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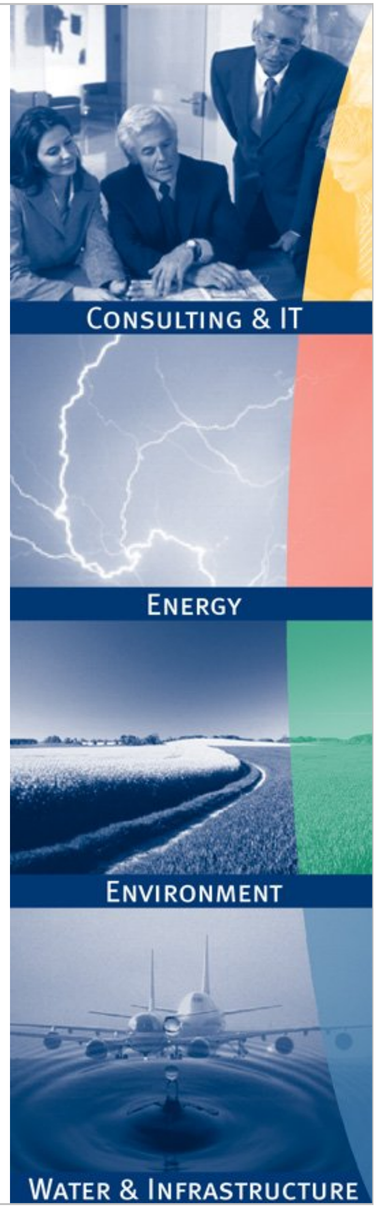
ESMAP
Energy Sector Management Assistance Program

Assessment of Technology Options for Development of Concentrating Solar Power in South Africa

for

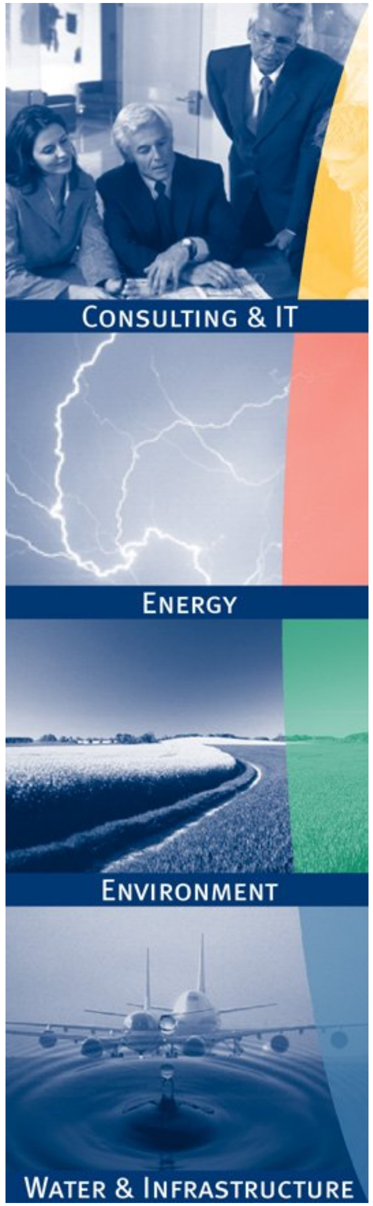
The World Bank



Johannesburg, 9th – 10th December 2010

Content

- CSP technology description
- CSP market assessment
- CSP technology selection
- Solar resource and site assessment
- Parabolic trough power plant design and performance
- Central receiver power plant design and performance
- Techno-economic evaluation

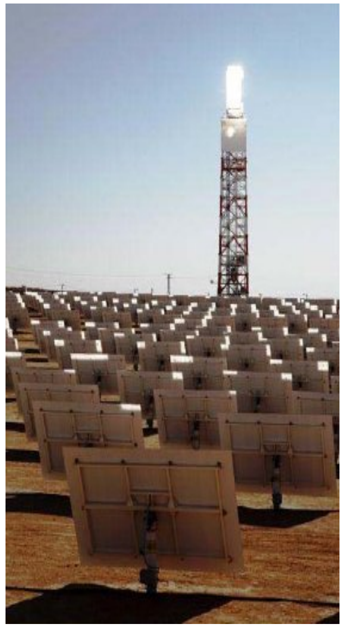


General Technology Principle

- Concentration of solar energy flow (direct irradiation required)
- Conversion of Solar irradiation into high temperature heat
- Conversion of high temperature heat into mechanical energy
- Conventional power generation technology

Characteristics

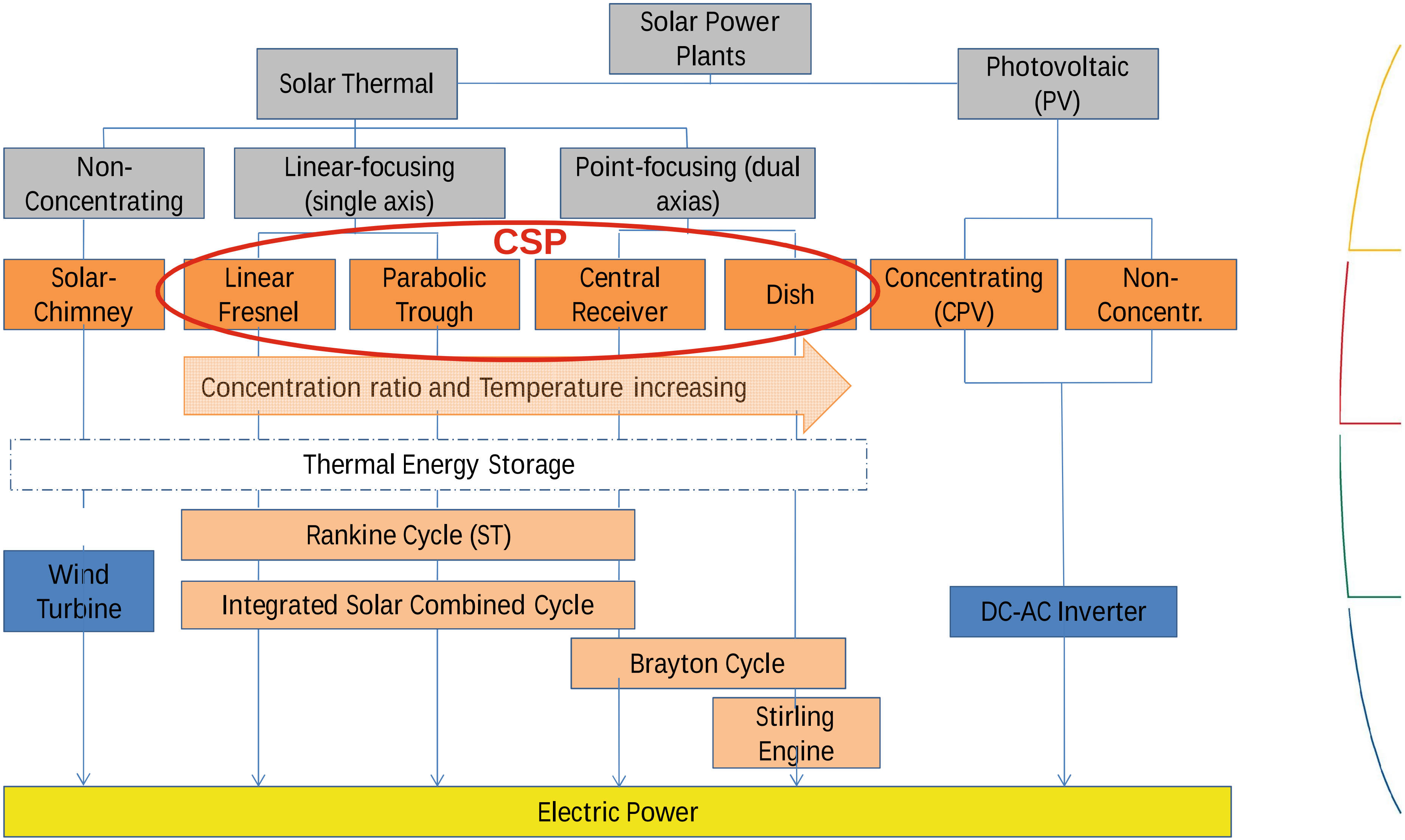
- High energy density
- Mainly conventional components used
- Economy of scale leads to larger plants (up to 300 MW)
- Possibility of thermal energy storage and hybridisation
- High capacity factors possible



Investigated types of CSP Plants

- Parabolic Trough
- Fresnel Trough
- Solar Tower (Central Receiver)
- Parabolic Dish (Dish/Stirling)

Solar Power Technologies - Overview



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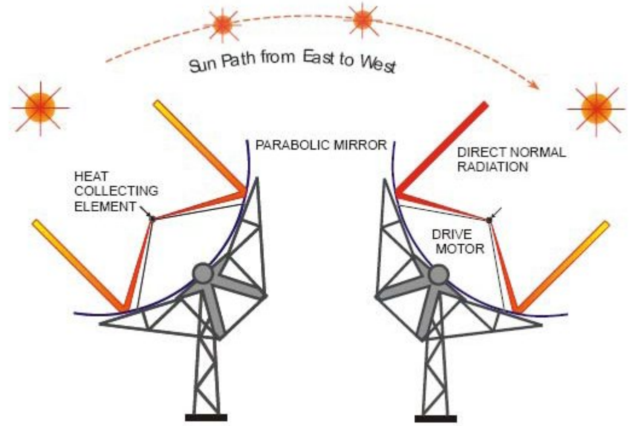
Parabolic Trough - Overview

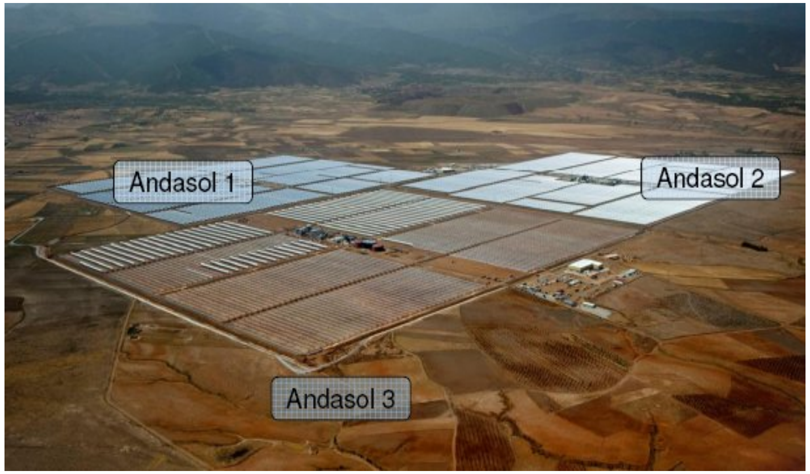
Principle / Characteristics

- Single-axis tracked parabolic trough collector (north-south axis alignment)
- Sunlight is reflected by parabolic shaped mirrors and concentrated on a „receiver” (absorber tube)
- Heat transfer fluid (currently synthetic oil) heats up to 395°C in receiver
- Generation of superheated steam via solar steam generator
- Conventional water-steam-cycle
- Possibility to store thermal energy (currently two-tank molten salt storage)



Status

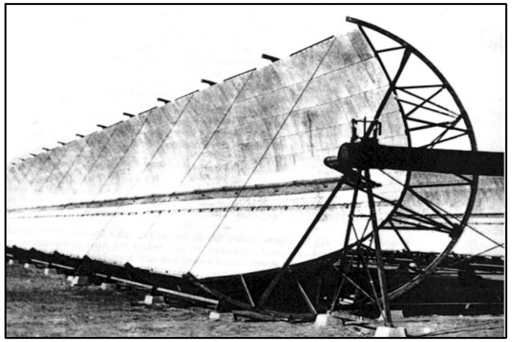
- Most mature and bankable CSP technology
- First nine plants (SEGS plants) successfully in operation since more than 20 years in California
- Several **Gigawatts** of parabolic trough power plants under construction or in planning
- Major cost reduction due to mass production, economy of scale and further technological advancements



Parabolic Trough - History

The beginning

- Technology goes back to 1907 when the first patent of a parabolic trough collector was filled in Stuttgart.
- In 1911, the first parabolic trough plant, a 55 kW pumping station, started operation in Egypt.



The Solar Energy Generating Systems (SEGS)

- After the second oil crisis the first nine commercial parabolic trough power plants have been built between 1984 and 1991 in California, USA.
- Capacities ranging between 14 and 80 MW (total capacity of 354 MW)
- SEGS are still in operation today

Modern era of parabolic trough power plants

- Development of new collector designs (e.g. SKAL-ET EuroTrough)
- In 2007, Nevada Solar One , the first new large parabolic power plant with a net capacity of 64 MW started operation in the USA
- Introduction of very attractive feed-in tariff for CSP in Spain
- In 2009, the first large European parabolic trough power plants started operation in Spain.

Parabolic Trough – Plant Configurations

Solar Only:

- Operates only with solar energy, no back-up fuel firing and no thermal energy storage
- Not-dispatchable and only suited for summer peaks
- Capacity factors of only 25 – 30%

Thermal energy storage:

- Incorporation of a thermal energy storage system in combination with an oversized solar field
- Indirect two-tank molten salt storage system (state-of-the-art)
- Capacity factors >50% possible

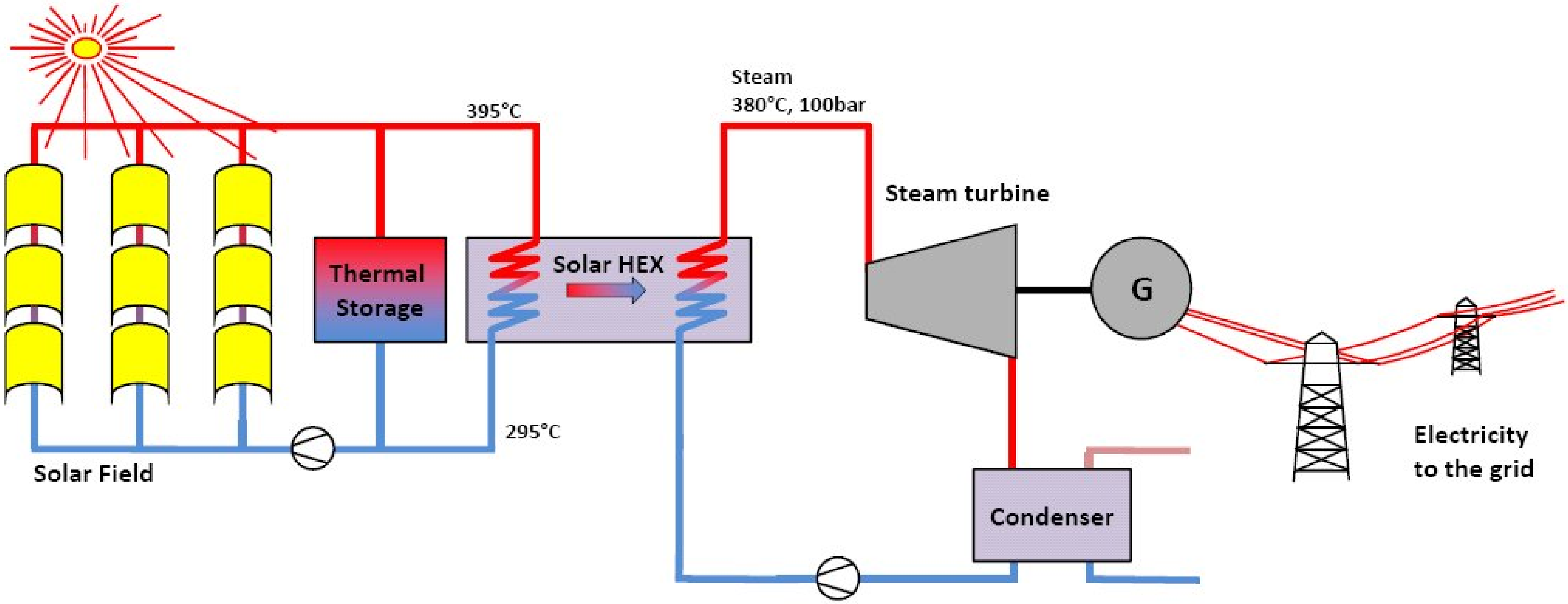
Solar-hybrid:

- Different options for hybridisation: HTF heater, back-up boiler or gas fired superheater
- Due to low Rankine cycle efficiency, only moderate hybridisation feasible
- Dependent on fuel availability and fuel costs

Integrated Solar Combined Cycle (ISCC):

- Integration of parabolic trough solar field in conventional combined cycle gas turbine power plant
- Only small solar shares possible

Parabolic Trough – Solar Rankine Cycle



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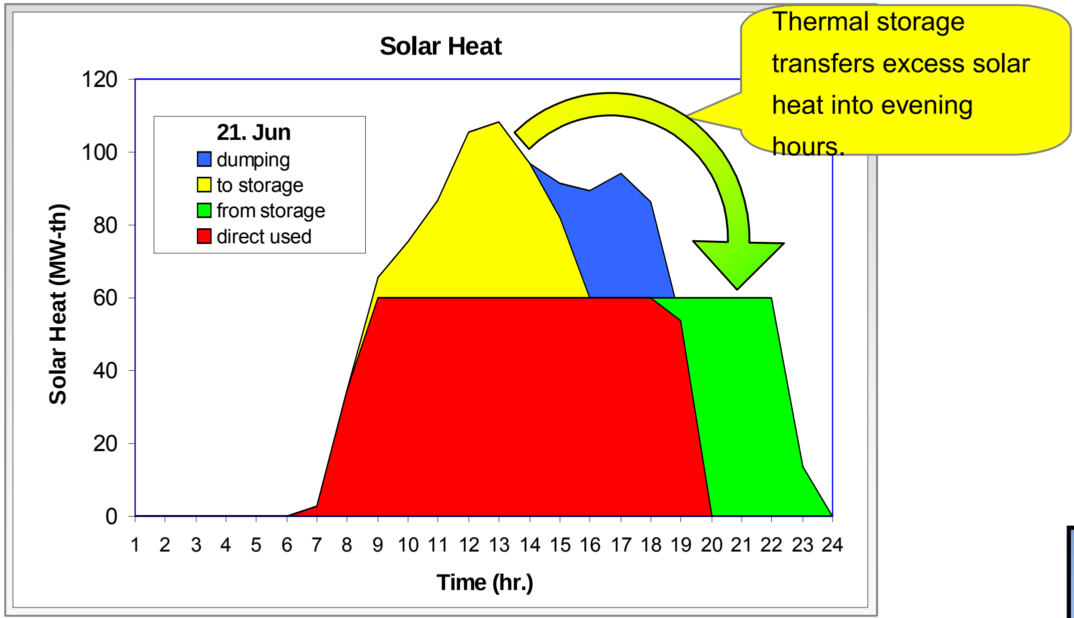
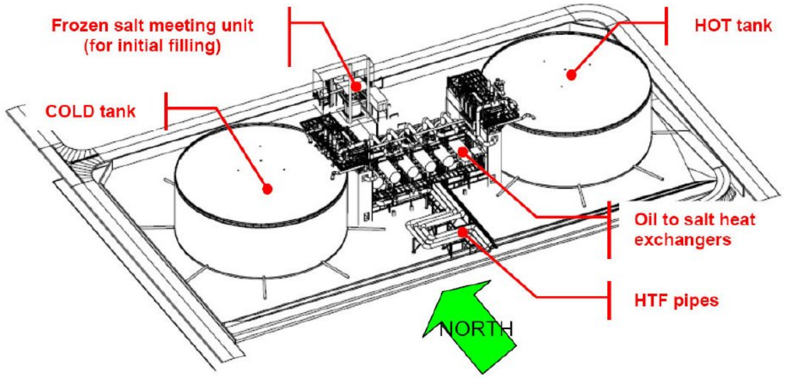
Thermal Energy Storage Design





- Extension of full load operation to night time hours
- Reduction of part load operation (cloud transients)
- Dispatchable power generation
- State-of-the-art technology: Two-tank molten salt storage
- Capacity factors > 50% feasible

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Parabolic Trough – Commercial Projects*

Project Name / Location	Country	Developer	(Estimated) First Year of Operation	Peak Output [MW_{el}]	Thermal Energy Storage / Dispatchibility
Nevada Solar One, Boulder City	USA	Acciona Solar Power	2007	74	None
Andasol I - III	Spain	ACS Cobra / Sener Solar Millennium	2008 - 2011	3 x 50	Molten Salt Thermal Storage
Solnova I- V	Spain	Abengo Solar	2009 - 2014	5 x 50	Gas heater
ExtreSol I-III	Spain	ACS Cobra / Sener	2009-2012	3 x 50	Gas heater
Kurraymat	Egypt	Iberdrola / Orascom & Flagsol	2010	20 (solar)	ISCC
Ain Beni Mathar	Morocco	Abener	2010	20 (solar)	ISCC
Shams 1	UAE	Abengoa Solar	2012	100	Gas fired superheater
Beacon Solar Energy Project, Kern County	USA	Beacon Solar	2012	250	Gas heater
Blythe	USA	Solar Millennium	2013-2014	4 x 250	Gas heater

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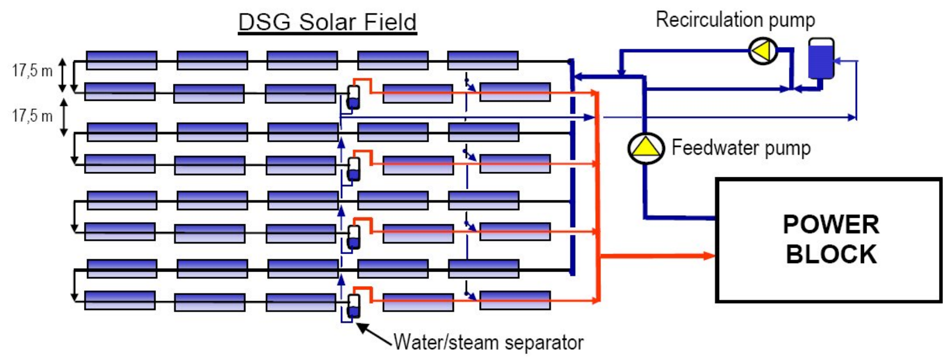
Parabolic Trough – Technology Improvements

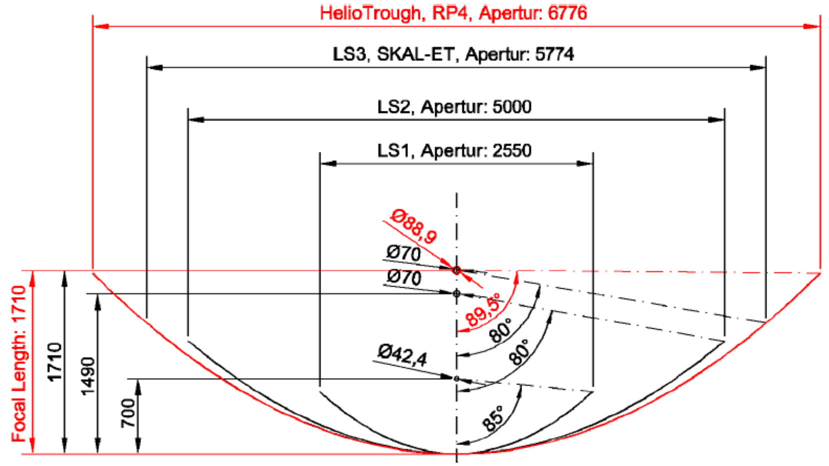
New heat transfer fluids:

- Direct Steam Generation (STG) in solar field
- Molten salt
- Improved synthetic oils



New collector designs:

- Increase of collector dimensions (e.g. HelioTrough)
- Lower specific weight
- Increase in solar field efficiency



Absorber tubes and mirrors:

- Selective coatings for higher temperatures
- Improvements of optical properties
- Development of new reflector materials, e.g. silvered polymer or aluminized polished reflectors

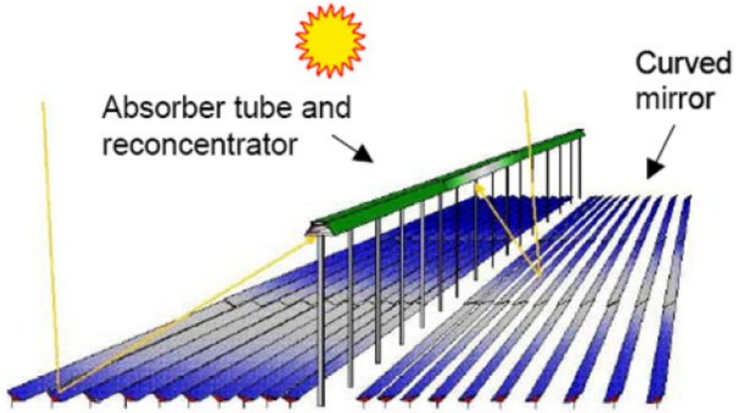
Other improvements:

- Rotating flex hoses instead of ball joints
- Expansion joints instead of lyra bows

Fresnel Trough - Overview

Principle / Characteristics

- Long plane reflectors which are grouped to a mirror field close to the ground
- Linear fixed receiver (option of secondary reflector)
- Lower optical efficiency compared to parabolic trough collector
- Direct generation of saturated or superheated steam in the solar field (other heat transfer fluids also possible)
- Efficient use of land (lowest specific land requirements)
- Possibility to store thermal energy limited



Status

- Relatively new CSP technology
- Concept proven in a number of demonstration projects
- First commercial Fresnel trough power plant with capacity of 30 MW currently under construction in Spain
- Several larger projects under development (up to 150 MW)
- Other promising application areas, such as steam augmentation, process steam, etc.

