CSP from dusk till dawn:
Blueprint for 200 MW tower plant fills the PV gap

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CSP is a key player in the renewable energy market, overcoming some of the issues PV plants leave in the dispatch of solar energy. Tower projects with molten salt storage have taken key attention of Concentrated Solar Power (CSP) projects, helping to provide dispatchability and flexibility to grid operators.

CSP plants are complex systems that need proper engineering, that's why the project "CSP Reference Plant" has developed a blueprint to save time and money through an optimized and standardized plant layout which fits with few adjustments to many locations and different requirements.

This webinar explores the typical requirements for future CSP plants to complement PV at achieving lowest LCOE around the clock:

- Explore how to use the blueprint for your tender to integrate CSP to your energy strategy to benefit from innovative technologies, project structuring and complementing PV.
- Examine how to overcome main challenges when designing and selecting the components for CSP tower with molten salt storage.
- Hear directly from the source how CSP can fill the gap of other renewables like PV with enhancing grid flexibility and reliability, enabling the supply of clean power 24/7.
- Find out about the bankability of these projects in the short to medium term and how ultimately they can help add more renewables in the grid.

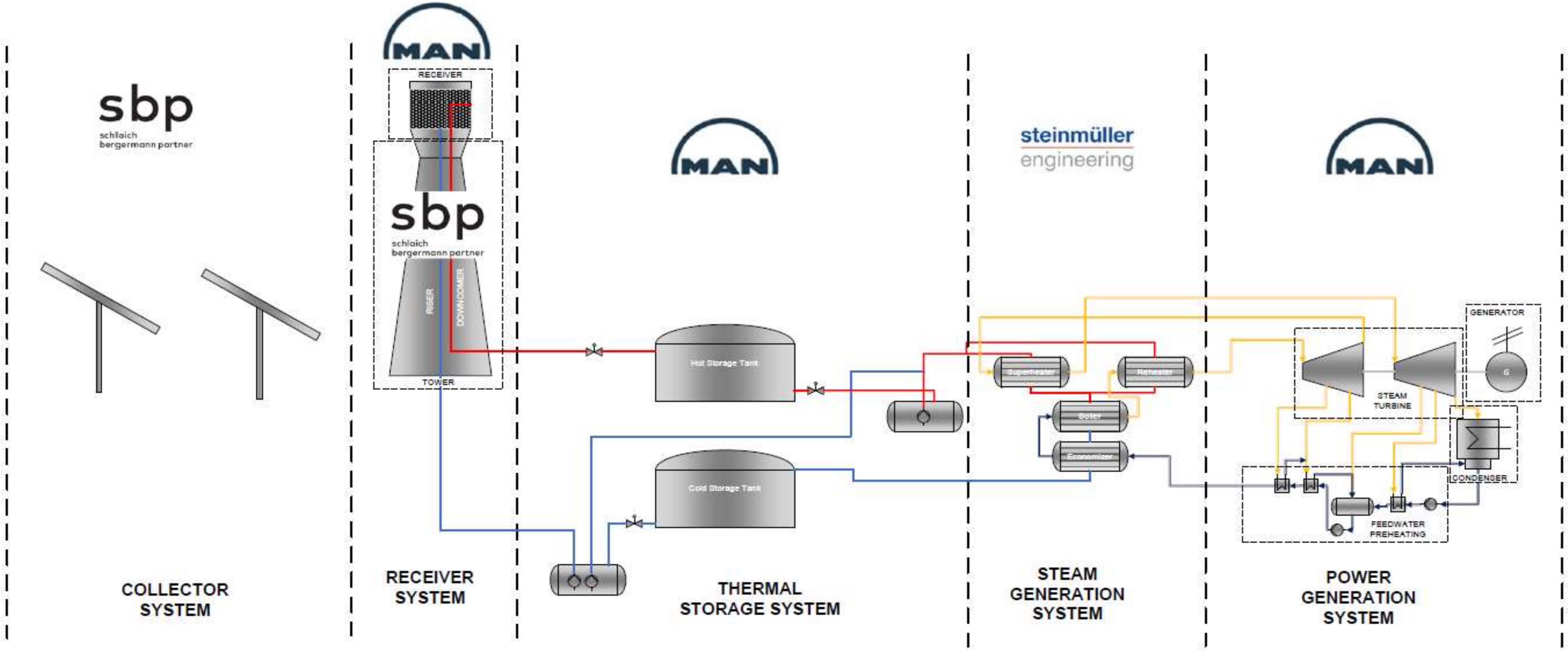
Project Goals

- Development of an optimized molten salt solar tower power plant which can be delivered by the project partners

