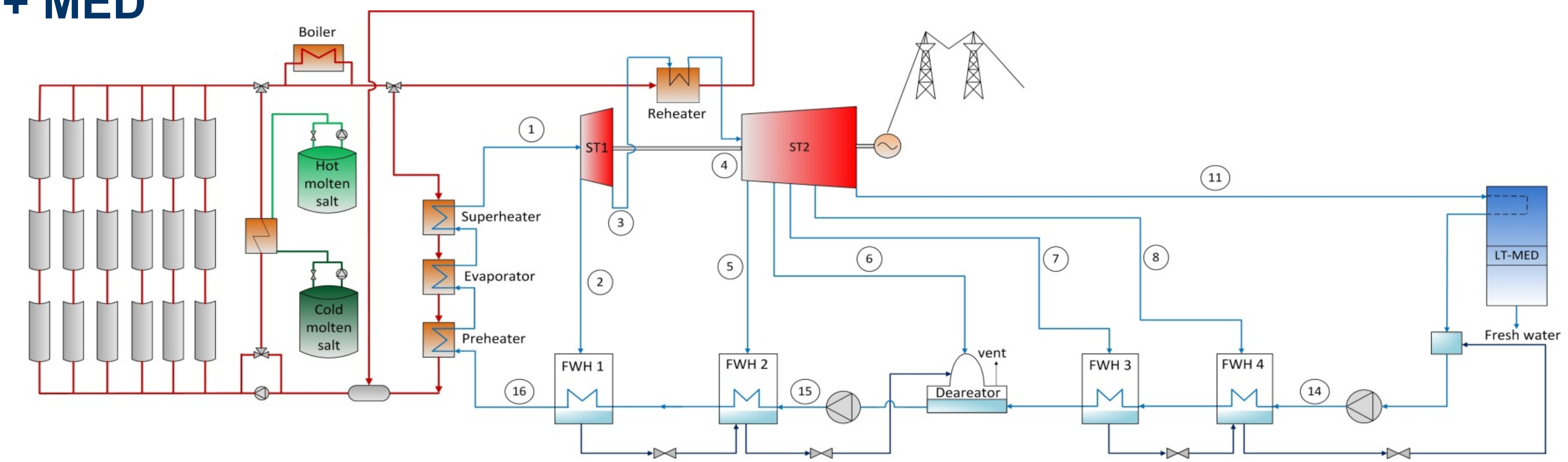
- Main assumption: the MED case (GOR = 10) defines the net fresh water production for the RO cases
- Electricity and heat cost for desalination are taken into account in the CSP plant
- Water consumption by CSP is assumed by the Desalination unit
- Plant layout bases on the definition of design conditions (no optimization)