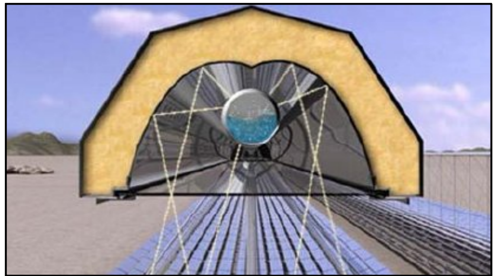
Fresnel Trough – Key Components

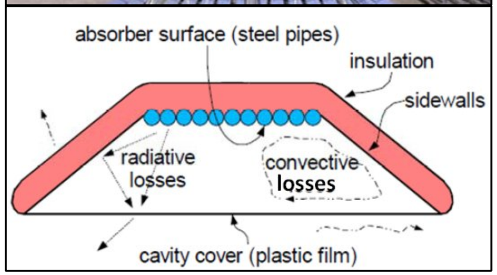
Collector

- Less expensive flat mirrors (3 mm thickness) pressured glued on substructure
- Simple tracking system of individual mirror facets
- Due to the mirrors being constructed close to the ground, wind loads and material usage are reduced.
- Automated production of collector components
- Efficient use of land (lowest specific land requirements)
- Lower maintenance requirements (e.g. automated mirror cleaning with low water requirements)
- Lower optical efficiency compared to parabolic trough collector

Receiver

- Fixed receiver (no receiver tracking)
- No need for flexible high pressure joints (ball joints or flexible
- Currently there are two different receiver designs:
  - Single absorber tube with secondary reflector
  - Multiple steel pipes





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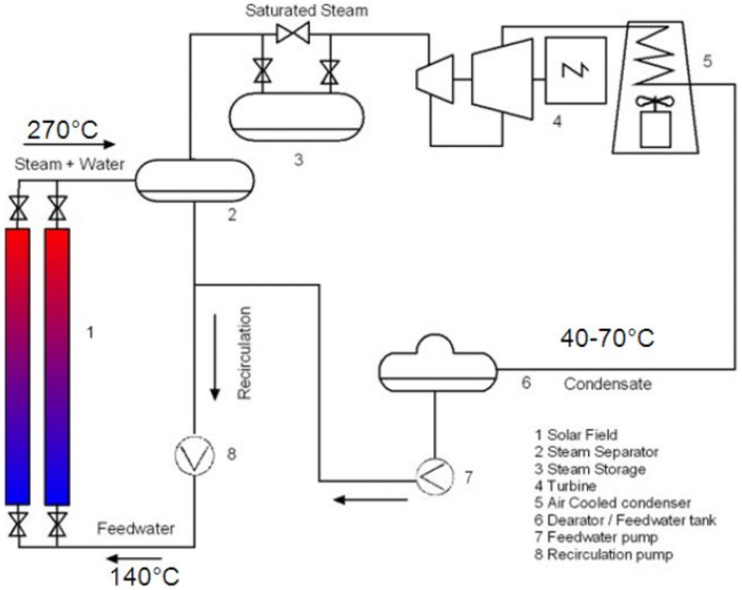
Fresnel Trough – Current Projects

30 MW PE 2 Plant



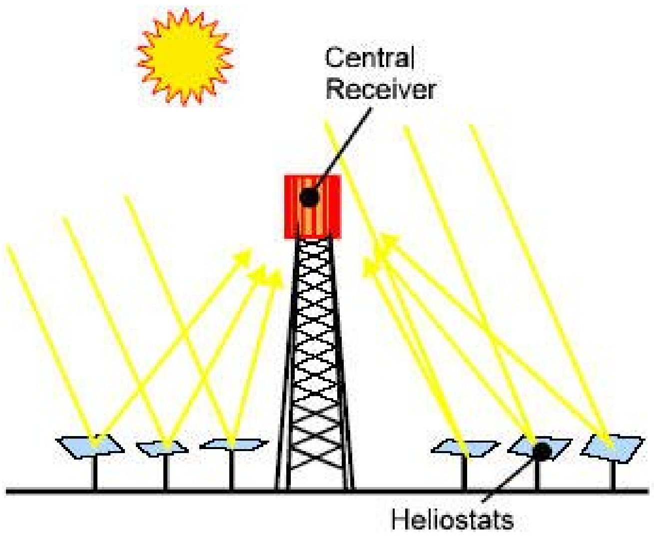
PE II Plant

- Located in Murcia, Spain (2,095 kWh/m²/a)
- Start of construction in 2010, start of operation 2012
- Solar field made out of 28 collector rows (aperture area ~ 300,000 m²)
- Saturated steam (270°C, 55 bar)
- Air cooled condenser
- Small steam accumulator as storage system
- Net generation capacity of 30 MW

Central Receiver - Overview

Principle / Characteristics

- Field of heliostats (two-axis tracked mirrors) is used to concentrate sunlight onto a central receiver mounted at the top of a tower
- Point focussing system: high concentration rates allow for high operating temperatures and high efficiencies
- Different heat transfer fluids (HTFs) possible:
    - Molten salt
    - Water/steam
    - Atmospheric air and pressurized air
- Depending on HTF cost effective thermal energy storage possible
- Capacity factor depending on HTF: 25 - > 75%



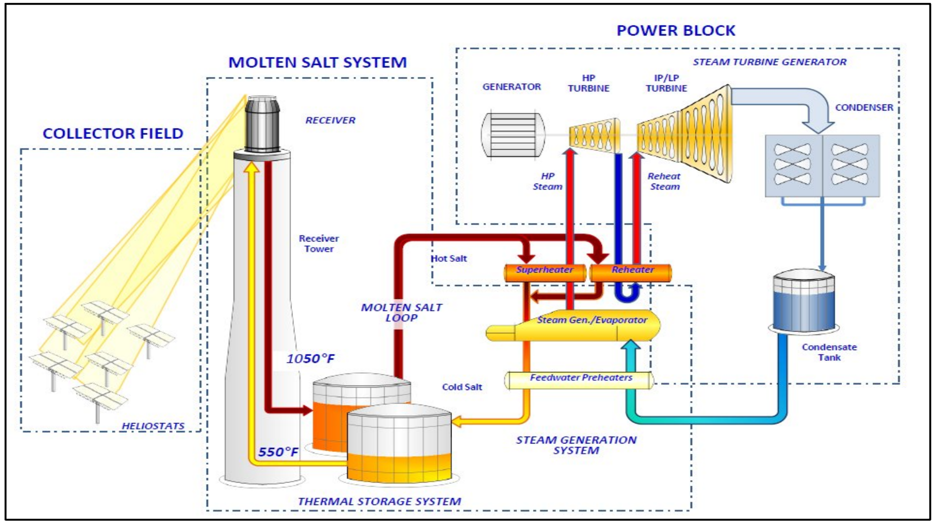
Status

- Concept proven in numerous demonstration projects
- Maturity varies for different central receiver technologies
- First commercial projects in operation since 2007
- Several larger projects under construction or under development (up to 150 MW)
- Increasing interest of CSP industry in central receiver technology

Central Receiver – Plant Configurations

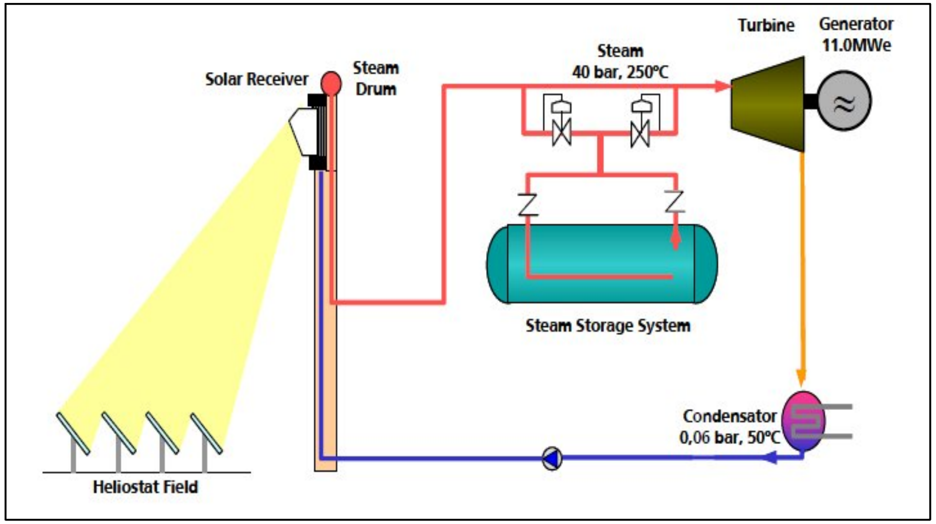
Molten Salt Central Receiver

- Solar salt (eutectic mixture of inorganic nitrates consisting of 60% of sodium nitrate ($NaNO_3$) and 40% of potassium nitrate (KNO_3))
- High operating temperatures (565°C)
- Efficient reheat steam cycle
- Direct storage of molten salt (two-tank system)
- High capacity factors: > 50%



Water/steam Central Receiver

- Direct steam generation in central receiver
- First commercial plants generate only saturated steam (250°C / 40 bar)
- Superheated steam generation (up to 540°C / 160 bar) demonstrated and now deployed
- No commercial storage system available (steam accumulator only for saturated steam)
- Low capacity factors: 25 - 30% (without gas firing)



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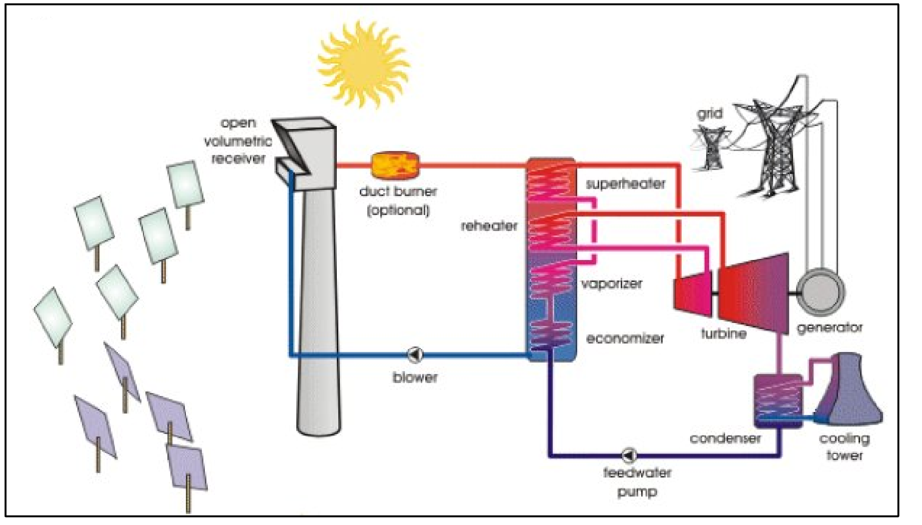
Central Receiver – Plant Configurations II

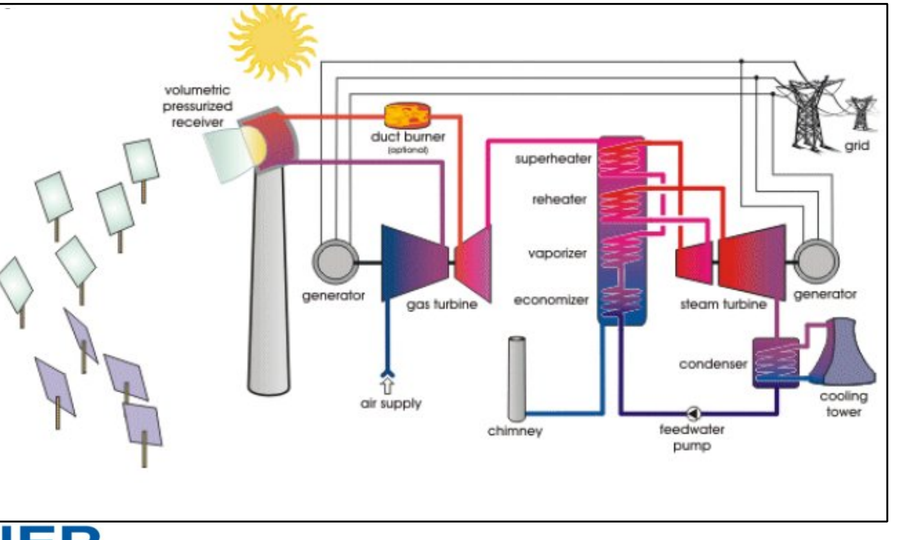
Atmospheric Air Central Receiver

- Use of ambient air as HTF, which is drawn by a blower through a volumetric receiver (wire mesh, ceramic or metallic foam) and heated up to 700°C
- Steam generation in heat recovery steam generator (superheated steam up to 540°C / 140 bar)
- Hybridisation with duct burner or incorporation of thermal energy storage possible.
- Medium capacity factors: 25 - 50%
- First demonstration projects



Pressurized Air Central Receiver

- Pressurized air (~15 bar) is heated up to 900 – 1,100°C in a pressurized volumetric receiver (REFOS concept)
- Hot air used to drive a gas turbine
- Co-firing with back-up fuel to increase the temperature
- Option for a solar-hybrid operation, also in a combined cycle (depicted to the right)
- Capacity factor depends on hybridisation
- First smaller demonstration projects



Central Receiver – Demo Projects

Name/Location/ Country	First Year of Operation	Electrical Output [MWel]	Heat Transfer Fluid	Thermal Energy Storage
SSPS, Spain	1981	0.5	liquid sodium	sodium
EURELIOS, Italy	1981	1	water/steam	salt / water
SUNSHINE, Japan	1981	1	water/steam	salt / water
Solar One, USA	1982	10	water/steam	synthetic oil / rock
CESA-1, Spain	1983	1	water/steam	molten salt
MSEE/Cat B, USA	1983	1	molten salt	molten salt
THEMIS, France	1984	2.5	Molten salt (hitec)	molten salt
SPP-5, Ukraine	1986	5	water/steam	water/steam
TSA, Spain	1993	1	atmospheric air	ceramics
Solar Two, USA	1996	10	molten salt	molten salt
Consolar, Israel	2001	0.5*	pressurized air	no (fossil hybrid)
Solagte, Spain	2002	0.3	pressurized air	no (fossil hybrid)
Solair, Spain	2004	3*	atmospheric air	-
CO-MINIT, Italy	2005	2 x 0.25	pressurized air	no (fossil hybrid)
CSIRO Solar Tower Australia	2006	1*	other (gas reformation)	chemical (solar gas)
DBT-550, Israel	2008	6*	water/steam (superheated)	-
STJ, Germany	2008	1.5	atmospheric air	ceramics
Eureka, Spain	2009	2*	water/steam (superheated)	-
Sierra SunTower / California, USA	2009	5	water/steam (superheated	-

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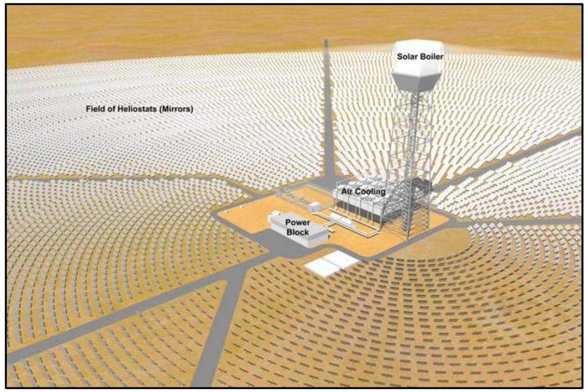
Central Receiver – Commercial Projects*

Name / Location	Company	Concept	Size [MWe]	Initial operation year / Status
PS 10 / Seville, Spain	Abengoa Solar	Water/Steam	10	2007
PS 20 / Seville, Spain	Abengoa Solar	Water/Steam	20	2009
Solar Tres / Seville, Spain	Sener	Molten Salt	17	2011 / Under Construction
Ivanpah 1-3 / California, USA	BrightSource Energy	Water/Steam	1 x 126 / 2 x 133	2013 / Under Construction
Geskell Sun Tower, Phase I-II / California, USA	eSolar	Water/Steam	1 x 105 / 1 x 140	Planning
Alpine Power SunTower / California, USA	eSolar / NRG Energy	Water/Steam	92	Planning
Cloncurry Solar Power Station / Queensland, AUS	Ergon Energy	Water/Steam	10	on hold
Upington / Upington, South Africa	Eskom	Molten Salt	100	Planning
Rice Solar Energy Project / California, USA	Solar Reserve	Molten Salt	150	Planning
Tonopah / Nevada, USA	Solar Reserve	Molten Salt	100	Planning



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Central Receiver – Project Examples I

Category	Unit	Solar Two	Torresol / GemaSolar
Capacity (gross)	**MW**	**10**	**19**
Heliostat field			
Heliostats per subfield		1818 + 108 *	2,650
Size of heliostat reflector	m²	39 + 95 *	115
Receivers and heliostat fields		1 (circular field)	1 (circular field)
Total heliostat area		81,162	304,750
Receiver system			
Receiver type		Cylindrical tube receiver	Cylindrical tube receiver
Heat transfer fluid		Molten salt	Molten salt
Receiver capacity	MWt	43	120
Optical tower height	m	~ 80	140
Thermal energy storage			
Type		Two-tank molten salt	Two-tank molten salt
Thermal capacity	MWh / h	105 / 3	650 / 15
Power block			
Type		non reheat cycle	Single reheat
Steam conditions	°C / bar	~ 510 / ~ 90	538 / 100
Cooling type		Wet cooling tower	Wet cooling tower
First year of operation		1995	2011

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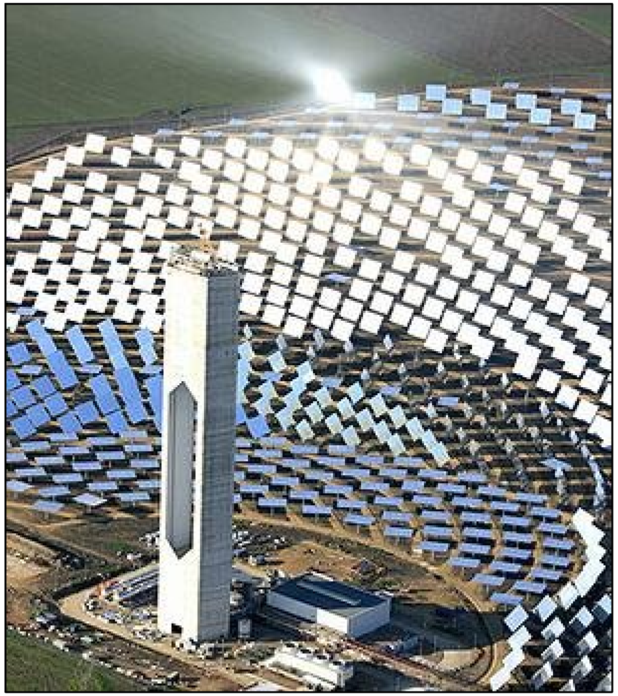
Central Receiver – Project Examples II