- Draft a blueprint of this CSP plant which may be used for several sites and countries with minimal adaption

- Aim to safe costs and time for future plants

Project Task Share



Project coordination, annual yield calculation

Market analysis, risk analysis and bankability

Methodology

- Fixing of assumptions and boundary conditions
- Selection of key equipment within reasonable sizes
- First optimization of key equipment sizing like Steam Turbine System, Steam Generation System, Heliostat Field and Solar Receiver
- Setup of a conceptual design
- Techno-economical analysis and further detail optimization for component sizing
- Full conceptual design and conceptual layout
- Risk analysis and bankability check

Our Road to Success

Demand for renewable energy from solar is high.

As solar electricity by PV can be produced inexpensive (but only at daylight), our analysis revealed that CSP power plants currently rather shall deliver electricity after sunset than during daylight hours.

Two general scenarios for electricity production by CSP may be observed:

- Operation from sunset to sunrise (Night operation)
- Operation after sunset for about 5 -7 hours (Peaker operation)

Boundary Conditions
Solar Energy

You want to develop your plant: **WHERE** should it be?

Locations are very different, all are demanding, no one is the same.

To start with a good compromise we selected as **exemplary site** Morocco‘s **Ouarzazate**: region with good conditions for CSP, moderate latitude and good irradiation (2500 kWh/m²a)

- Site not too good and optimistic (like Chile)
- Site not too challenging or too low in DNI (like Dubai or China)
- Meteorological conditions allows easy variation to suit a future site location

A **good set of meteorological data** is common available.

Boundary Conditions
The Power Machine

You want to sell power. How much and how profitable?

We started with the typical size of realized plants. We asked ourselves:
How much bigger?

We continued with the demand: When to sell power most profitable? Can we serve this market? **What do we need?**

- 50MW$_e$ is small. 100MW$_e$ is state of the art. Does **200MW$_e$** work out?

Power at daytime is hard to sell, PV is cheaper.
Power at nighttime is a good deal – **power on urgent demand** even a better sell:

- Build a **Thermal Storage System** to serve at best during peak demand (evening hours).

Boundary Conditions
Keep in Mind…

What else do you need to consider at the start:

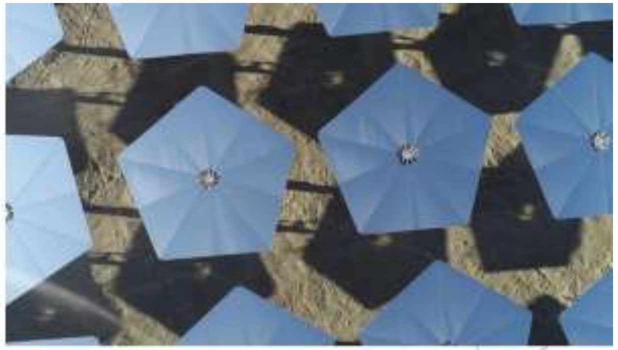
You convince your Client → the Project needs to be lucrative

You convince your Financier → the Project needs to be affordable and bankable

You convince the Community → the Project needs to be future oriented

- Selection of state-of-the-art technologies and equipment, wherever possible at a borderline to the newest developments and latest experiences.