ANALYZED CONFIGURATIONS

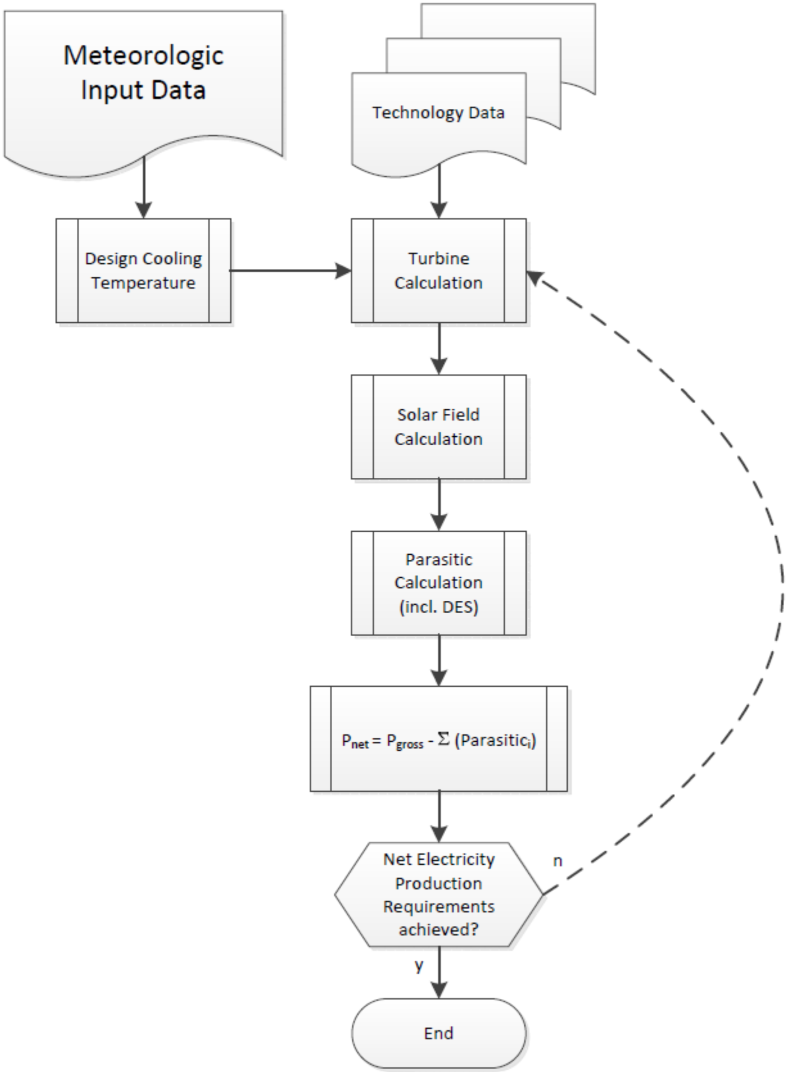
CSP + RO



CSP + MED



METHODOLOGY



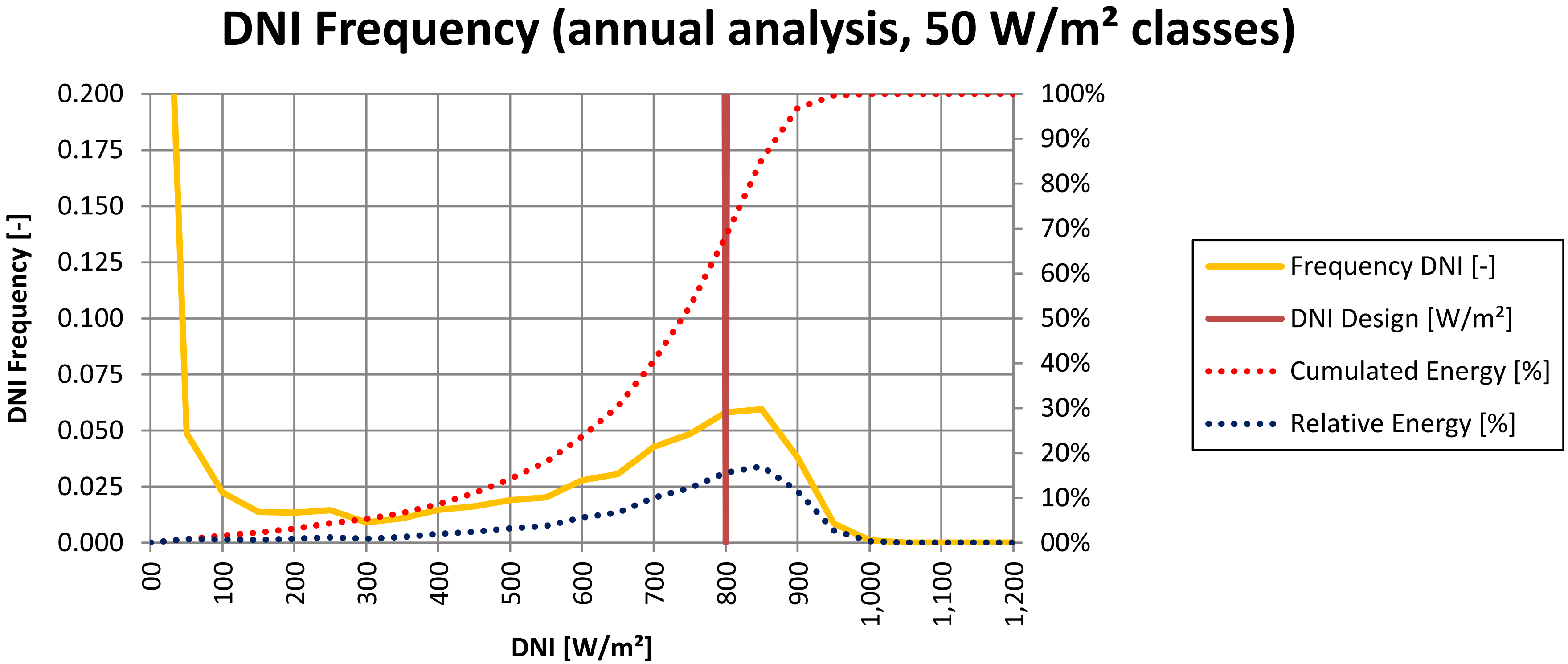
1. Calculation of cooling temperature at design conditions
2. Thermodynamic calculation of the turbine (using typical published values of Andasol plants)
3. Solar field design
4. Calculation of the internal electricity and water consumption of the plant components