Category	Unit	Abengoa / PS 20	BrightSource / Ivanpah	eSolar / Basis Modul
Capacity (gross)	**MW**	**20**	**126**	**46**
Heliostat field				
Heliostats per subfield		1,255	50,900	6,090
Size of heliostat reflector	m²	121	15.18	1.14
Receivers and heliostat fields		1 (north field)	1 (circular field)	12
Total heliostat area		151,855	772,662	166,622
Receiver system				
Receiver type		Cavity tube reciver	Cylindrical tube receiver	Natural circulation boiler with superheat
Heat transfer fluid		Saturated steam	Superheated steam	Superheated steam
Receiver capacity	MWt	~100	393.6	~230
Optical tower height	m	165	~ 180	65
Thermal energy storage				
Type		Steam accumulator	-	-
Thermal capacity	MWh / h	~50 / ~1	-	-
Power block				
Type		Single reheat	Single reheat	Rankine cycle
Steam conditions	°C / bar	~250 / 45	550 / 160	440 / 60
Cooling type		Wet cooling tower	Air cooled condenser	Wet cooling tower
First year of operation		2009	2013	2012



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Central Receiver – Technology Improvements

Plant layout and design:

- Introduction of multitower designs (e.g. use standardized towers of wind turbines);
- Development of an optimized heliostat calibration system;
- Improvements of the aiming strategy;
- Upscaling of block size
- Standardization, mass-production of key-components

Receiver design :

- Reduction of receiver surface area (proportional to heat loss reduction)
- Development of selective coatings (withstanding higher temperatures)
- Development of new nickel alloys (allowing higher solar fluxes)
- Reduction of spillage losses on edge zones (improved aiming strategy)
- Development of new receiver design concepts (durability and high life span)

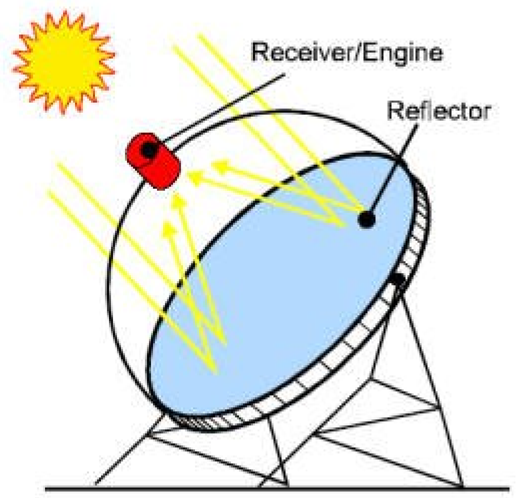
Heliostat design:

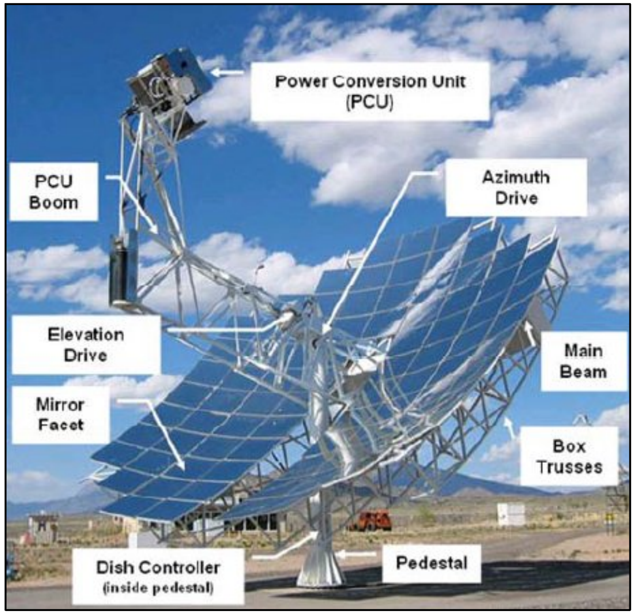
- Development of new azimuth drive designs (hydraulic drives)
- Increase tracking accuracy (improved aiming strategy)
- Improved collector structures
- Establishment of wireless communication systems
- Introduction of anti-fouling coating
- Use of thin-glass or other advanced reflector materials

Parabolic Dish - Overview

Principle / Characteristics

- Concentrator consists of mirror facets which form a parabolic dish
- Concentration to a receiver mounted on a boom at the dish's focal poir
- Point focussing system: high concentration rates allow for high operatiı temperatures and high efficiencies (>30% solar-to-electric)
- Dish based CSP plants can be divided into groups:
    - Individual parabolic dish units (Stirling or Brayton engines)
    - Distributed parabolic dishes (heat transport from an array of dish to a single power block)
- State-of-the-art parabolic dish systems uses Stirling engines (3 – 25 kW)
- Modular plant designs
- Little water requirements
- Low capacity factors of dish-Stirling systems: 25-30%

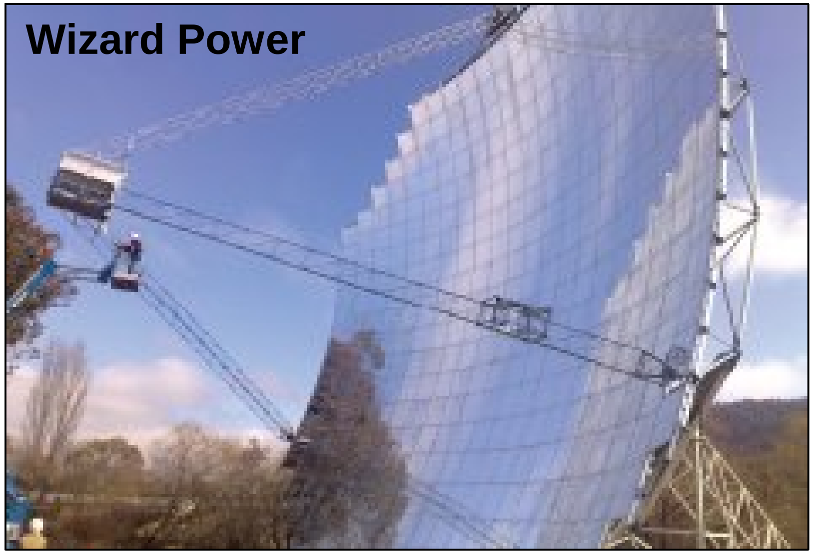




Status

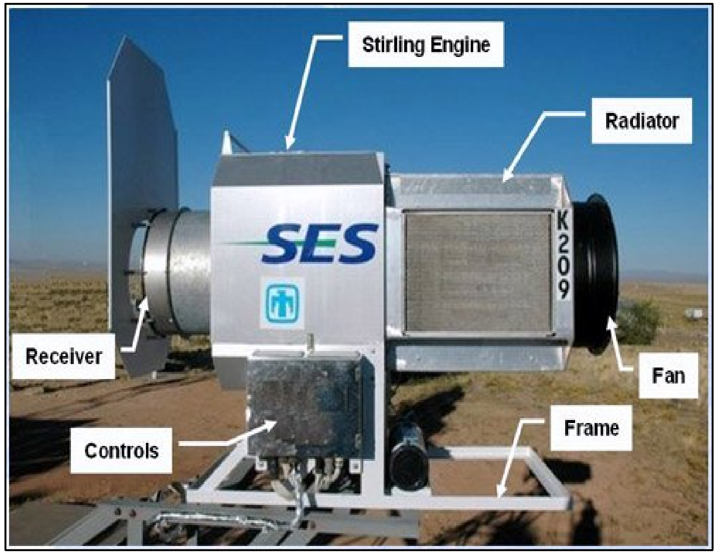
- Development of several dish generations and tested (mainly based on Stirling engines)
- First large commercial projects under development (up to 850 MW)
- Major cost savings expected through mass-production

Parabolic Dish - Examples

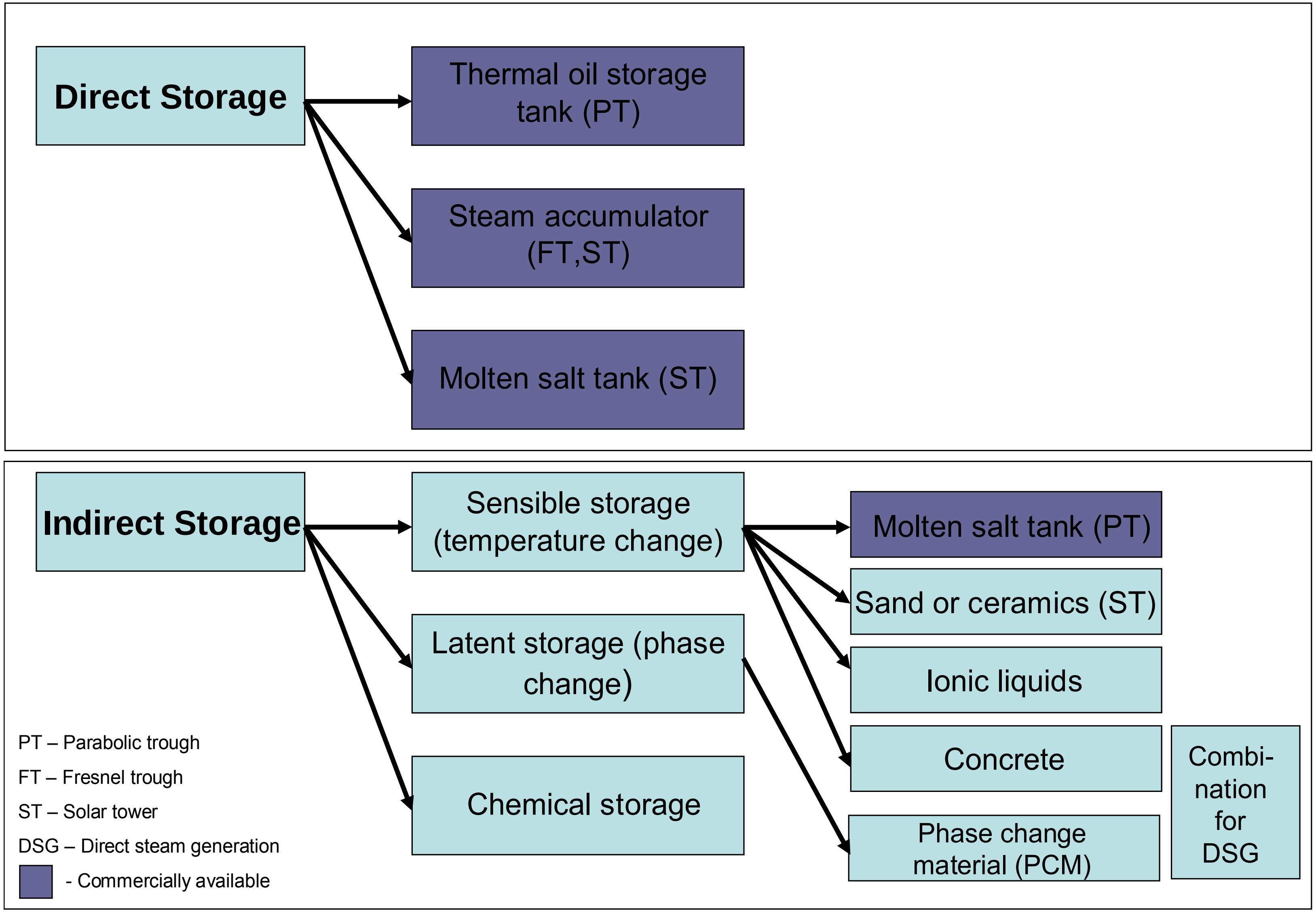


Parabolic Dish - Examples

Technical Parameters	Estimation based on SES Solar One
Plant Size	100 MW
Size of Land	~ 3 km^2
Power of each receiver	25 kW
Reflective Area of one Dish	90 m^2
Receiver Units	4,000
Water requirements	~ 10 m^3/d
Peak Solar-to-Electricity Efficiency	31.25 %
Annual Capacity Factor	~25%
Annual Solar-to-Electricity Efficiency	22 – 24%



Thermal Energy Storage - Overview



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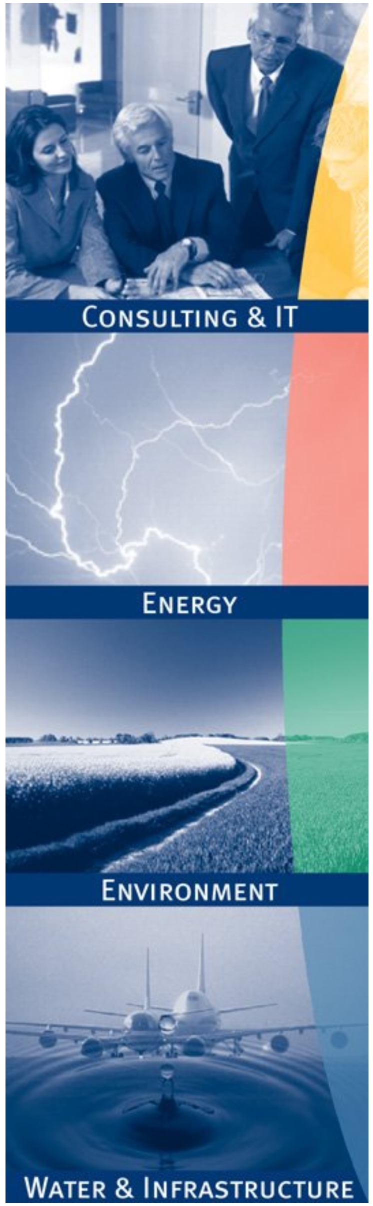
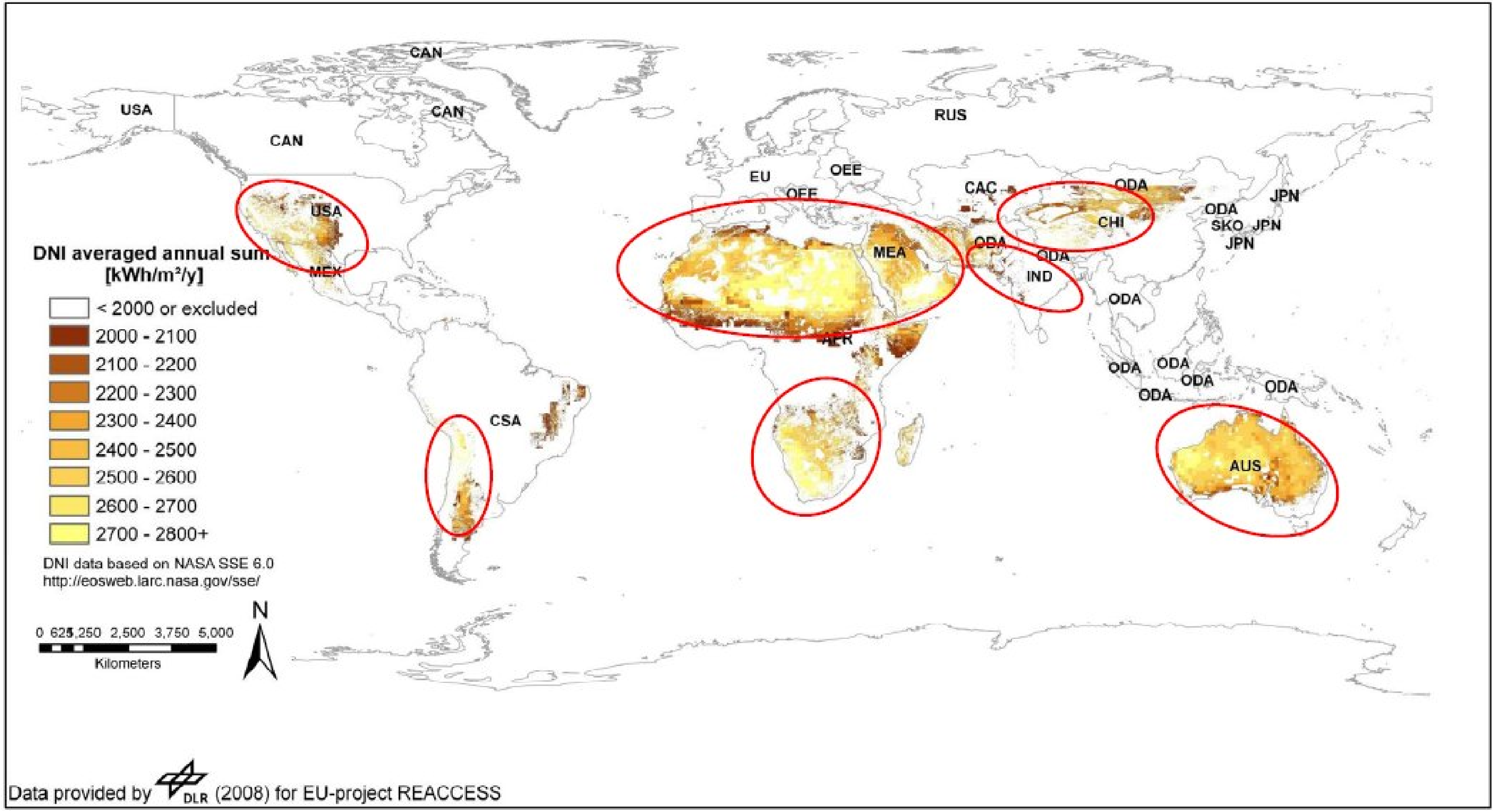


Solar Resource – World's Solar Potential II



- Areas with annual DNI > 2,000 kWh/m²/a suitable for Solar Thermal Power Plants
- South Africa is one of prime regions for large CSP deployment

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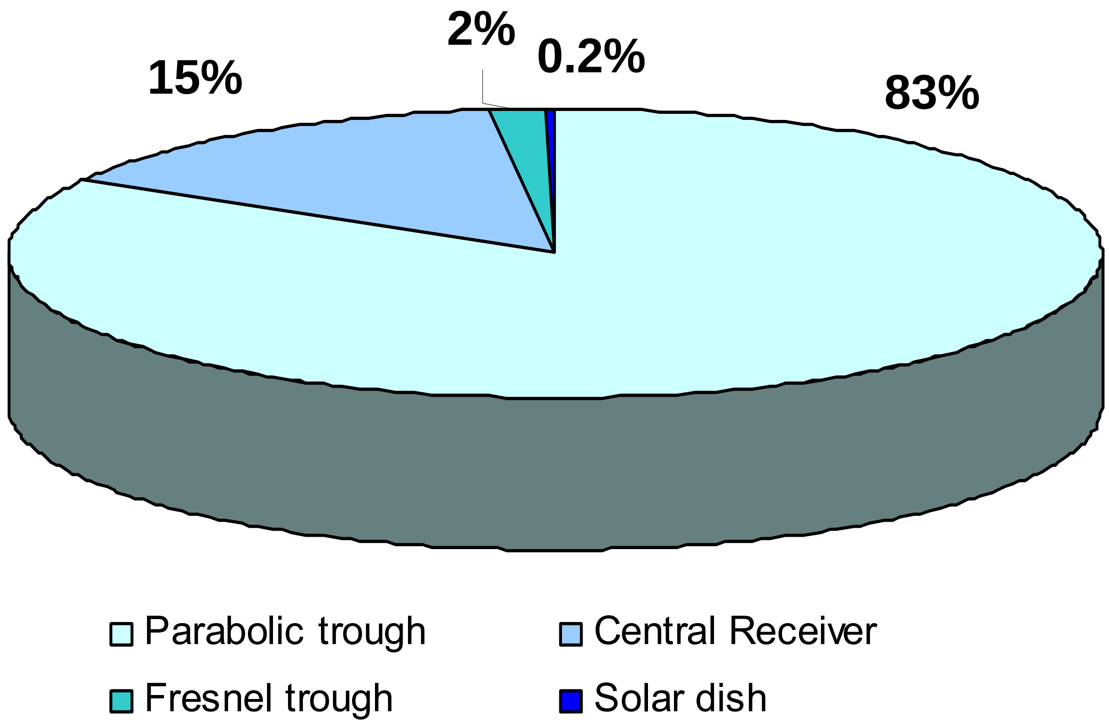
CSP Market – Current Market Situation

ESMAP Energy Sector Management Assistance Program



- At the end of 2010 around of 1,200 MW of CSP in operation.
- More than 80% of capacity already installed or under construction based on parabolic trough technology.
- CSP market is currently dominated by Spain.
- Several Gigawatts of CSP capacity in planning mainly in the USA, the Middle East and North Africa (MENA).