sbp
schlaich
bergermann partner



Heliostat field

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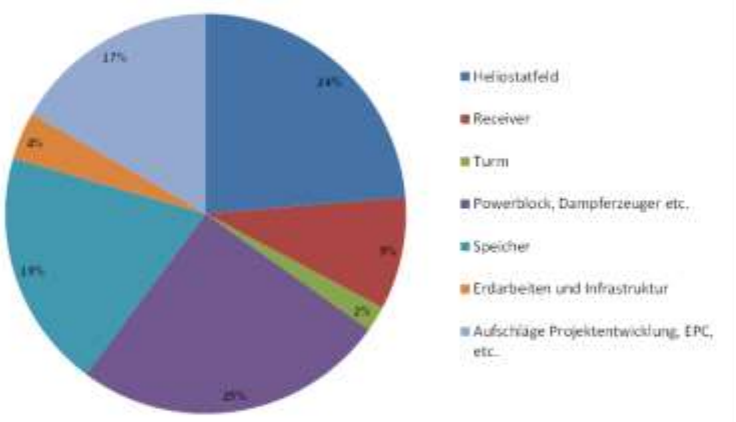
Speaking about Cost:
Input Parameters

For the techno-economic analysis and optimization the plant and its components needs to be priced. Existing Datasets for modeling were aligned with real project data.

This dataset, consisting of dozens of individual items, is our starting point for optimization.



	Spec. Cost	Unit
Civil Works	2	€/m²
Heliostat Field	100	€/m²
Tower	61706	€/m
Receiver System	70	€/kW$_{th}$
Thermal Storage	20	€/kWh$_{th}$
Steam Generator (net power)	110	€/kW$_{el}$
BoP incl. Steam Generator (gross power)	810	€/kW$_{el}$
Loan Period	25 (35)	years
Interest Rate	6 (3)	%
EPC Marge, Project Development, other costs	20 (15)	%
Insurance during Construction	1	%
…	…	

However, costs are very volatile and are different for each project environment – you need to critical review such data and modify to your needs.

Techno-Economic Analysis

Optimization as an iterating process has been executed by all partners with several tools and models:

- ➢ Reduction of receiver overload
- ➢ Optimal storage capacity (Annual Yield Analysis)
- ➢ Operation mode (Solar only, Night supply, Peaker Mode, etc.)
- ➢ Variation of operation times (e.g. time of startup and shut down of ST)
- ➢ Variation of economic parameters (like loan period, interest rates, margins, etc.)

One sample for optimization: Annual Yield Analysis

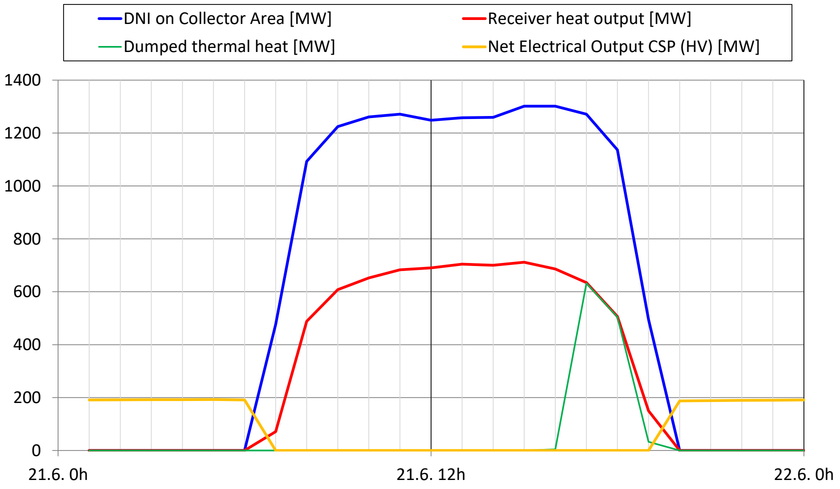
- The solar field and PB performance of the optimized systems were finally used to find the storage capacity leading to lowest LCOE for both scenarios