- *Steps 2-4 need an iteration in order to meet the net power requirements*
- *Solar field and thermal energy storage optimization was not carried out*

DNI DATA ANALYSIS

DNI value provided by IRSOLAV: 2,496 $kWh/m^2/y$

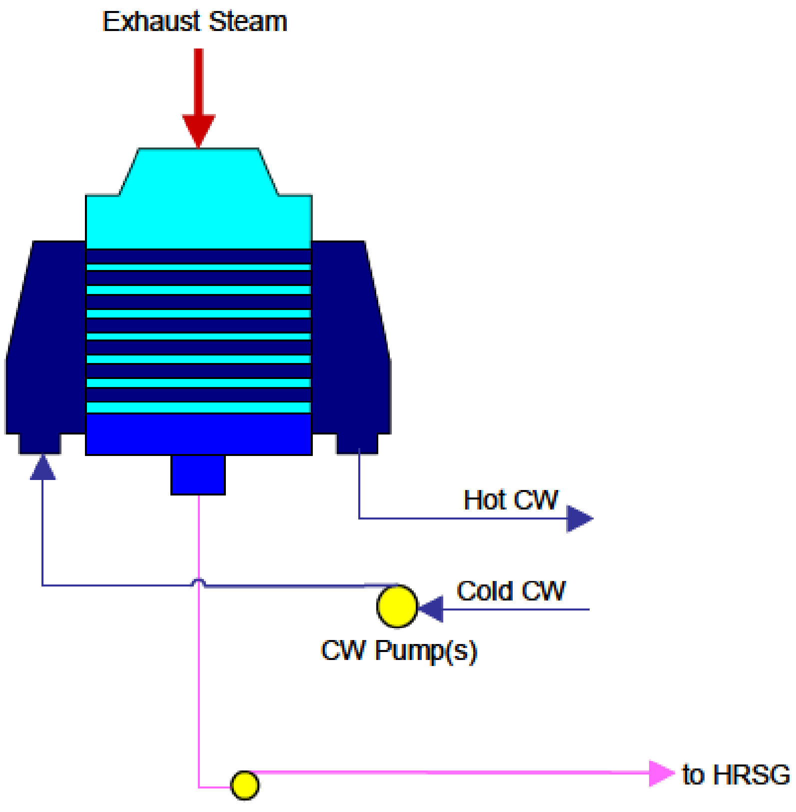
DNI annual sum (DLR): 2,486 $kWh/m^2/y$



ONCE-THROUGH COOLING

- Cold water from the sea is circulated through the condenser in order to remove the waste heat
- After flowing through the condenser, the hot water is returned to the environment
- The steam condensation temperature (T_{cond}) depends on the seawater temperature (T_{sw}) and on the temperature difference in the heat exchanger ($\Delta T_{condenser}$ = 10 °C):