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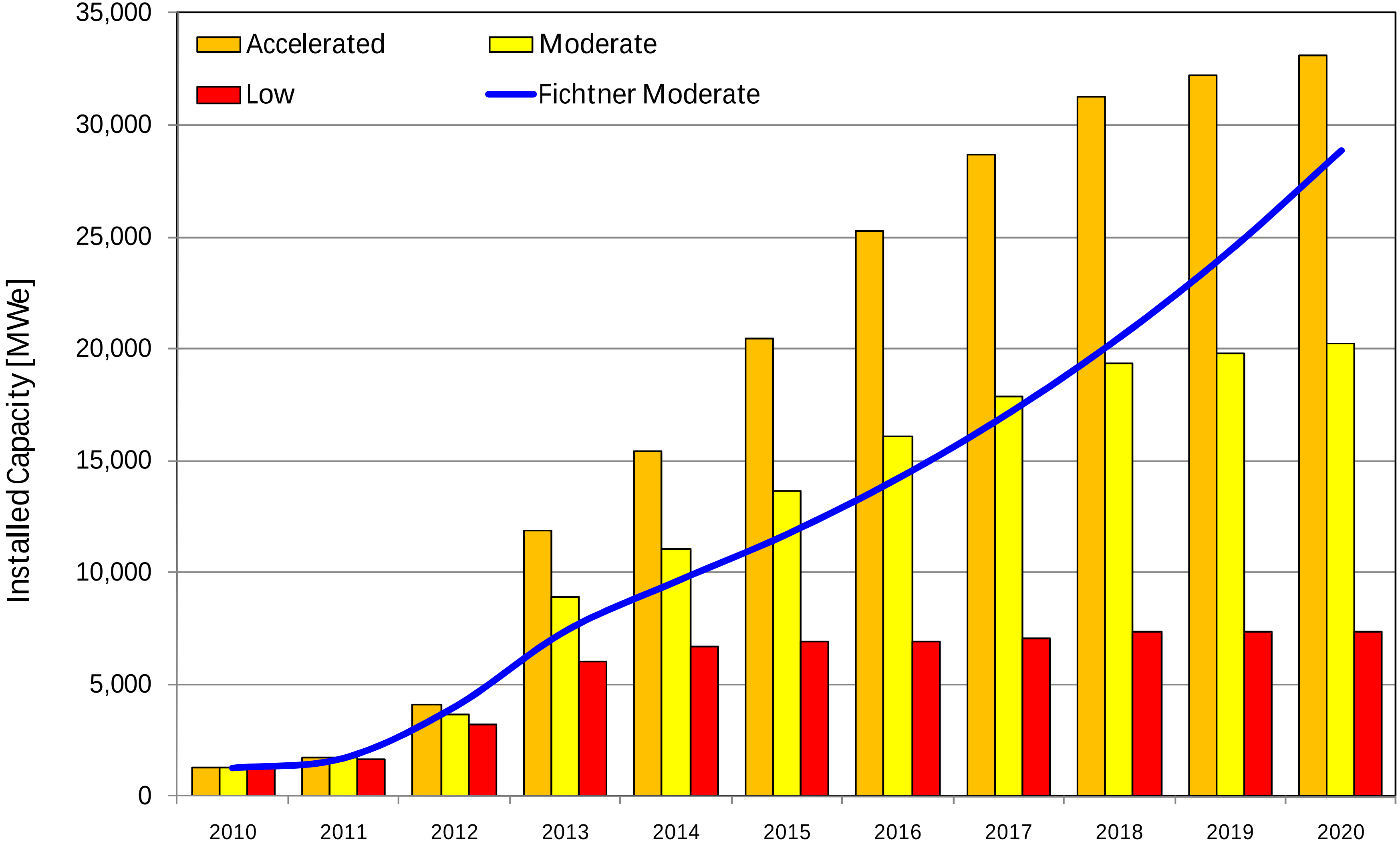
CSP Market – Medium perspective



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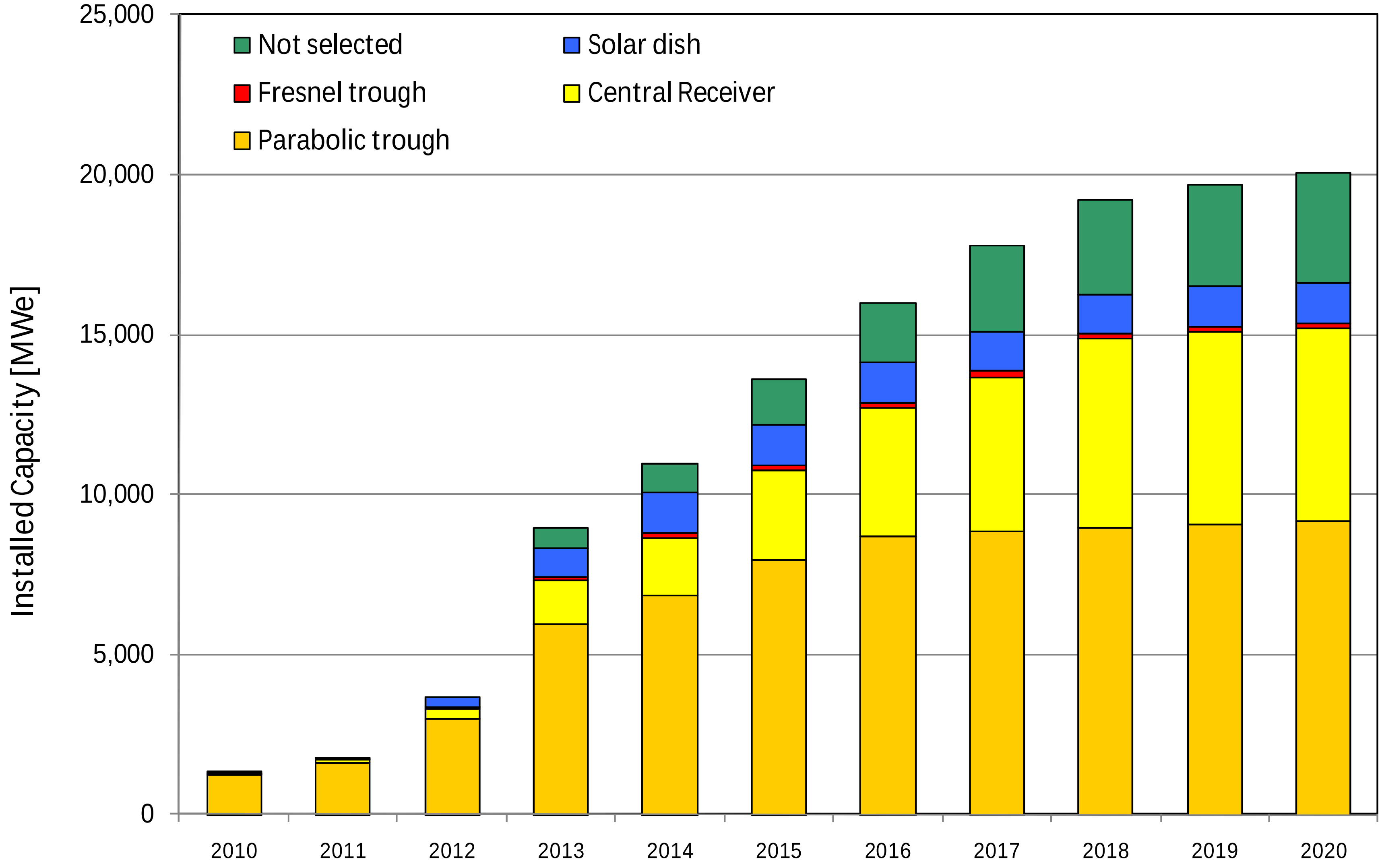
Announced CSP Capacity by Technology



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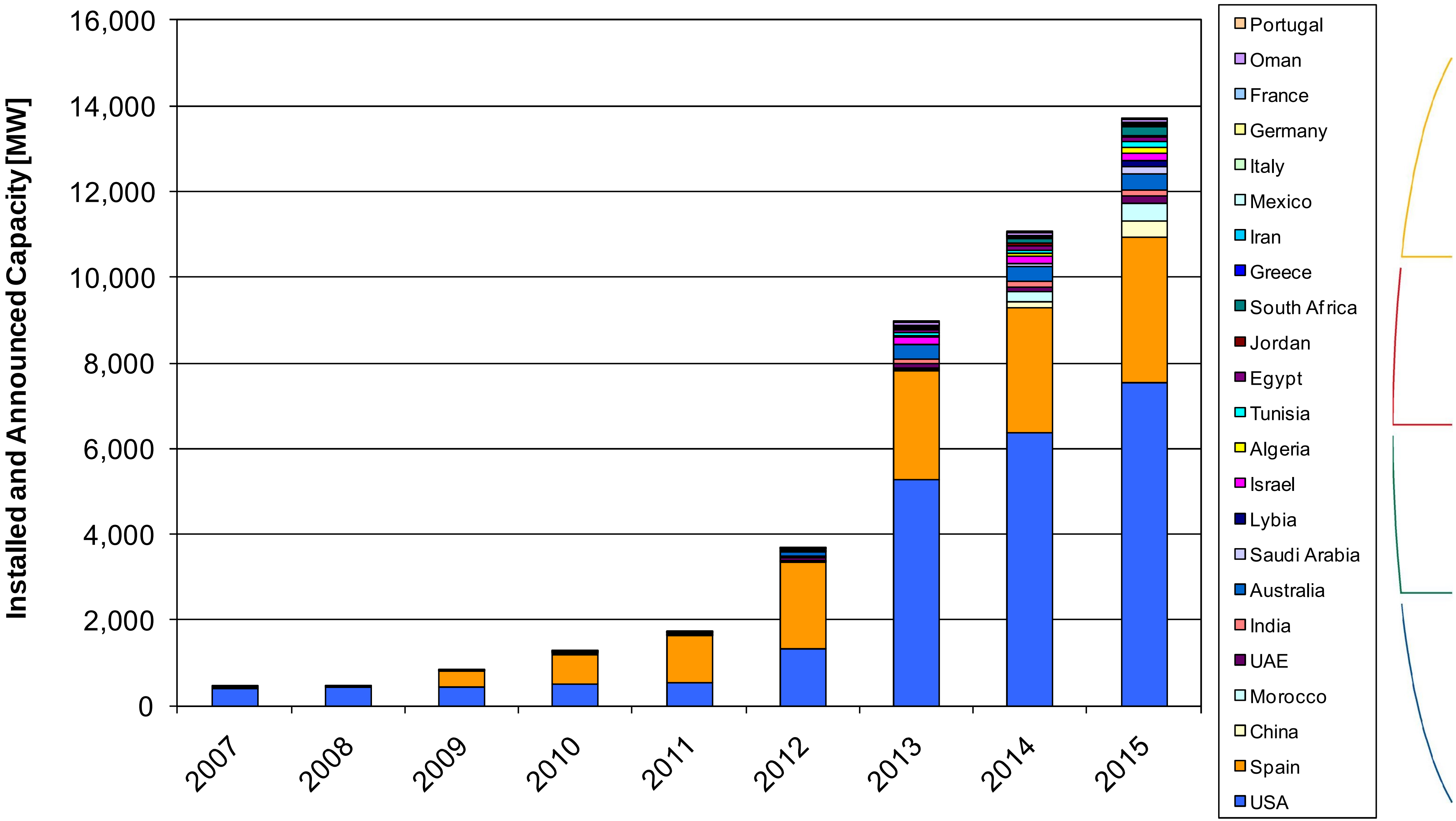
Announced CSP Capacity by Country



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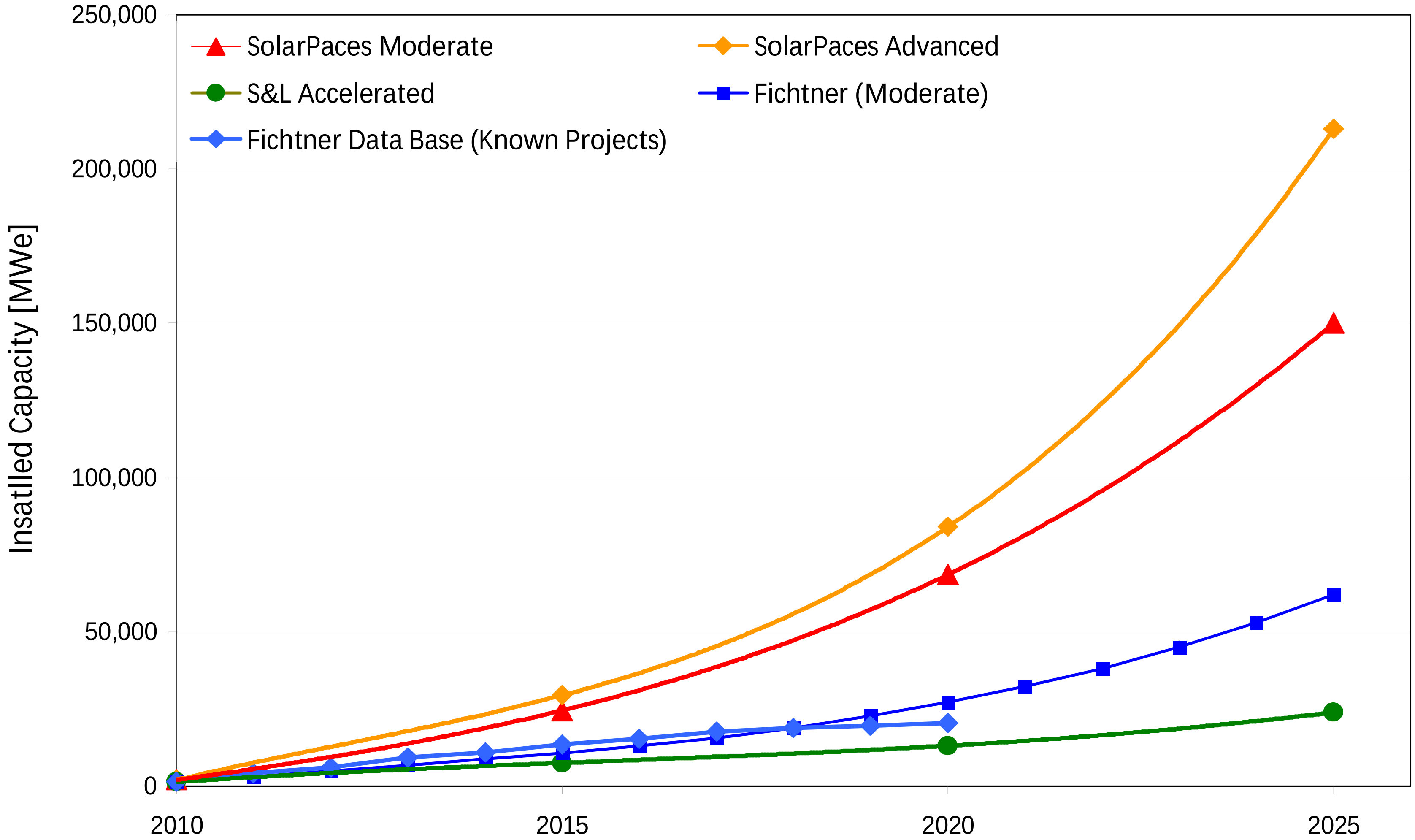
CSP Market – Long term perspective

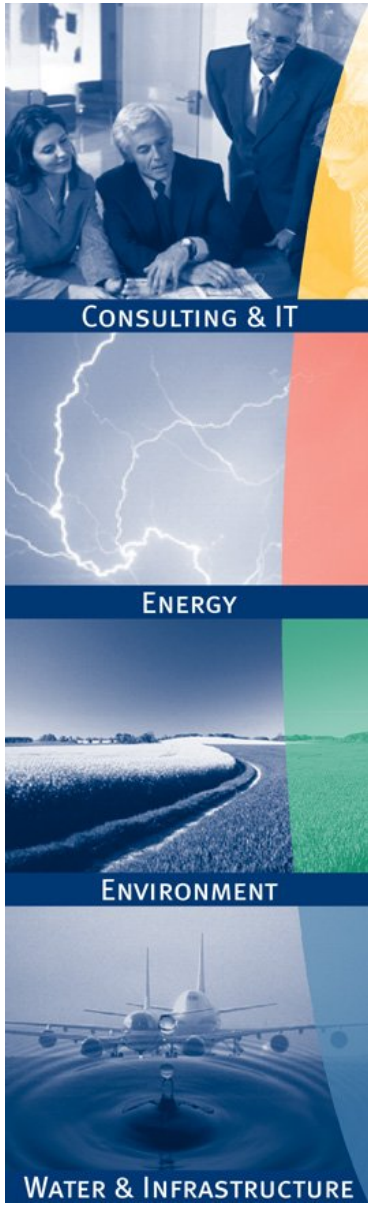


THE WORLD BANK

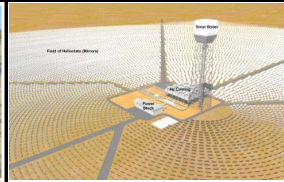
Content

ESMAP
Energy Sector Management Assistance Program

- CSP technology description
- CSP market assessment
- **CSP technology selection**
- Solar resource and site assessment
- Parabolic trough power plant design and performance
- Central receiver power plant design and performance
- Techno-economic evaluation

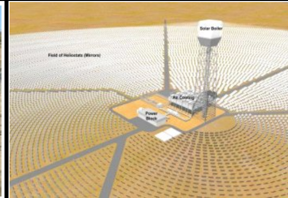


CSP Technologies – Comparison I

Technology	Units	Parabolic Trough	Fresnel Trough	Molten Salt Solar Tower	Water Steam Solar Tower	Parabolic Dish
						
Technical Parameters						
Plant Size, envisaged	[MWe]	50 - 300 *	30 - 200	10 - 200 *	10 - 200	0.01 - 850
Plant Size, already realized	[MWe]	50 (7.5 TES), 80 (no TES)	5	20	20	1.5 (60 units)
Collector / Concentration	[-]	Parabolic trough (70 - 80 suns)	Fresnel trough / > 60 suns, depends on secondary reflector	Heliostat field / > 1,000 suns	Heliostat field / > 1,000 suns	Single Dish / > 1,300 suns
Receiver / Absorber	[-]	Absorber fixed to tracked collector, complex design	Absorber fixed to frame, no evacuation, secundary reflector	External tube receiver	External or cavity tube receiver, multi receiver systems	Multi receiver system
Storage System	[-]	Indirect two-tank molten salt (380°C; dT = 100K)	Short-time pressurized steam storage (<10min)	Direct two-tank molten salt (550°C; dT = 300K)	Short-time pressurized steam storage for saturated steam (<10min)	No storage for dish Stirling, chemical storage under development
Hybridisation	[-]	Yes, indirect (HTF)	Yes, direct (steam boiler)	Yes	Yes, direct (steam boiler)	Not planned
Grid Stability	[-]	medium to high (TES or hybridisation)	medium (back-up firing possible)	high (large TES)	medium (back-up firing possible)	low
Cycle	[-]	Rankine steam cycle	Rankine steam cycle	Rankine steam cycle	Rankine steam cycle	Stirling cycle, Brayton cycle, Rankine cycle for distributed dish farms
Steam conditions	[°C/bar]	380°C / 100 bar	260°C / 50 bar	540°C / 100 - 160 bar	up to 540°C / 160 bar	up to 650°C / 150 bar
Land requirements **	[km²]	2.4 - 2.6 (no TES) 4 - 4.2 (7h TES)	1.5 - 2 (no TES)	5 - 6 (10 - 12 h TES)	2.5 - 3.5 (DPT on the lower site)	2.5 - 3
Required slope of solar field	[%]	< 1-2	< 4	< 2-4 (depends on field design)	< 2-4 (depends on field design)	>10%
Water requirements ***	[m³/MWh]	3 (wet cooling) 0.3 (dry cooling)	3 (wet cooling) 0.2 (dry cooling)	2.5-3 (wet cooling) 0.25 (dry cooling)	2.5-3 (wet cooling) 0.25 (dry cooling)	0.05 - 0.1 (mirror washing)
Annual Capacity Factor	[%]	25 - 28% (no TES) 40 - 43% (7h TES)	22 - 24%	55% (10h TES), larger TES possible	25 - 30% (solar only)	25 - 28 %
Annual Solar-to-Electricity Efficiency (net)	[%]	14 - 16%	9 - 10% (saturated)	15 - 17%	15 - 17%	20-22%

* maxiumum/optimum depends on storage size ** 100 MWe plant size ***Depends on water quality

CSP Technologies – Comparison II

Technology	Units	Parabolic Trough	Fresnel Trough	Molten Salt Solar Tower	Water Steam Solar Tower	Parabolic Dish
						
Commercial Aspects						
Maturity	[-]	- Proven Technology on large scale; - Commercially viable today	- Demonstration projects, first commercial projects under construction - Commercially viable 2011 onwards	Demonstration projects, first commercial projects under construction Commercially viable 2011 onwards	- Saturated steam projects in operation - Superheated steam demonstration projects, first commercial projects under construction - Commercially viable 2012 onwards	- demonstration projects, first commercial projects (first units) in 2011; - Commercially viable 2012 onwards
Total Installed Capacity (in operation Q4 2010)	[MWe]	1,000	7	10	10 (superheated /demo) 30 (saturated steam)	1.7
Estimated total Installed Capacity (in operation 2013)	[MWe]	3,000 - 4,000	200 - 300	200 - 400	400 - 500	500 - 1,000
Number of Technology Provider	[-]	high (> 10), Abengoa Solar / Abener, Acciona, ASC Cobra / Sener, Albiasa Solar, Aries Ingeniera, Iberdrola, MAN SolarMillenium, Samca, Solel / Siemens, Torresol etc.	medium (3 - 4), Areva, Novatec Biosol AG, Sky Fuels, Solar Power Group, etc.	medium (2 - 5) SolarReserve and Torresol others like Abengoa Solar and eSolar, SolarMillenium are planning entry	medium (3 -4), Abengoa Solar, BrightSource Energy, eSolar etc.	medium (4 - 5), Abengoa Solar, Infinia, SES / Tessera Solar, SB&P, Wizard Power
Technology Development Risk	[-]	low	medium	medium	medium	medium
Investment costs for 100MW	[$/kW]	4,000-5,000 (no storage) 6,000-7,000 (7-8h storage)	3,500-4,500 (no storage)	8,000-10,000 (10h storage)	4,000-5,000 (no storage)	4,500-8,000 (depending on volume production)
O&M Costs	[m $/a]	6 - 8 (no storage)	5.5 - 7.5	7 - 10 (molten salt with TES)	5 - 7 (water steam, no TES)	10 - 15 (water steam, no TES)

CSP Technology Assessment - Summary

- There are several different solar power technologies, which differ not only from a technical and economic point of view, but also in relation to reliability and maturity.
- Up until today, mainly parabolic trough power plants have been built and most CSP projects currently under construction and development are of this type.
- In the short term, parabolic trough will remain the leading CSP technology on the market place, as it is the most mature CSP technology showing the lowest technology and development risks.
- Out of the emerging CSP technologies, primarily molten salt and water steam central receiver technology as well as Fresnel trough technology are considered to be able to compete against parabolic trough technology in the medium term, provided that bidders can offer similar guarantees regarding availability and reliability.
- Due to the lowest specific thermal energy storage costs, high capacity factors and firm output and dispatching capabilities, which also supports the grid stability, molten salt central receiver technology is expected to be the leading technology for solar power plants with high capacity factors.
- It is expected that an increasing number of technology providers, stronger competition and technological advancements will have positive effects on the prices for CSP applications in the short and medium term.

CSP Technologies – Conclusion

- Based on the technology assessment a SWOT analysis (Strengths, Weaknesses, Opportunities, Threats) was conducted, taking into account the local resource conditions and performance requirements for South Africa.
- Main requirement for the implementation of CSP plants in South Africa is the current status of maturity which considers development and cost risks for large-scale commercial plants.
- For the Eskom project in Upington additionally a the capacity factor above 50% is required to allow for grid integration.
- Technologies and technology combinations which are considered with a low maturity as well as capacity factors below the 50% requirement are considered as not suitable for the implementation in South Africa.
- In addition, technologies and technology combinations with high auxiliary requirements for fuel and water are also considered as not suitable.