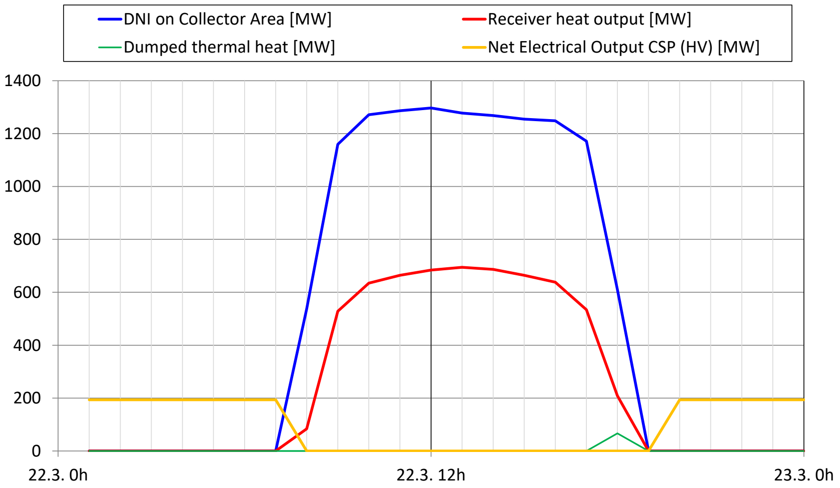
- The storage capacity (in full load hours) is mainly determined by the number of hours the plant may deliver electricity, but this number varies seasonally

- Variation of the start and end hour (±1 hour) has only limited impact on the optimal storage size

Operation mode	Nominal power	Storage capacity	Storage capacity	Rel. LCOE	Net electricity	Solar capacity factor*)
	MW	h	MWh		GWh	%
Solar only	200	5	2295	1.00	672.4	41
Nighttime	200	13	5967	1.30	628.8	69
Peaker	2*200	6	5508	1.84	539.5	64
Peaker	2*200	6.5	5967	1.85	544.9	64

*) Based on the total number of hours the individual plant would be allowed to deliver electricity





Some results for minimizing LCOE

Operation mode	Nominal power	Storage capacity	Storage capacity	Rel. LCOE	Gross electricity	Net electricity	Dumping	Solar capacity factor*)
	MW	h	MWh	€/kWh	GWh	GWh	GWh	%
Solar only	200	5	2295	0.0878	717.5	672.4	39.9	41
Nighttime	200	13	5967	**0.1115**	651.4	628.8	184.9	**69**
Peaker	2*200	6	5508	0.1599	558.2	539.5	335.4	64
Peaker	2*200	6.5	5967	0.1603	563.7	544.9	321.2	64

*) Referenced to the hours of power export

- **Solar only**: reference value – power export at anytime, max power production
- **Nighttime**: power export from dawn to dusk
- **Peaker**: power export from dawn to midnight only

Of course, limitation on power export increases the costs – storage needs to grow and operation hours / power production decrease.

Auxiliary Consumption Supply: To add PV in a beneficial way

We investigated how a PV installation could improve our CSP plant. Here is one exemplary option for our 200 MW reference plant with nighttime operation:

80% of the daylight auxiliary consumption provided by a PV plant (e.g. about 7.7 MW)

Price for grid electricity €/kWh	Cost of PV electricity €/kWh	LCOE CSP €/kWh	Rel. LCOE Reduction %
0,15	no PV utilization	**0,1115**	0
0,15	0,03	0,1081	**3,1**
0,15	0,05	0,1087	2,5
0,10	no PV utilization	0,1098	0
0,10	0,03	0,1077	1,9
0,10	0,05	0,1083	1,4

PV support can help.

A lot of different setups are possible and can be adjusted to your very specific needs.

Our Solar Tower Design at a Glance

The **CSP Reference Plant** developed so far comprises:

- A Heliostat Field size of around 1.5 km² Aperture Area
- A Receiver of 700 MW_{th} with a Mean Heat Flux of around 500 kW/m²
- 200 MW_e Single Reheat Cycle, live steam: 140 bar at 550°C
- Air Cooled Condenser
- Thermal Salt Storage of 13 hours

We calculated for a nighttime operation the LCOE of **0,1115 €/kWh.**

Not all boundary conditions or real costs could be included, but missing items will be outlined in our report for your consideration to complete our CSP Reference Plant.

Summary and Outlook

- A reference molten salt solar tower plant has been defined for typical operation scenarios
- Cost savings are due to standardized and modular design and the utilization of cost optimized subsystems
- This plant design should fit also to other sites (fine tuning during detailed engineering required)

The full results of the project will be published by the end of 2020.

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Thank you

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