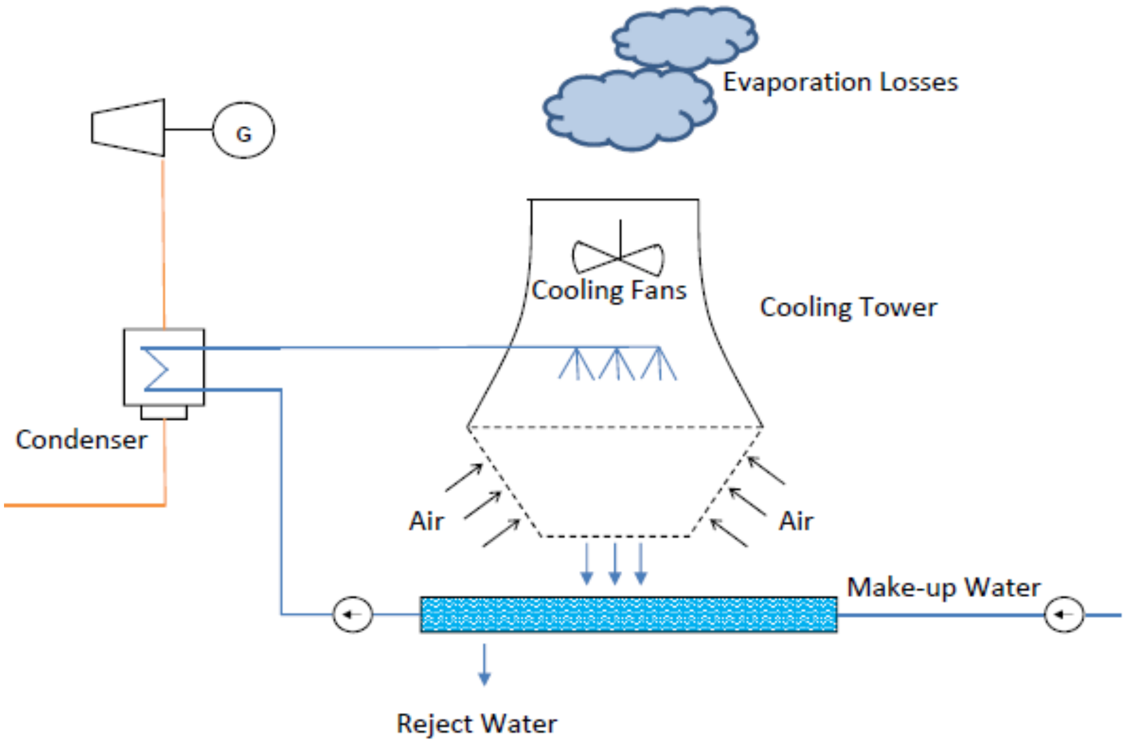
$$T_{cond} = T_{sw} + \Delta T_{condenser}$$



Source: Tawney, 2003

EVAPORATIVE COOLING

- The evaporative cooling condenses the steam inside tube bundles that are constantly over-sprayed with water from the cooling tower basin
- The heat exchange process is governed by the **wet bulb** air temperature
- Assumptions of ΔT:
  - 7°C tower approach ($T_{water\_tower\text{-}out} - T_{air\_wb\_tower\text{-}in}$)
  - 3°C condenser approach ($T_{water\_cond\text{-}out} - T_{steam\text{-}in}$)
  - 8°C difference between the inlet and outlet temperature in the condenser