SWOT Analysis

Technology combinations	Main requirements		Auxiliary requirements	
	Maturity	Capacity factor > 50%	Fuel	Water
Parabolic trough				
- solar only	high	no	no / low	medium
- thermal energy storage	**high**	**yes**	**no / low**	**medium**
- solar hybrid	high	yes	high	medium
Fresnel trough				
- DSG (saturated)	medium	no	no / low	low
- DSG (superheated)	low	no	no / low	low
- thermal energy storage	low	yes	no / low	medium
Central receiver(solar tower)				
- water/steam	medium	no	no / low	medium
- molten salt	**medium**	**yes**	**no / low**	**medium**
- atmospheric air	low	no	no / low	medium
- pressurized air	low	yes	high	low
Parabolic dish				
- individual dish collector	medium	no	no	no / low
- array dish collector	low	no	no	no / low

The following two technologies are pre-selected for the Upington CSP project and have been further investigated:

1. Parabolic trough with thermal energy storage (two-tank molten salt)
2. Central receiver based on molten salt technology

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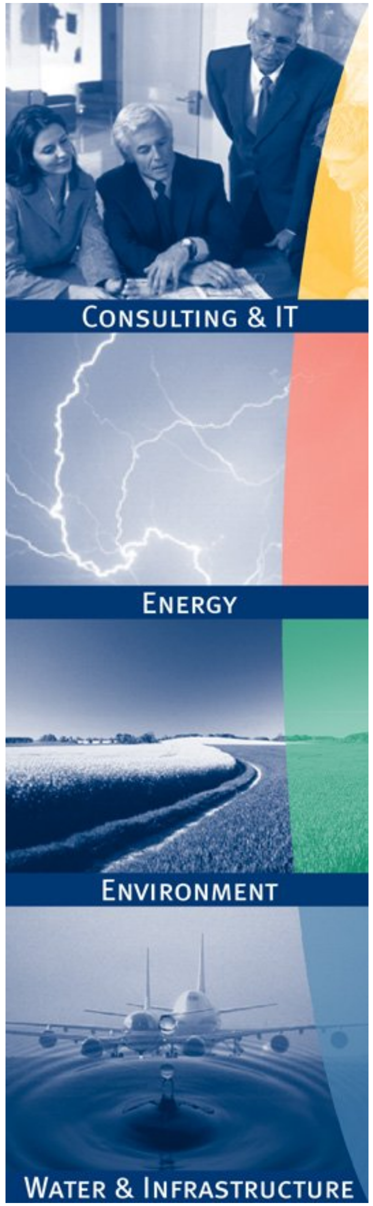
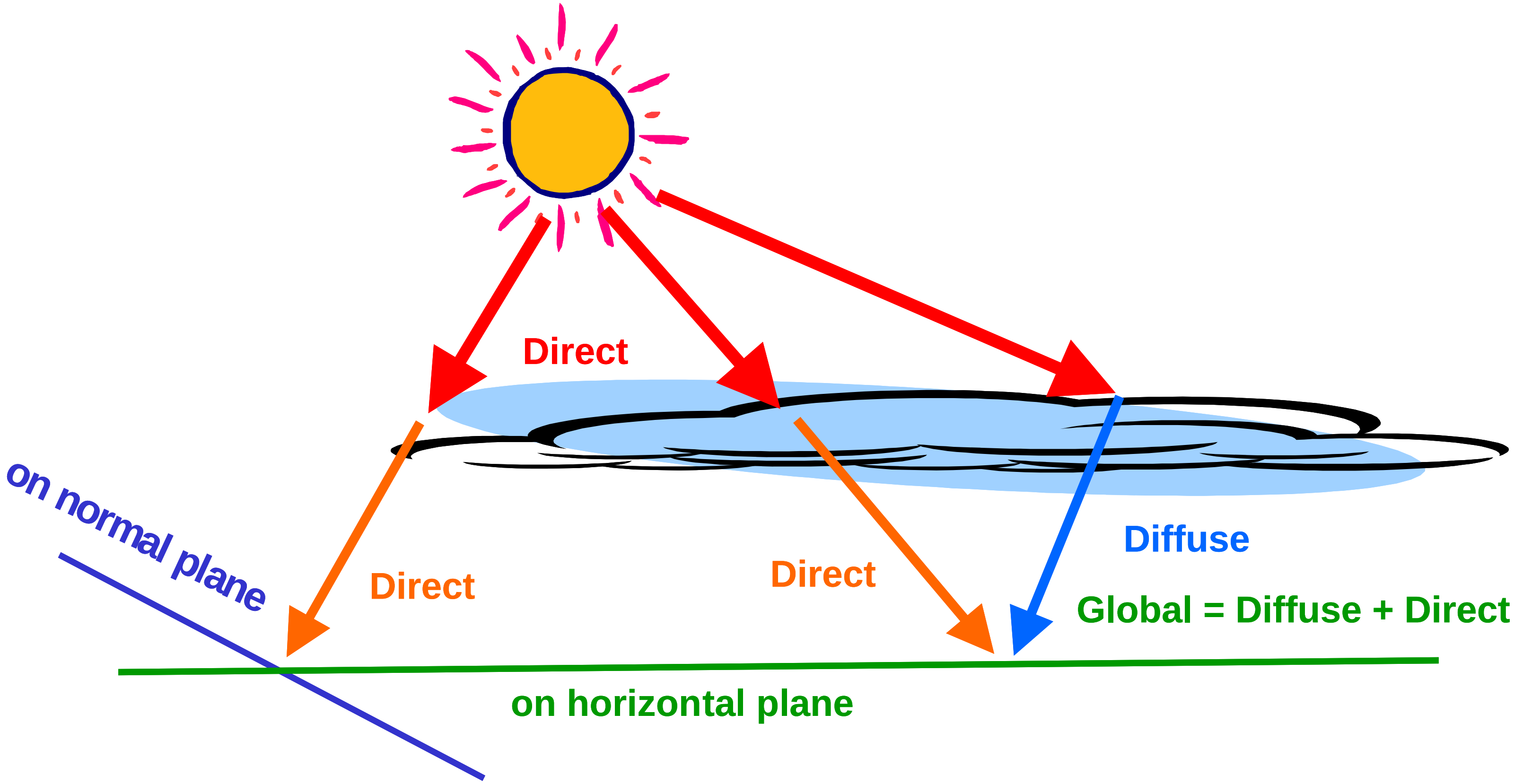
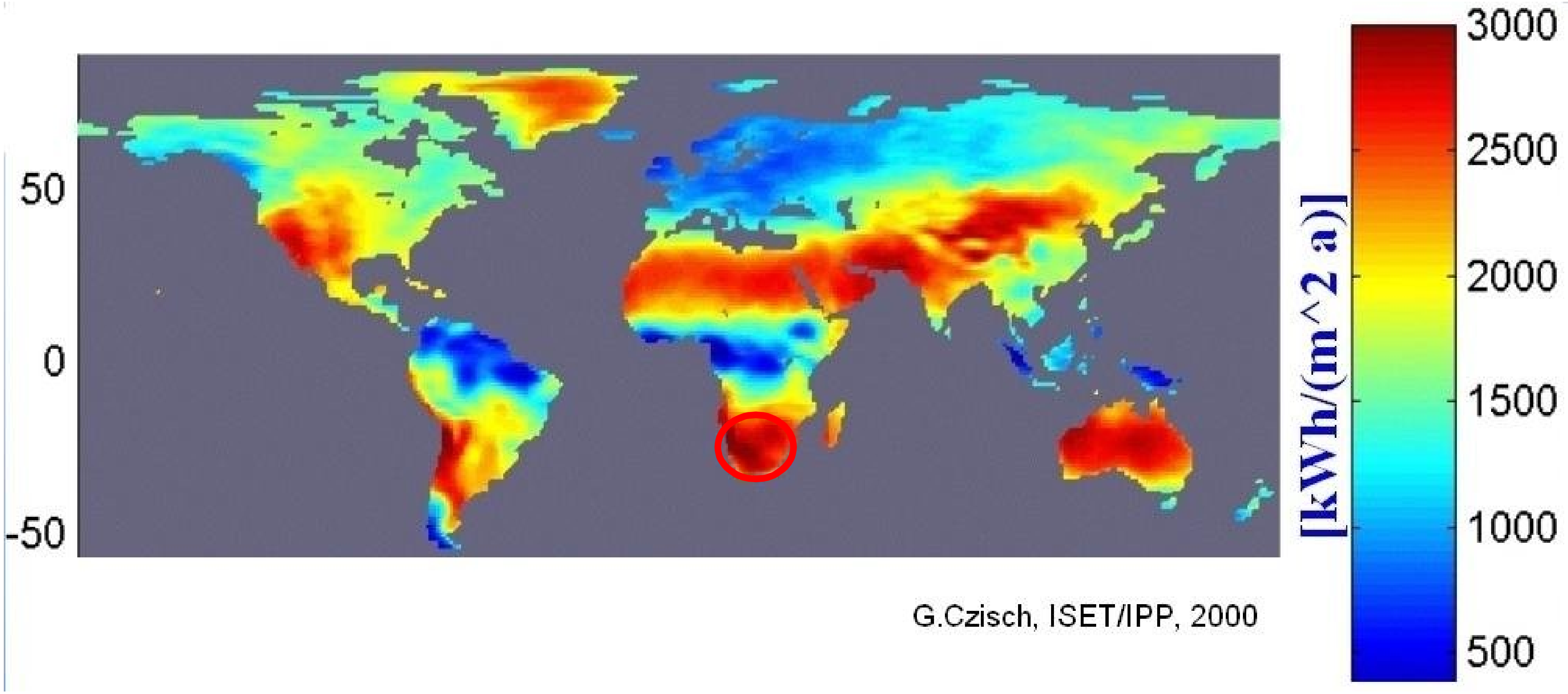


Solar Resource – Types of Irradiation



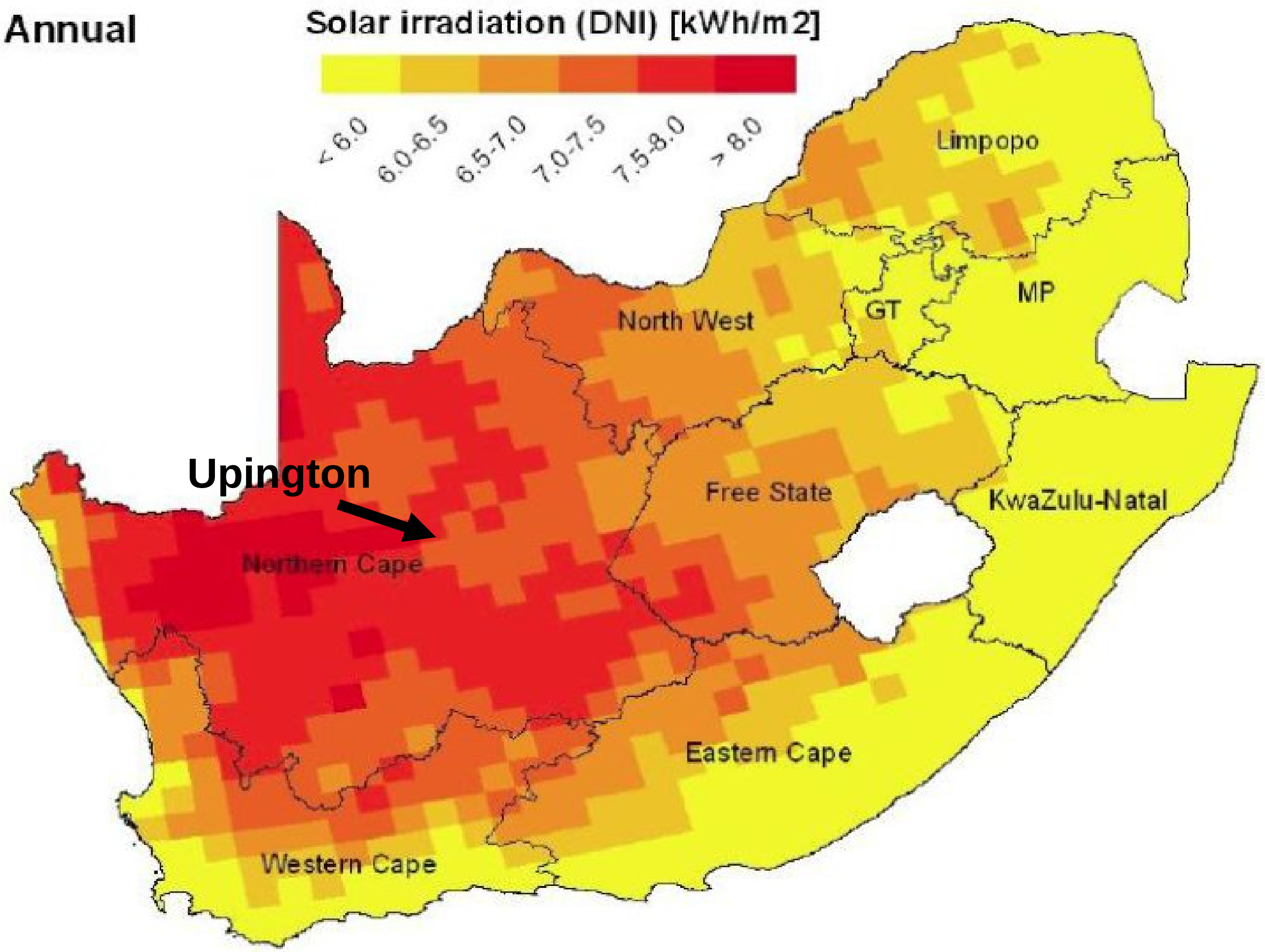
CSP technologies can only use the direct portion of the global irradiation

Solar Resource – World's Solar Potential



- Areas with annual DNI > 2,000 kWh/m²/a suitable for Solar Thermal Power Plants
- South Africa offers one of the best solar resource in the World with DNI data above 2,800 kWh/m²/a

Solar Resource Potential in South Africa



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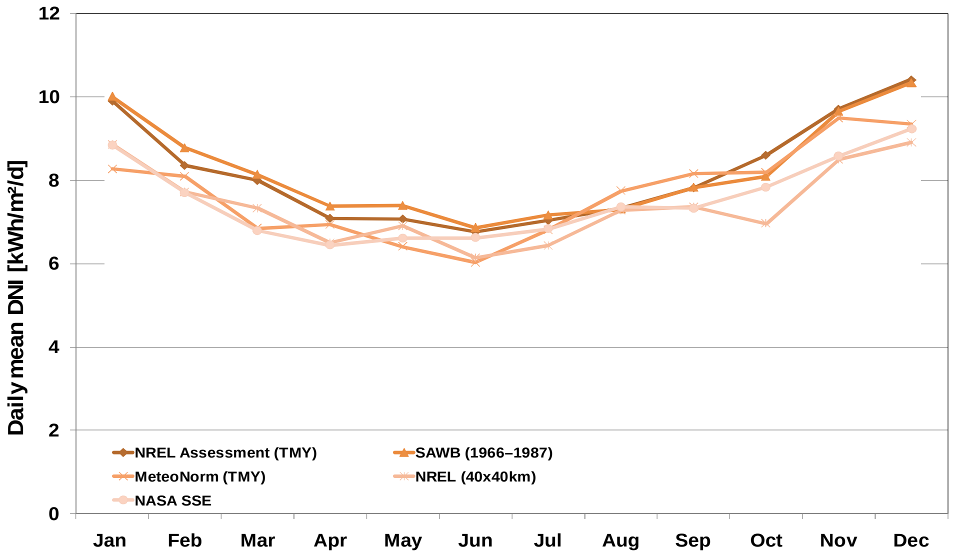
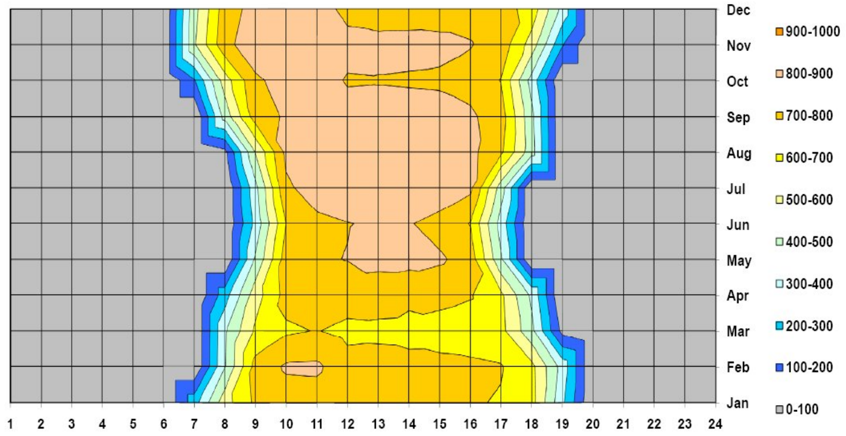
Solar Resource Assessment for Upington

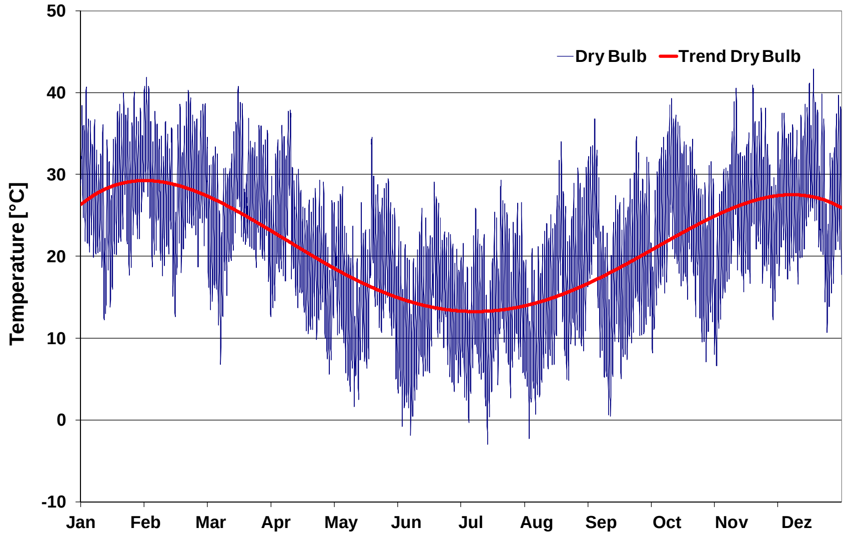


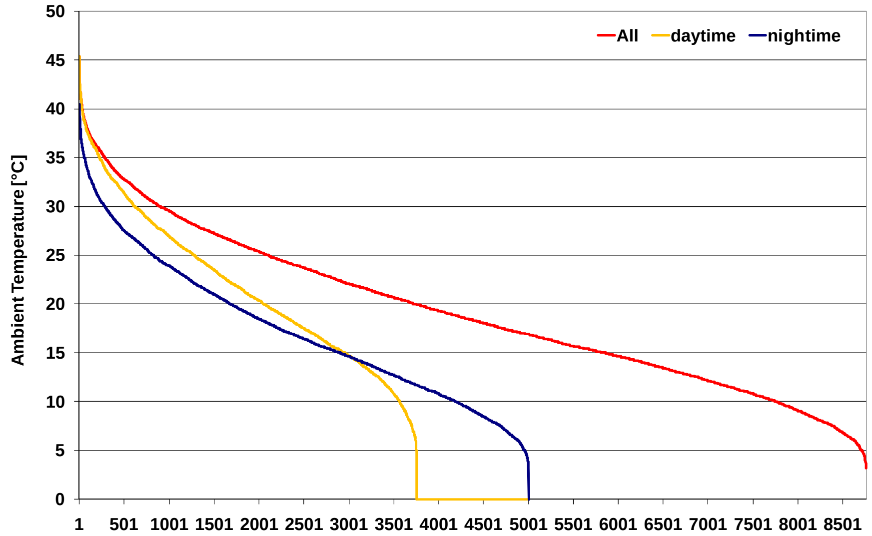


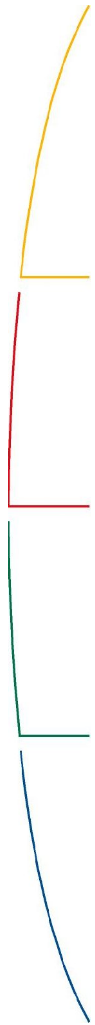
	NREL Assessment (TMY)	SAWB (1966–1987)	MeteoNorm (TMY)	NREL (40x40km)	NASA SSE
Jan	9.89	10	8.26	8.86	8.84
Feb	8.35	8.77	8.09	7.71	7.69
Mar	8.00	8.13	6.84	7.33	6.79
Apr	7.09	7.37	6.93	6.49	6.44
May	7.06	7.39	6.40	6.90	6.61
Jun	6.76	6.86	6.03	6.14	6.61
Jul	7.04	7.16	6.81	6.43	6.83
Aug	7.32	7.3	7.74	7.27	7.36
Sep	7.81	7.82	8.15	7.36	7.32
Oct	8.59	8.09	8.18	6.96	7.83
Nov	9.71	9.65	9.49	8.50	8.58
Dec	10.41	10.34	9.34	8.91	9.23
Annual	**2982.05**	**3007.6**	**2805.56**	**2703.04**	**2741.85**

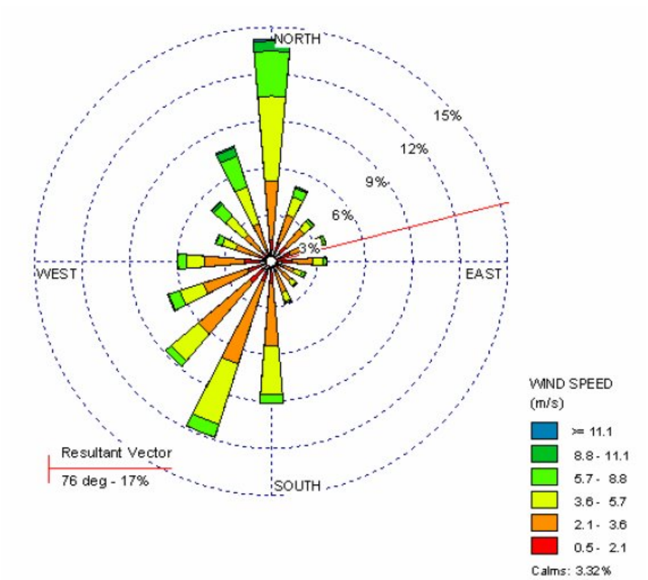
- Some ground measured DNI data available (not sufficient to create a typical meteorological year (TMY)
- Assessment of satellite derived radiation data
- Annual DNI sums vary between 3,007 kWh/m²/a (SAWB) and 2,703 kWh/m²/a (NREL 40x40 km grid)
- MeteoNorm TMY data set with an annual DNI of 2,806 kWh/m²/a selected for performance simulations

Site Assessment - Meteorological Data



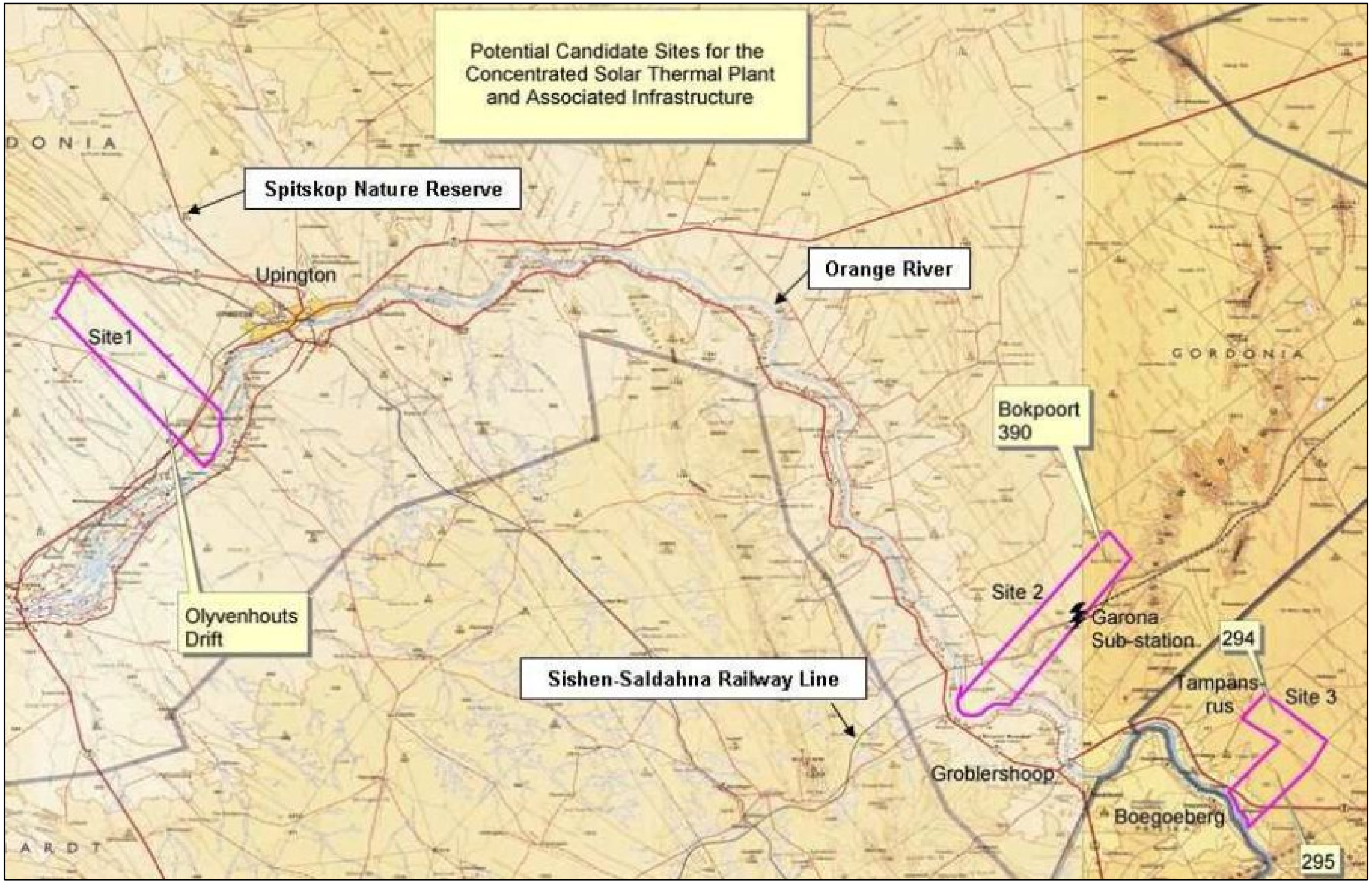




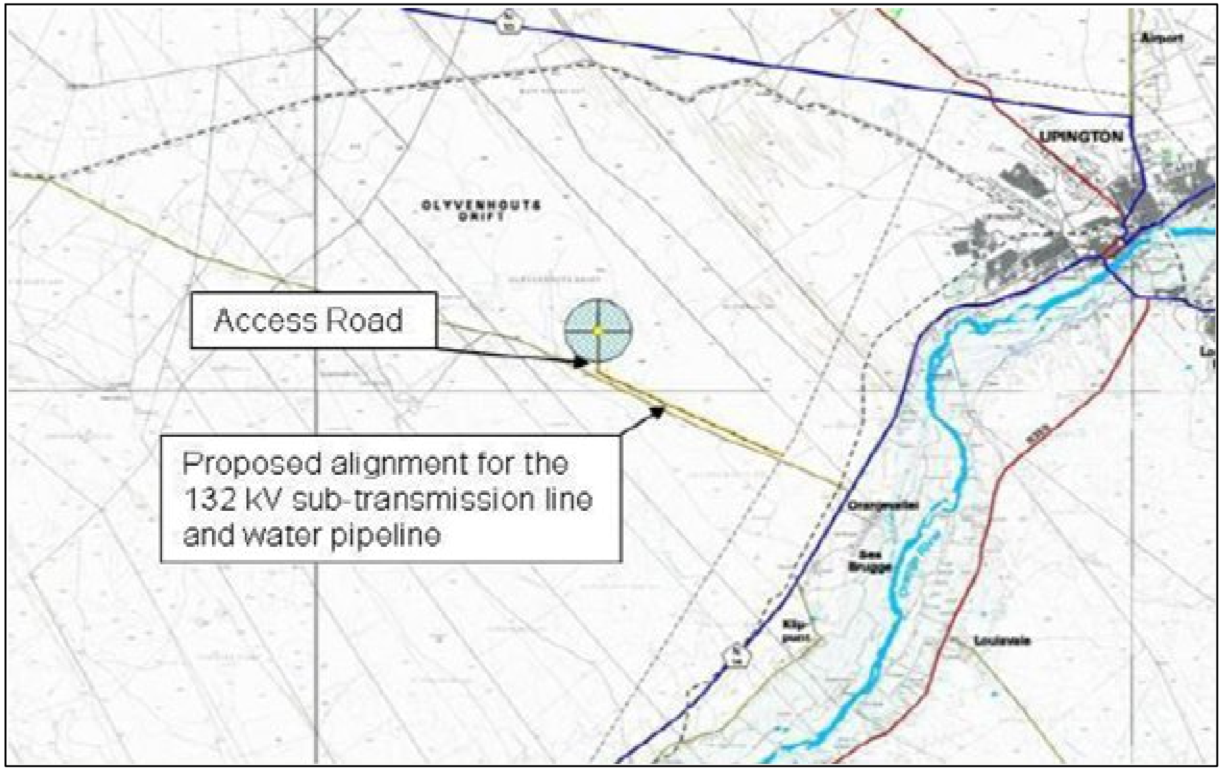


- Annual mean temperature of around 21°C.
- High temperatures, exceeding 40°C, during summer
- In winter frost can occur, but usually not severe.
- Low average wind speed with only 3-4 m/s.
- Wind gusts with wind speeds of more than 20 m/s.
- Low annual rainfall (170-240 mm). Mainly during late spring and the summer months.
- Within the period 1961-1990 the highest 24 hour rainfall was 59 mm.
- High annual evaporation (~2,300 mm/a).

Site Assessment - Investigated sites in EIA



Site Assessment – Olyvenhouls Drift Farm



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Site Assessment – Olyvenhouls Drift Farm I

Topography:

- The topography of the Olyvenhouts Drift farm is generally flat with only little topographic reliefs. There is a small slope from the south-east (Orange River) to the north-west, which would require some cut and fill work during the site preparations.

Soil conditions:

- The geology of the area is characterized by the metamorphosed sediments and volcanics, intruded by granites and is known as the Namaqualand Metamorphic Province.
- The soils are reddish, moderately shallow, sandy and often overlaid layers of calcrete of varying depths and thickness which is known for its hardness. The average clay content of the topsoil is less than 10 – 15 % and the soil depth varies between 400 and 750 mm.
- In view of the geology the proposed site is adequate. Nevertheless, intensive soil investigations have to be performed by the contractor.

Hydrology and drainage:

- The primary water resource in the Upington area is the Orange River passing by the proposed site in the south-east .
- There are two different aquifer systems indicated in the hydrogeological map of the site. The aquifer shows unfavourable characteristics (borehole yields and storage of groundwater).
- One larger seasonal drainage line is traversing the site from the north-west to the south and there are several small seasonal drainage lines and water courses within the site, which would have to be diverted around the solar field.

Site Assessment – Infrastructure

Transportation:

- The proposed site itself can be accessed through a secondary road which divert from the N14 highway near the small town of Oranjevallei. The gravel road would have to be upgraded to be used as an access road for the CSP plant.
- The N14, N10, R360 and R359 are the primary roads in the region and are the main link between Johannesburg and Namibia.
- The nearest deep water sea port is Saldanha Bay near Cape Town around 800 km to the south-west of Upington.

Water supply:

- Although, there is the Orange River close to the site (~5km), wet cooling is not considered for the power plant due to the water scarcity in the region. Furthermore, in 2000 the river had experienced a zero flow condition, which will most likely occur in the future more frequently.
- There are two options for the water supply of the proposed plant: Water supply from the local municipality or the direct abstraction of water from the Orange River.
- Recently it has been confirmed that the local municipality will supply water to the plant .

Back-up fuel supply:

- As there are no large quantities of back-up fuel available in Upington, hybridisation is not an option.
- For the moderate fuel requirement it is considered that either fuel oil or LPG (liquid petroleum gas) will be used, which would have to be transported by road to the site.

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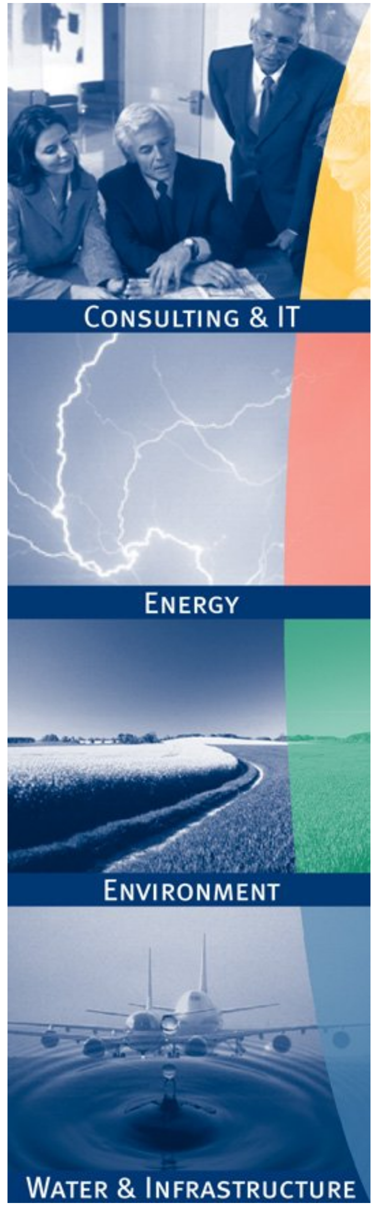
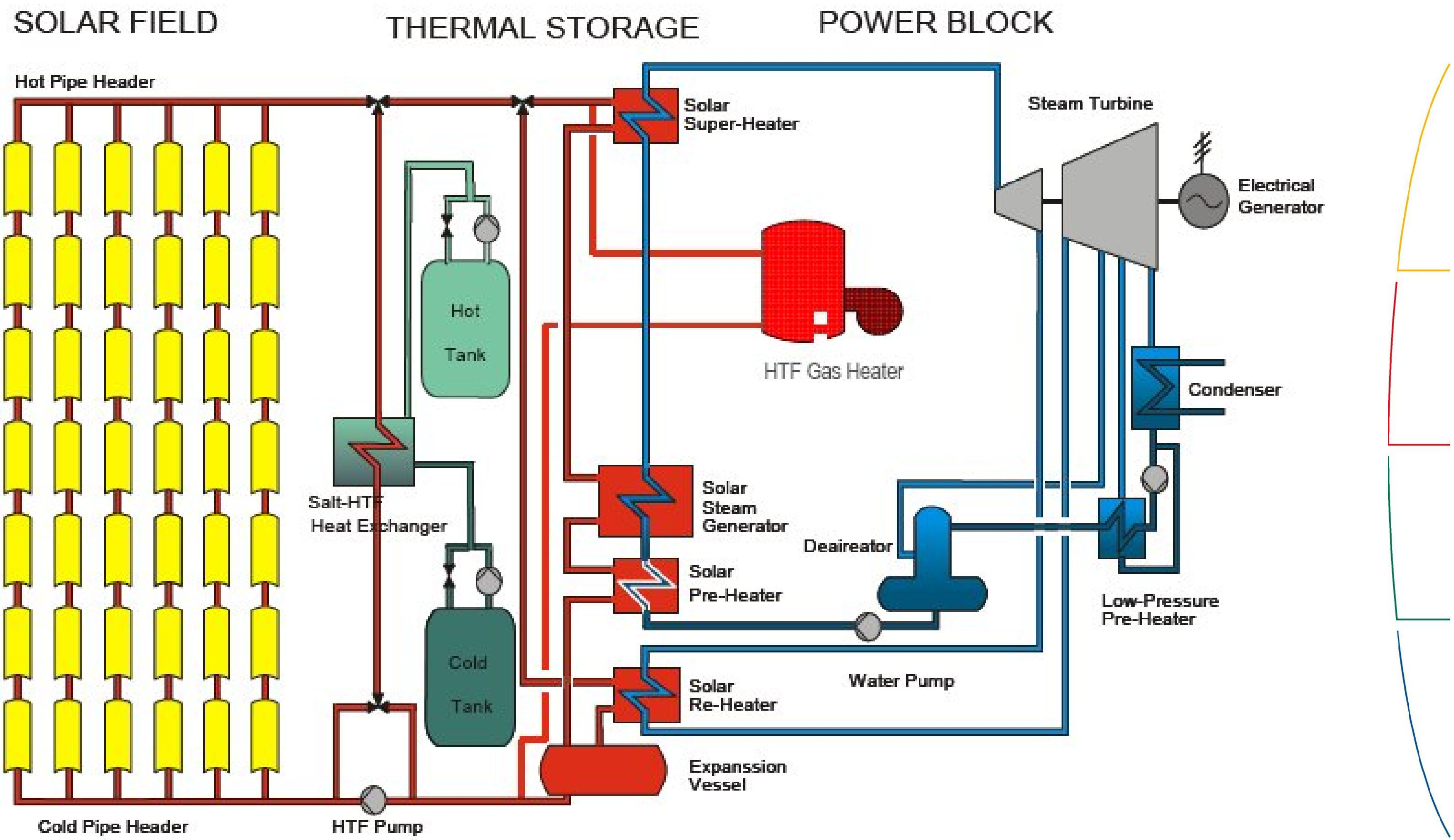


Parabolic Trough – Schematic



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Parabolic Trough – Investigated Options

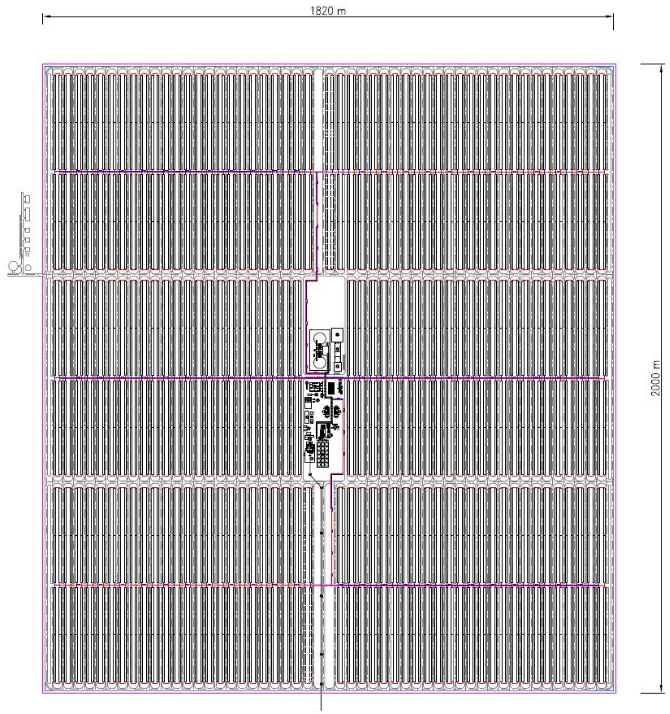
- Three options based on the following premises:
  - Annual capacity factor higher than 50%
  - Highest annual electricity production at lowest capital expenditures
  - Technical feasibility of plant design and practicability of operation
- Different thermal energy storage capacities investigated and solar field optimized.

Item	**Unit**	**Option**			
Rated power plant capacity, gross	MW_e	100			50
Thermal Energy Storage (TES):					
Thermal storage capacity	MWh_t	1050	2100	3150	1050
Hours of full load operation *)	h	4.5	9	13.4	9
Capacity factor	-	50%	56%	67%	55%

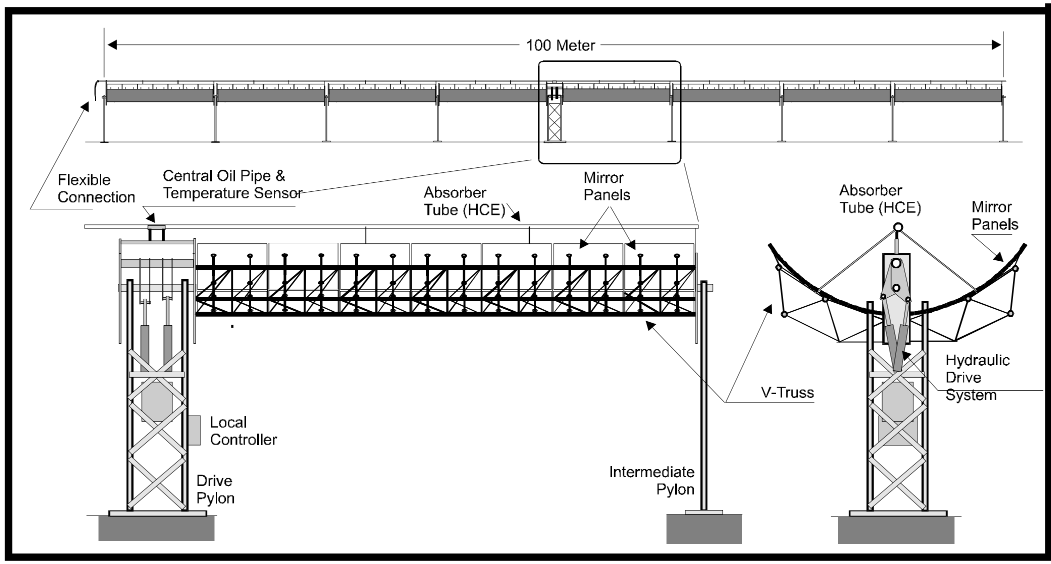
*) hours of full load operation of the power plant from TES referred to the rated capacity

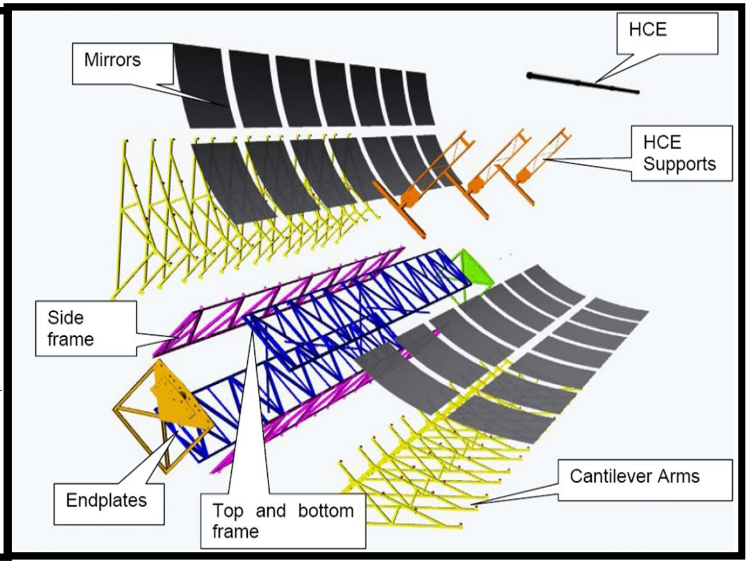
Parabolic Trough – Solar Field

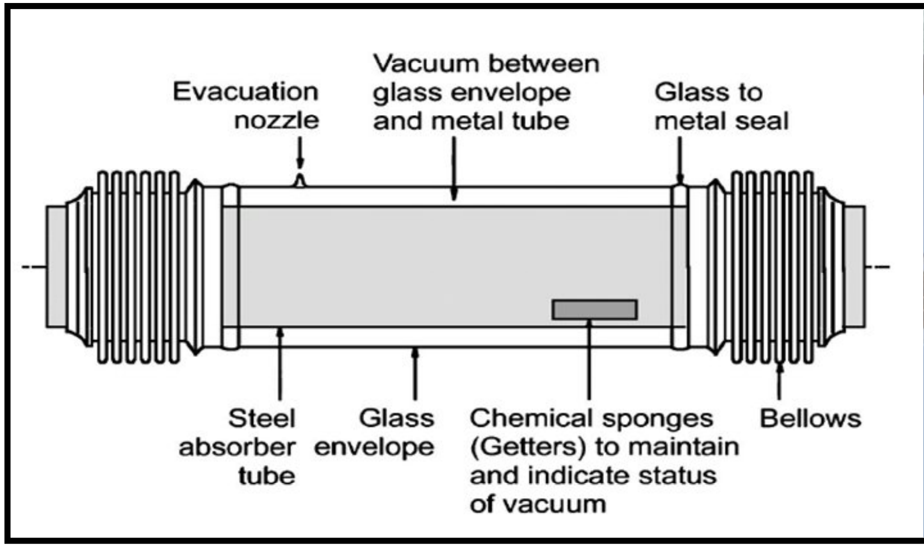
Item	Unit	Option			
		100 MW			50 MW
		TES 4.5 h	TES 9.0 h	TES 13.4 h	TES 9.0 h
Size of the solar field					
Direction of center line of collector	-	N-S	N-S	N-S	N-S
Net aperture area for one collector	m^2	817.50	817.50	817.50	817.50
Total collector area of Solar Field	1000 m^2	1,086	1,216	1,282	593
North South dimension of Solar Field	m	1,880	1,880	1,880	1,280
East West dimension of Solar Field	m	1,985	2,215	2,331	1,638
Land area of Solar Field	1000 m^2	3,731	4,165	4,381	2,097
Factor Land area / Collector area	-	3.44	3.42	3.42	3.54
Number of Collector and loops					
Number of subfields (N-S)	-	6	6	6	4
Number of collectors	-	1,328	1,488	1,568	725
Number of Collectors for each loop	-	4	4	4	4
Number of loops	-	332	372	392	181