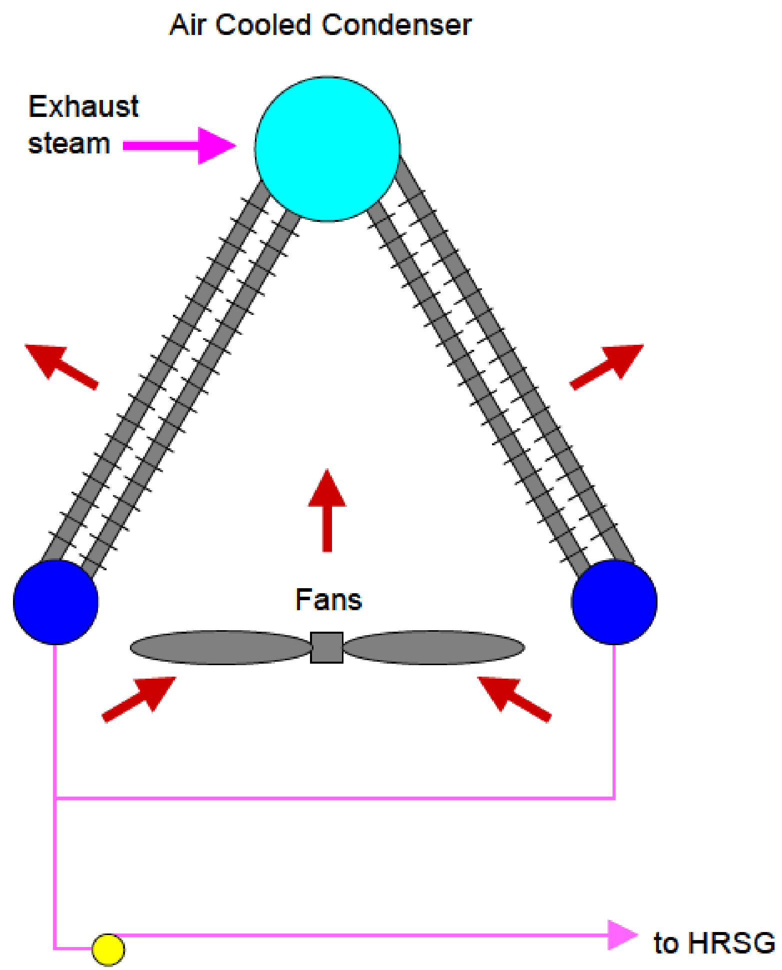
Source: Sokrates, 2003

DRY COOLING

- Dry-cooling systems rely on convective heat transfer between air and finned tubes
- The heat exchange process is governed by the **dry bulb** air temperature
- Assumptions: 20°C of ΔT at the aero-condenser (US DoE, 2009)

The design air temperature for the wet cooling is not the same as for the dry cooling

***Assumption**: the design is performed for each cooling system at the "most adverse" conditions in the year*



Source: Tawney, 2003

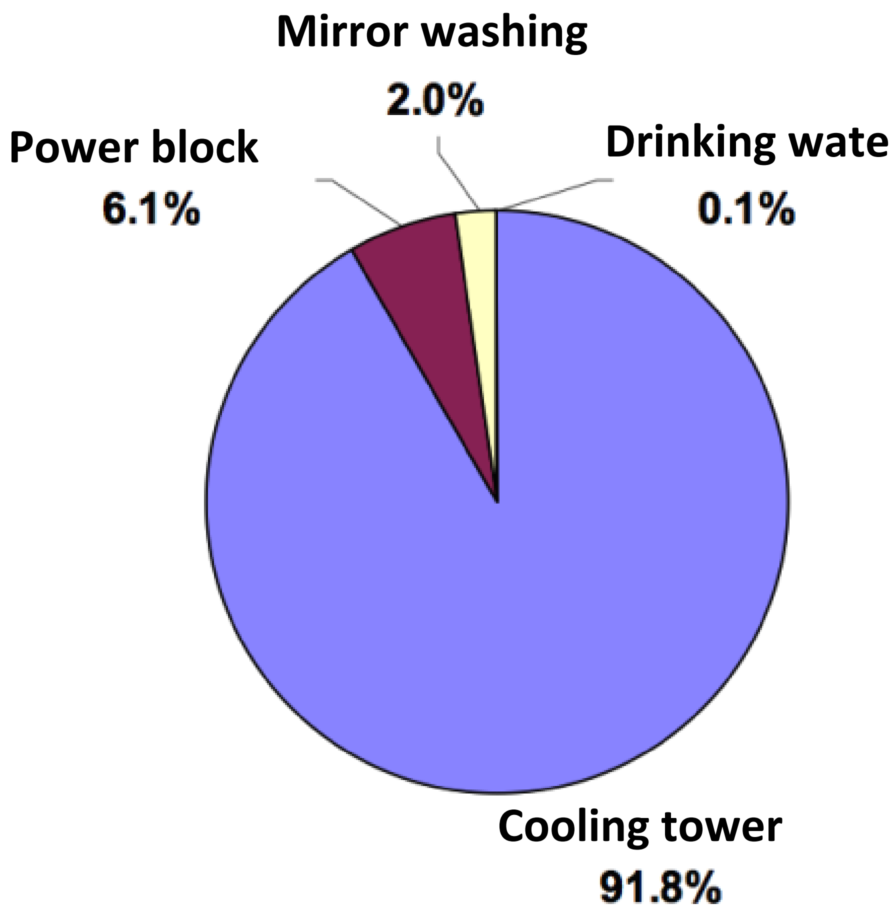
STEAM CONDENSING TEMPERATURES

- As expected, the once-through cooling is the most efficient cooling system
- The efficiency difference between dry and wet cooling system is the higher the lower is the design relative humidity

Cooling Systems				
	Units	Once through	Evaporative	Dry cooling
T_{amb}	°C	-	30.0	40.0
Rel. Hum.	-	-	0.65	0.00
T_{sw}	°C	28.0	-	-
$\Delta T_{aerocondenser}$	°C	-	-	20.0
$\Delta T_{condenser}$	°C	10.0	3.0	-
Tower approach	°C	-	7.0	-
Cooling range	°C	-	8.0	-
T_{wb}	°C	-	25.0	-
T_{cond}	°C	38.0	43.0	60.0

WATER CONSUMPTION

Percentage of water consumed in a solar thermal power plant with evaporative cooling, to be provided by the desalination plant



Source: Richter, 2010

MAIN RESULTS

Power Cycle					
Value	Unit	Once-Through + RO	Evap. Cooling + RO	Dry Cooling + RO	MED
P_{gross}	MW_{el}	65.8	68.3	69.4	60.2
P_{net}	MW_{el}	50.0	50.0	50.0	50.0
η_{turb_th}	-	39.4%	38.7%	36.0%	34.5%
η_{turb_gross}	-	38.3%	37.5%	35.0%	33.5%
η_{turb_net} (CSP w/o DES)	-	33.9%	32.3%	29.4%	29.4%
η_{turb_sys} (incl. DES)	-	29.1%	27.5%	25.3%	27.8%
Q_{turb_in}	MW	172	182	198	180
T_{cond}	°C	38.0	43.0	60.0	70.0
P_{par_SF}	MW_{el}	5.1	5.5	6.2	5.4
P_{par_TES}	MW_{el}	0.9	1.0	1.1	1.0
P_{par_TURB}	MW_{el}	0.9	0.9	1.0	0.9
P_{par_COOL}	MW_{el}	0.7	2.2	2.9	0.0
P_{par_DES}	MW_{el}	8.2	8.6	8.2	2.9

CSP Plant					
Solar Field (SF)					
Loop Number	-	192	204	222	202
Net Mirror Area (A_{sf})	m^2	627,960	667,200	726,070	660,660
Thermal Energy Storage (TES)					
TES Thermal Capacity	MWh_{th}	1,118	1,182	1,288	1,170
Molten Salt Mass	tons	28,800	30,500	33,200	30,100

THERMODYNAMIC CONCLUSIONS

Thermodynamic Analysis Conclusions

- The gross power generation in the different cases varies up to more than 5 MW (due to the different internal power consumption of the system components)
- The power consumption of the MED is roughly 1/3 of the consumption of the RO. Therefore in all RO cases a larger gross capacity is required in order to achieve the 50 MW net power production.
- Lower thermal efficiency (MED, dry cooling) → higher thermal requirements for the turbine → larger solar field
- Dry cooling presents the lowest system efficiency and the highest internal power consumption for the cooling

COST ESTIMATIONS

Input Parameters - Main Assumptions

- They have been taken from the literature (i.e. NREL, 2010; Tawney et al., 2003) and personal communications (CIEMAT / DLR)
- It has been assumed an additional power production of 15% with natural gas
- Solar Multiple (SM) is considered 1.9

	Unit/Reference	Once-Through + RO	Evap. Cooling + RO	Dry Cooling + RO	MED
Interest Rate	%/tot_inv/y	6.5%			
Insurance Rate	%/tot_inv/y	1.0%			
Plant Life	y	20			
Total land requirement	Ha	200			
Parasitic loads	Net yearly power production	10%			
Plant availability	---	0.96			