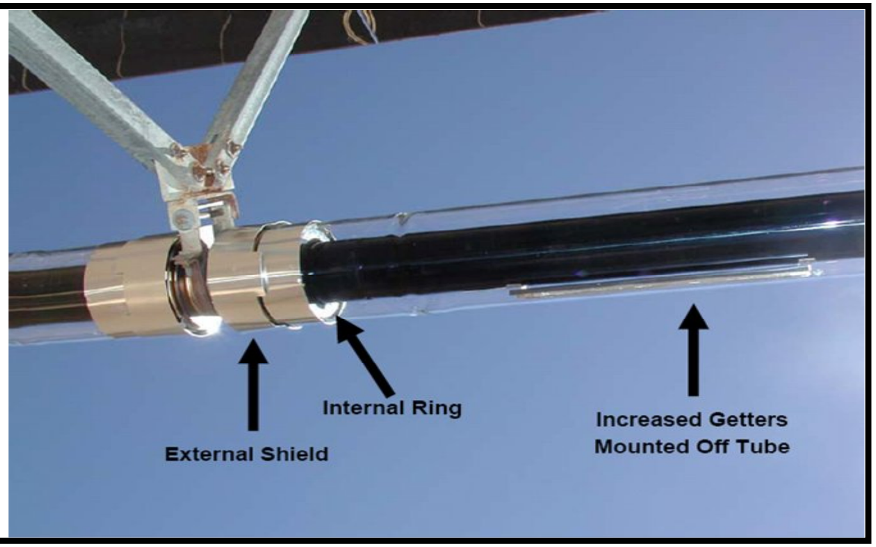


Parabolic Trough – Solar Field Components









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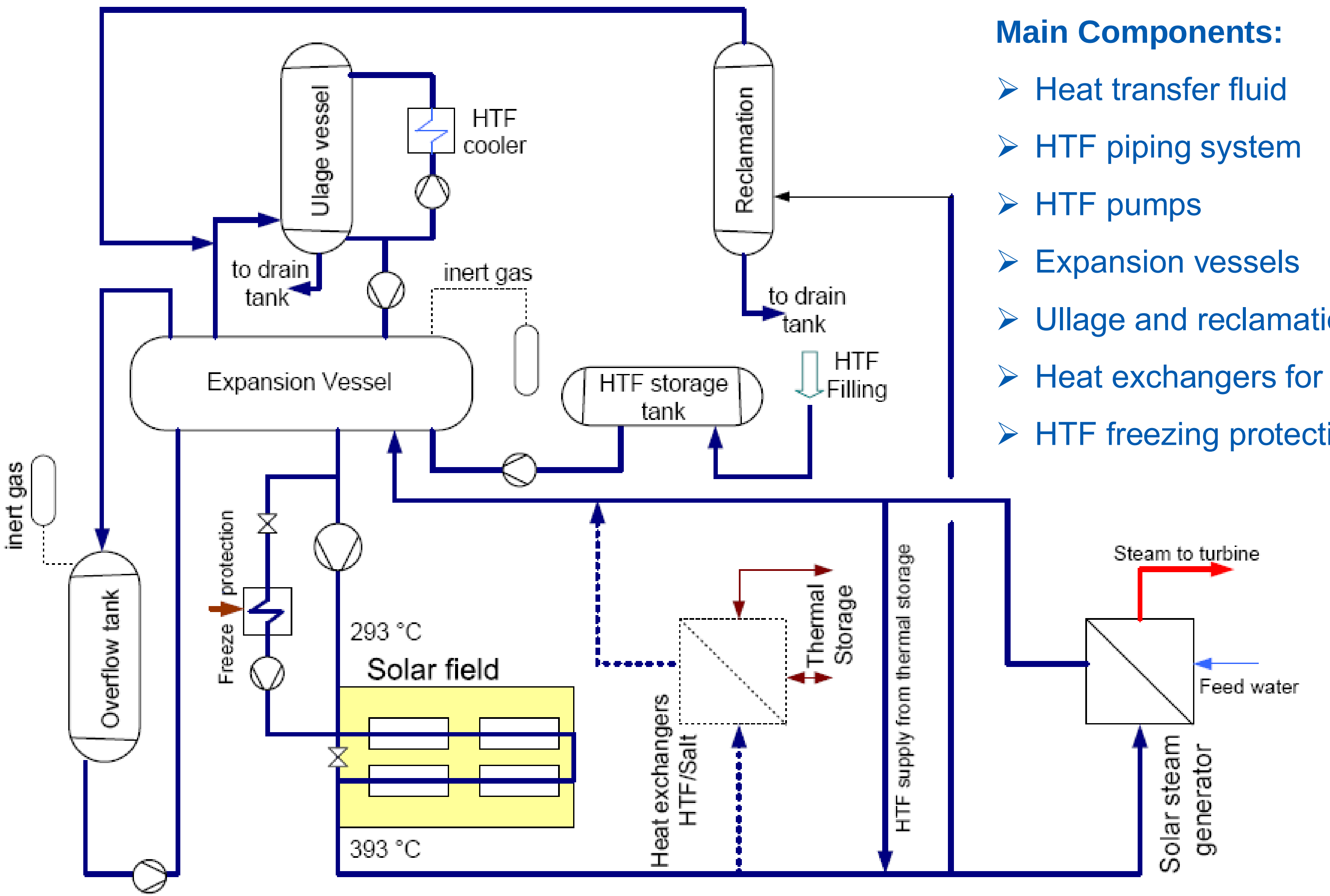
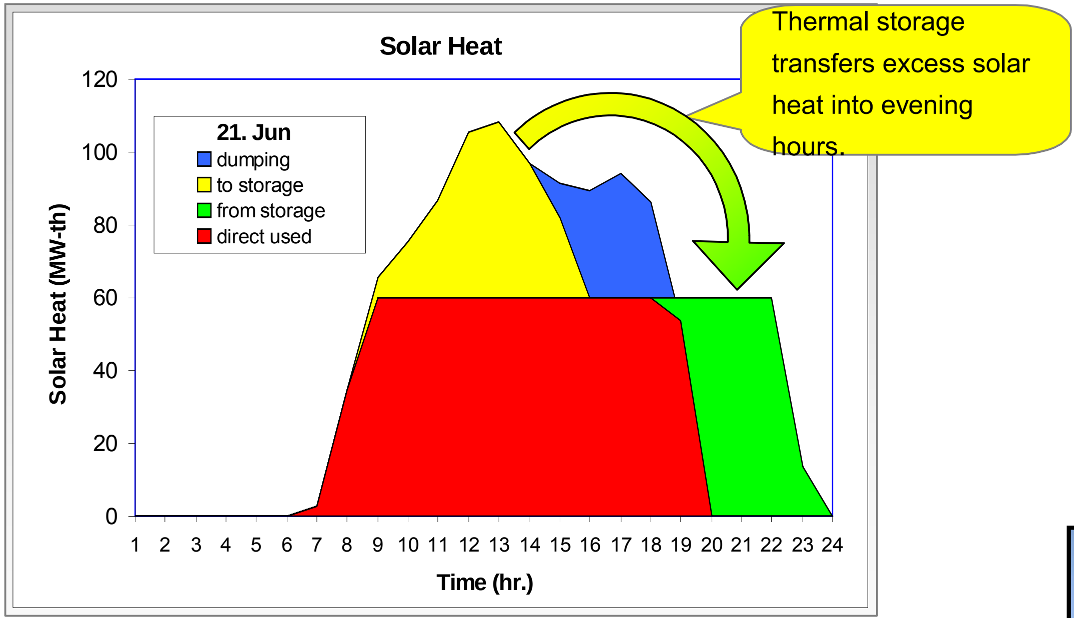
Parabolic Trough – HTF System

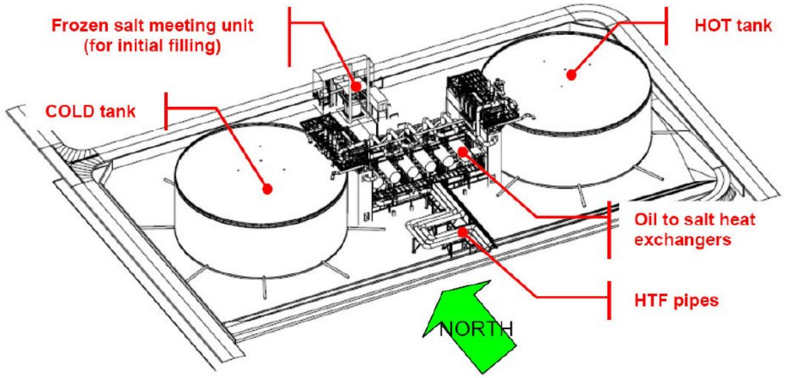


Main Components:

- Heat transfer fluid
- HTF piping system
- HTF pumps
- Expansion vessels
- Ullage and reclamation system
- Heat exchangers for thermal storage
- HTF freezing protection heater and pumps

Thermal Energy Storage Design





- Extension of full load operation to night time hours
- Reduction of part load operation (cloud transients)
- Dispatchable power generation
- State-of-the-art technology: Two-tank molten salt storage
- Capacity factors > 50% feasible

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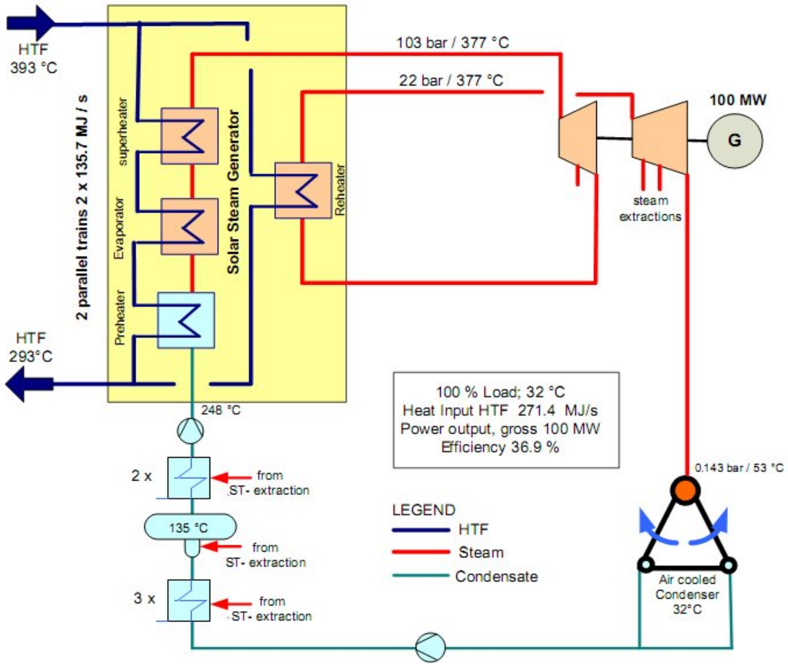
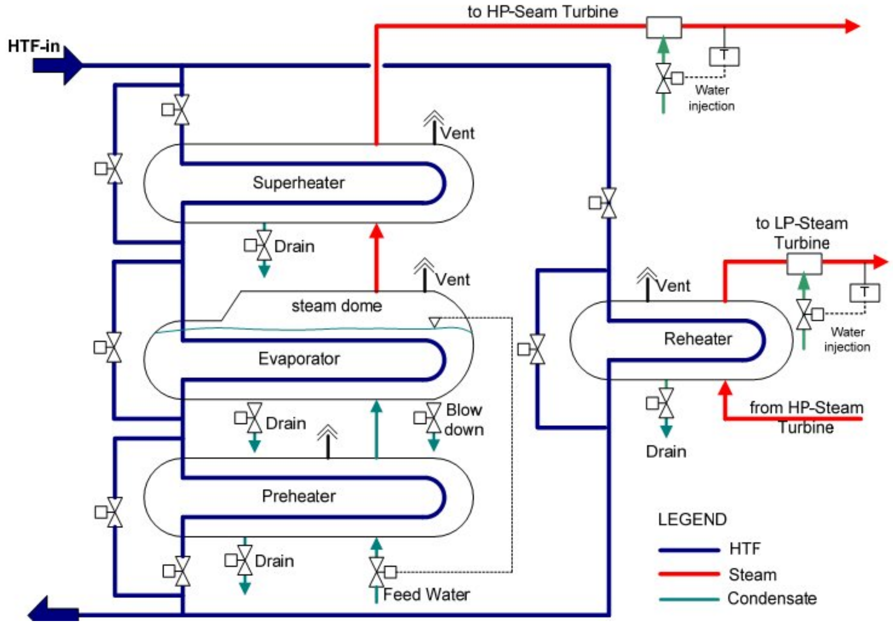
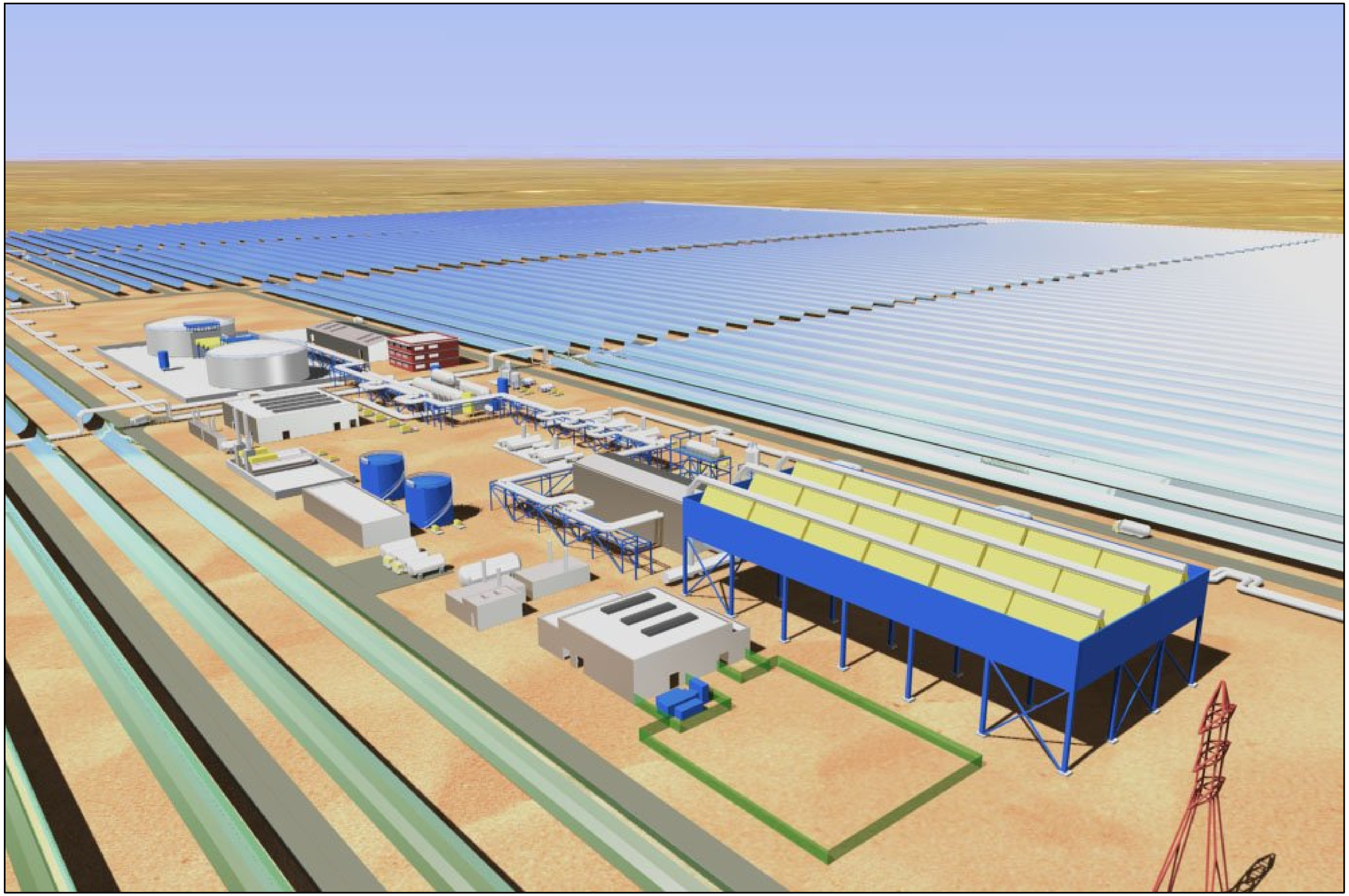
Parabolic Trough – Power Block





Item		Unit	Option Parabolic Trough			
			100 MWe			50 MWe
			TES 4.5 h	TES 9.0 h	TES 13.4 h	TES 9.0 h
Power Block Design Data						
Solar heat to power block day mode		MJ/s	271.4	271.4	271.4	135.7
Solar heat to power block storage mode		MJ/s	234	234	234	117
Steam turbine gross efficiency day mode		%	36.85	36.85	36.85	36.85
Steam turbine gross efficiency storage mode		%	36.27	36.27	36.27	36.27
Rated gross electric power output day mode		MWe	100	100	100	50
Gross electric power output storage mode		MWe	85	85	85	43
Net electric output day mode		MW	82	82	80	42
Solar steam generators		units	4	4	4	2
Rated thermal capacity, each		MJ/s	67.9	67.9	67.9	67.9
Condeser cooling system		-	Air cooled	Air cooled	Air cooled	Air cooled
Cooling load (including auxiliary cooling system load)		MJ/s	177.7	177.7	178.4	88.5

Parabolic Trough – Power Island Layout

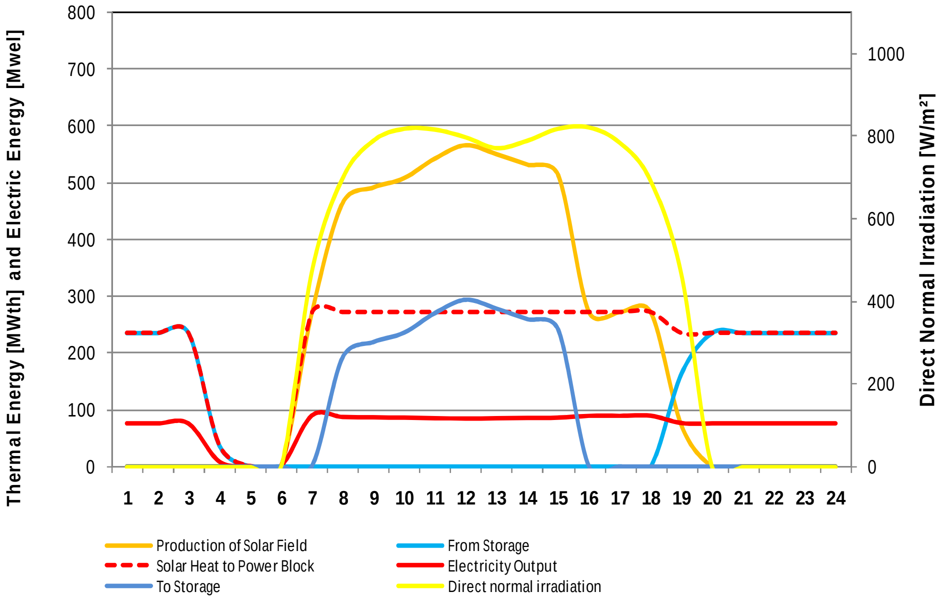


Performance at Design Point

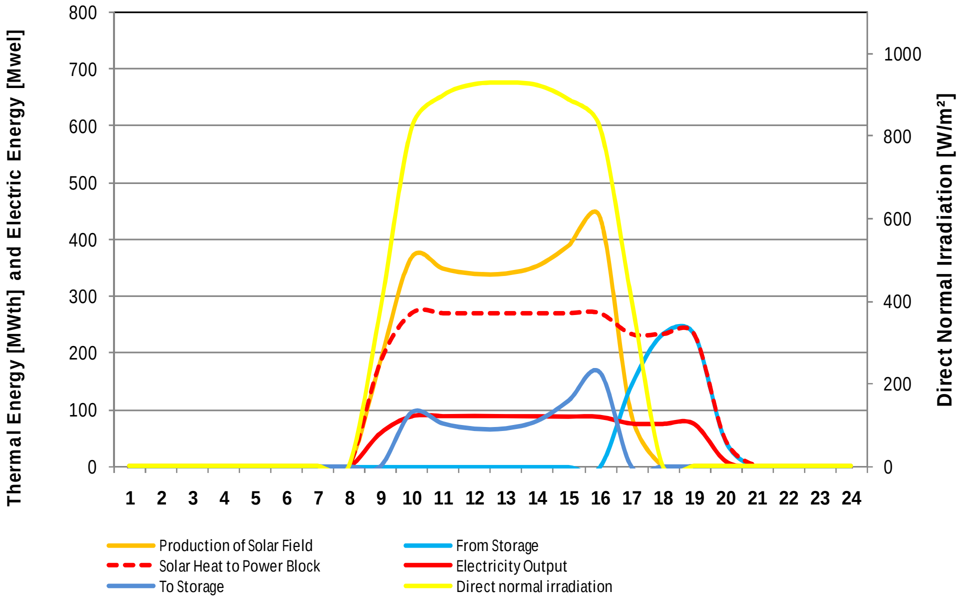
Item	Unit	Option Parabolic Trough			
		100 MWe			50 MWe
		TES 4.5 h	TES 9.0 h	TES 13.4 h	TES 9.0 h
Solar Field Design Data (at Reference Site Conditions)					
Design / Reference DNI	W / m²	950	950	950	950
Incident angle	Deg	5.6	5.6	5.6	5.6
Design point solar field efficiency	%	66.7	66.7	66.7	66.7
Thermal power of solar field (rated at 100% load of HTF system)	MJ/s	764.7	687.9	805.8	320.7
Solar Heat to Power Block (day mode)	MJ/s	271.4	271.4	271.4	135.7
Solar multiple	-	2.8	2.5	3.0	2.4
Solar Heat to TES	MJ/s	493.3	416.5	534.4	185.0
Power Block Design Data					
Solar heat to power block day mode	MJ/s	271.4	271.4	271.4	135.7
Solar heat to power block storage mode	MJ/s	234	234	234	117
Steam turbine gross efficiency day mode	%	36.85	36.85	36.85	36.85
Steam turbine gross efficiency storage mode	%	36.27	36.27	36.27	36.27
Rated gross electric power output day mode	MWe	100	100	100	50
Gross electric power output storage mode	MWe	85	85	85	43
Net electric output day mode	MW	82	82	80	42
Cooling load (including auxiliary cooling system load)	MJ/s	177.7	177.7	178.4	88.5
Plant efficiencies, at design point					
Design / Reference DNI	W / m²	950	950	950	950
Solar to heat efficiency	%	66.7	66.7	66.7	66.7
Power plant efficiency at design point, gross	%	36.8%	36.8%	36.8%	36.8%
Solar to electricity efficiency, gross	%	24.6%	24.6%	24.6%	24.6%