METHODOLOGY

Results – CSP Plant Annual Analysis

	Units	Once-Through + RO	Evap. Cooling + RO	Dry Cooling + RO	MED
DNI	kWh/m²/y	2486			
FLH	h/y	4140			
Capacity factor		0.47			
Parasitic cooling	Mwel-h/y	2740	9019	11928	0
Parasitic desal plant	MWel-h/y	33485	41019	33527	11813
Parasitics loads	MWe-h/y	19874	19874	19874	19874
Pel_net_tot	GWh/y	198.7	198.7	198.7	198.7
Pel_net_tot (including 15% gas)	GWh/y	228.6	228.6	228.6	228.6
Pel_gross_tot	GWh/y	262.1	268.7	264.1	230.4
Pel_gross_tot (including 15% gas)	GWh/y	301.4	309	303.7	265

METHODOLOGY

Results – Desalination Plant Annual Analysis

Technical analysis: specific water consumption for power block, mirror washing, drinking water

	Units	Once-Through + RO	Evap. Cooling + RO	Dry Cooling + RO	MED
Water consumed by the CSP plant	Mio. m^3/y	0.08	0.08	0.09	0.08
Water consumed by the cooling tower	Mio.m^3/y	n/a	0.9	n/a	n/a
Total Water Production	Mio. m^3/y	7.4	7.9	7.5	7.4

Technical analysis: specific water consumption for the cooling tower

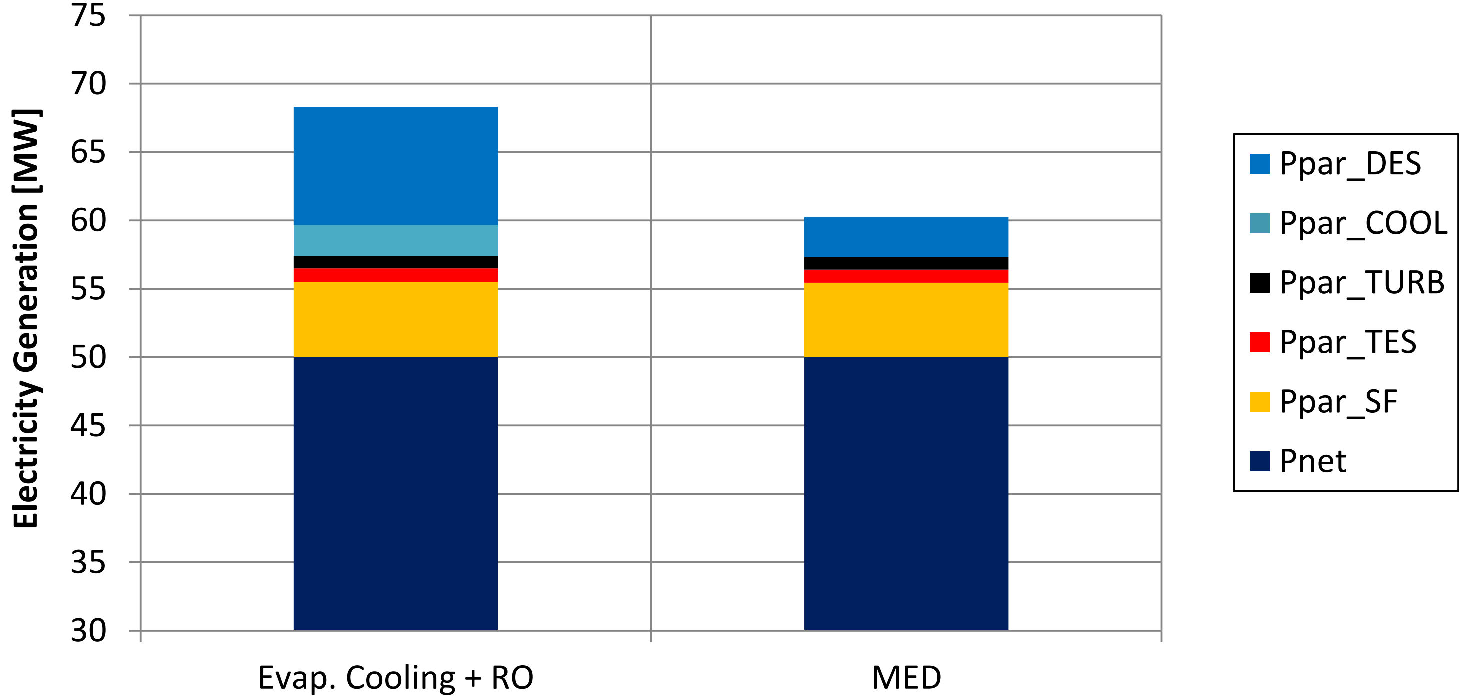
RESULTS: INVESTMENT COSTS

Breakdown of main CSP+D components investment

	Units	Once-Through + RO	Evap. Cooling + RO	Dry Cooling + RO	MED
SF	Mio. €	126.9	135.4	146.5	132.1
Land preparation and infrastructure	Mio. €	43.2	43.2	43.2	43.2
HTF and hydraulic circuit	Mio. €	45.7	48.7	52.7	47.6
TES	Mio. €	44.6	47.6	51.5	46.4
PB	Mio. €	45.5	47.6	48.0	41.5
Cooling	Mio. €	2.7	4.3	16.6	0
Auxiliary gas burner	Mio. €	7.2	7.1	8.3	7.5
DES	Mio. €	43.4	53.1	43.4	43.9

LEC & LWC RESULTS

Comparison of Internal Electricity Consumption



	Units	Once-Through + RO	Evap. Cooling + RO	Dry Cooling + RO	MED
LEC	€cent/kWh	21.75	23.00	25.01	21.68
LWC	€/m³	0.83	1.00	0.83	0.87

COST CONCLUSIONS

Comments on Economic Results

- Among the RO cases, the Once-Through is the best one in terms of LEC and LWC
- Under the given boundary conditions, the MED performs the lowest LEC although the thermal efficiency is relatively low. This can be explained by the low internal electricity consumption of the plant
- The high LWC for the evaporative cooling case is due to the elevated internal water requirements of the cooling system (evaporative losses)

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TASK VI STATUS

- **Task VI structure:** Successful creation of a nucleus of interest in the related topics
- **Effective participation (to date)**: Egypt, Germany, Mexico, South Africa, Spain and United States
- **Main activities to date**:
  - Information sharing (mainly through Task Meetings)
  - Active collaboration (mainly through SolarPACES funded activities)
- **Specific topics of active collaboration (to date)**:
  - CSP+D (integration of desalination into CSP plants).
  - Assessment of cooling technologies performance (initiated)
  - Solar detoxification and disinfection

TASK VI STATUS

- Participation in the Task has been increasing (slowly) and it is expected to continue that way
- Two main topics of interest: concentrating solar power & desalination and solar detoxification.
- CSP cooling issues are relevant to the CSP+D subject
- Economics is also a relevant associated topic of high interest
- SolarPACES funded activity considered as highly relevant to promote and enhance Task collaboration
- New collaboration possibilities and opportunities are envisaged for the future (EERA)

TASK VI MEETINGS EVOLUTION

Task VI organized meetings:

1) Paris (13.11.2007) → Launching meeting with 5 people attendance
2) Las Vegas (08.03.2008) → 13 participants from 8 countries [Australia (2), France (2), Germany (3), Israel (2), Mexico (1), South Africa (1), Spain (1) and Switzerland (1)]
3) Berlin (14.09.2009) → 13 participants from 6 countries [Germany (4), Japan (1), Mexico (2), South Africa (2), USA (1), Spain (3)]
4) Perpignan (20.09.2010) → 12 participants from 6 countries [Egypt (2), Germany (1), Mexico (2), South Africa (3), USA (2), Spain (2)]
5) Granada (19.09.2011) → 15 participants from 7 countries [Egypt (2), Germany (2), Mexico (4), South Africa (2), USA (1), Spain (3) and Cyprus (1)]
6) Marrakech (10.09.2012)

Thanks for your attention …