Performance - Typical Summer & Winter Day

Summer



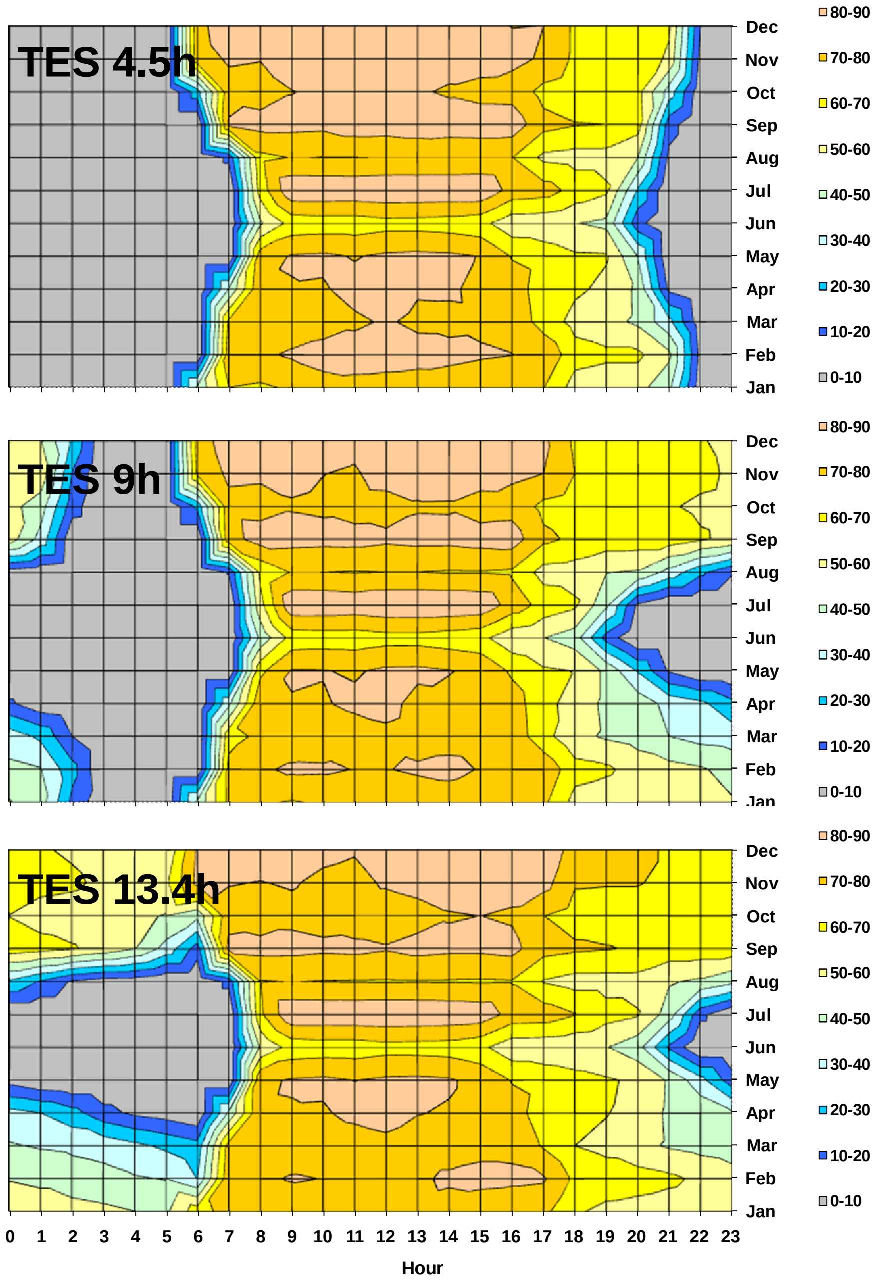
Winter

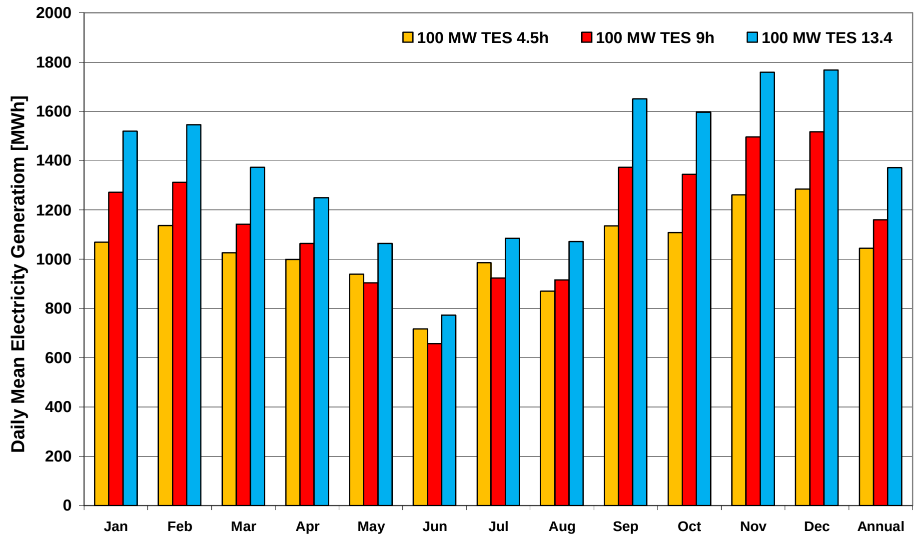


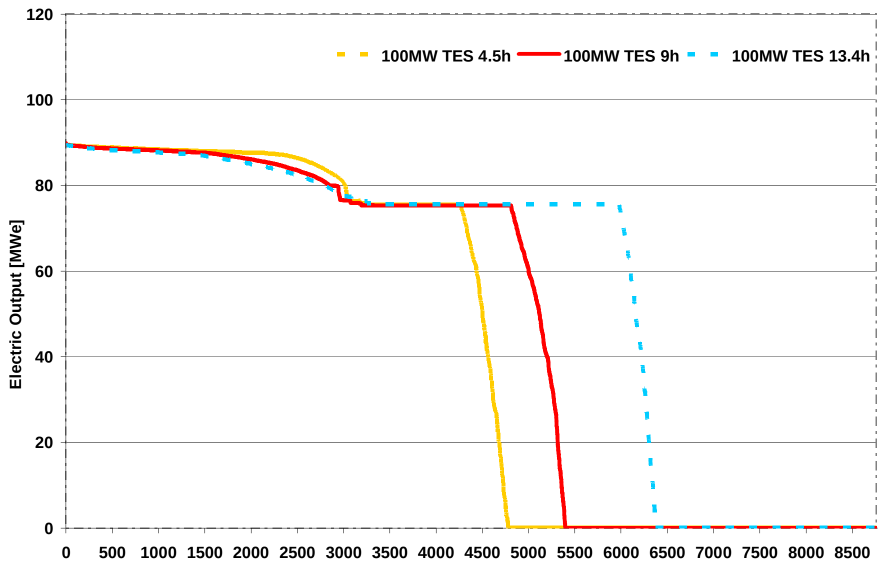
Parabolic Trough – Annual Performance

Item	Unit	Option Parabolic Trough			
		100 MWe			50 MWe
		TES 4.5 h	TES 9.0 h	TES 13.4 h	TES 9.0 h
Annual plant performance					
Annual solar irradiation	$kWh / m^2 a$	2,806	2,806	2,806	2,806
Heat production of solar field	GWh_t / a	1,209	1,354	1,610	652
Solar energy to storage	GWh_t / a	301	458	696	211
Solar energy to power block	GWh_t / a	1,204	1,346	1,597	649
Gross electricity generation, total	GWh_e / a	441	492	584	237
Own consumption during operation	GWh_e / a	53.5	62.1	75.4	25.7
Down time consumption imported from grid	GWh_e / a	10.2	8.5	6.0	4.9
Net electricity generation, total	GWh_e / a	377.4	421.8	502.4	206.6
Capicity factor	-	**0.50**	**0.56**	**0.67**	**0.54**
Equivalent full load operating hours	h / a	4,411	4,924	5,838	4,744
Annual plant efficiencies					
Annual average solar to heat efficiency	%	48.4	48.4	48.4	48.4
Average annual steam turbine efficiency, gross	%	36.6%	36.6%	36.6%	36.6%
Own consumption/Gross electricity generation	%	11.9	12.4	12.8	10.6
Annual solar to electricity efficiency, gross	%	12.9	16.2	16.2	16.6
Avoided CO2 emissions	**1000 t / a**	**450**	**502**	**595**	**242**

Parabolic Trough – Annual Performance

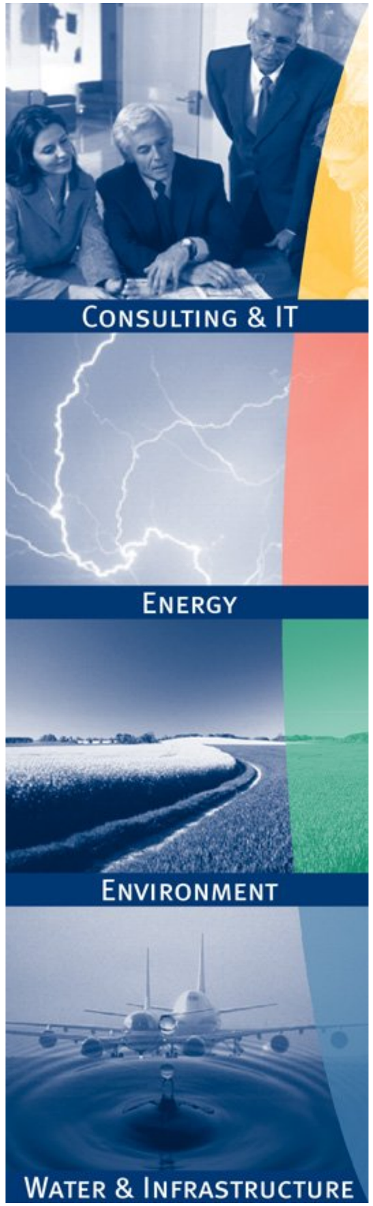






Content

- CSP technology description
- CSP market assessment
- CSP technology selection
- Solar resource and site assessment
- Parabolic trough power plant design and performance
- Central receiver power plant design and performance
- Techno-economic evaluation



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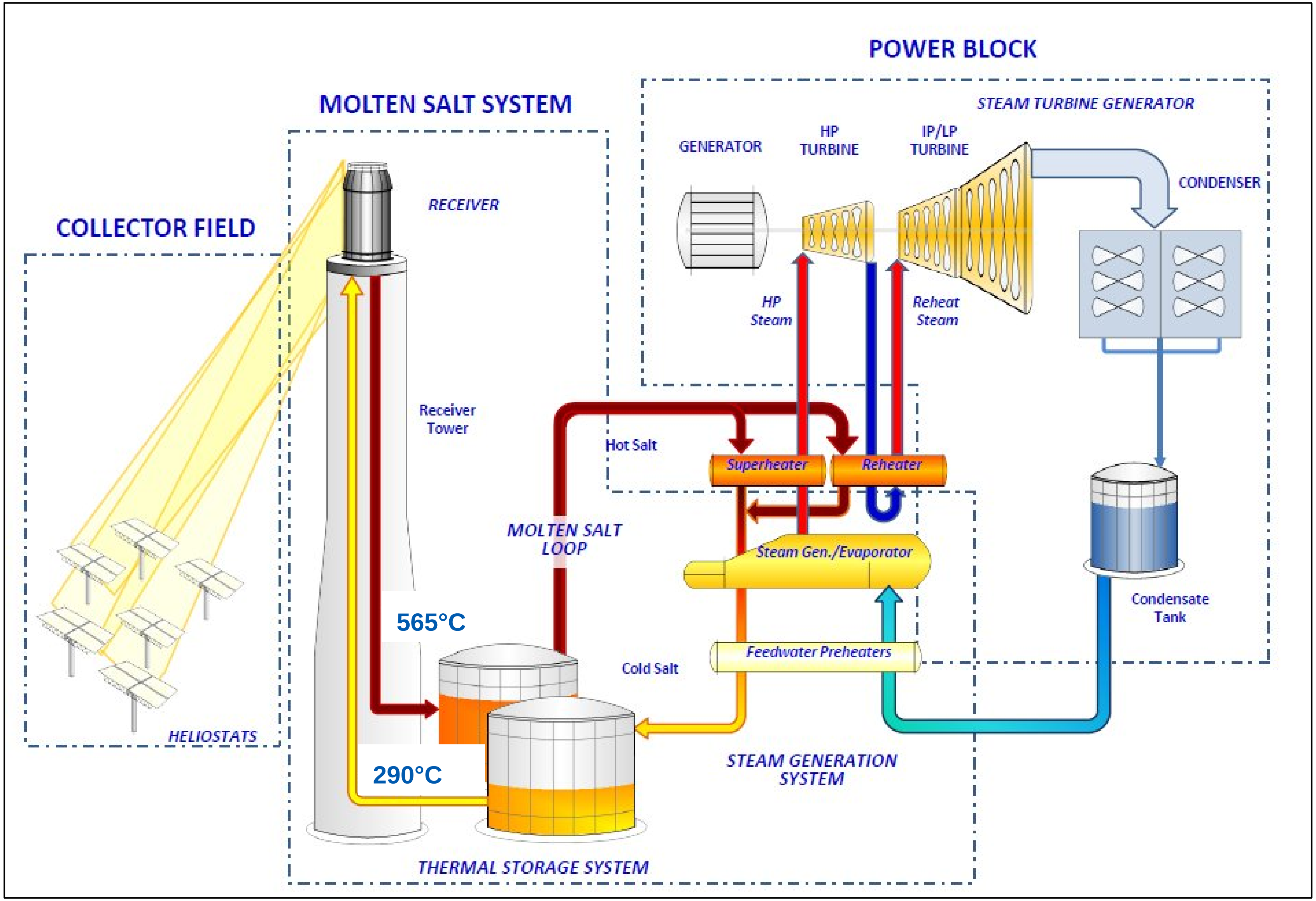
Molten Salt Central Receiver – Schematic



Central Receiver – Investigated Options

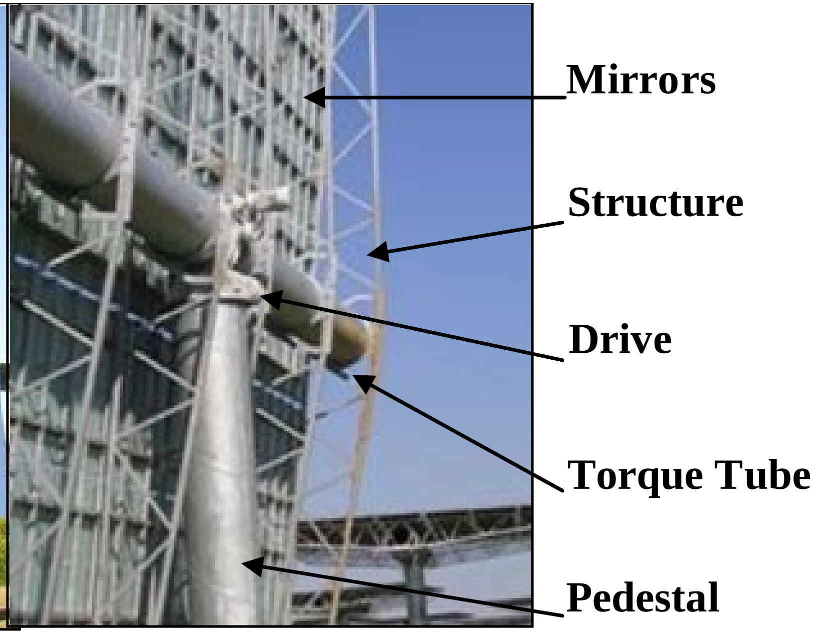
- Three options based on the following premises:
  - Annual capacity factor higher than 50%
  - Highest annual electricity production at lowest capital expenditures
  - Technical feasibility of plant design and practicability of operation
- Optimization for different solar field sizes (solar multiples) with a number of different thermal energy storage capacities.

Item	Unit	Option Central Receiver			
		100 MWe			50 MWe
		TES 9.0 h	TES 12.0 h	TES 15.0 h	TES 15.0 h
Rated power plant capcity, gross	MW	100			50
Solar multiple	-	2.0	2.5	3.0	3.0
Net aperture area	1000 m²	866.1	866.1	1,340.0	636.3
Thermal storage capacity	MWh	2,138	2,851	3,564	1,782
Thermal power storage charging	MJ /s	238	357	476	202
Capacity factor	-	0.54	0.68	0.79	0.79

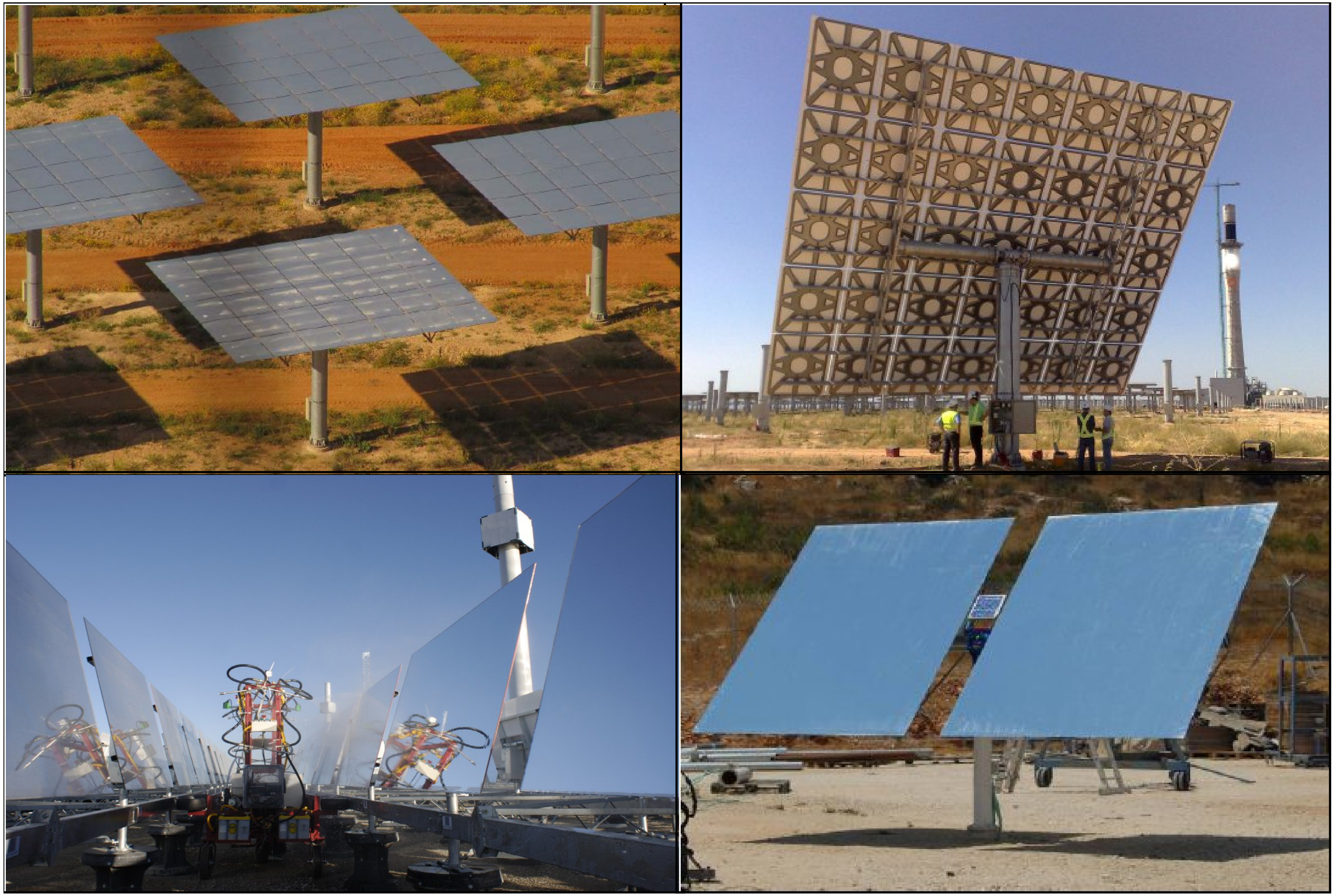
Central Receiver – Heliostats

The most important factors that influence the effectiveness of a heliostat are:

- Mirror reflectivity
- Mirror slope (quality)
- Mirror degradation
- Tracking accuracy (tracking error, canting)
- Wind outage due to high wind speeds
- Drive / Structural / Mirror failures



Central Receiver – Heliostats



Central Receiver – Heliostats

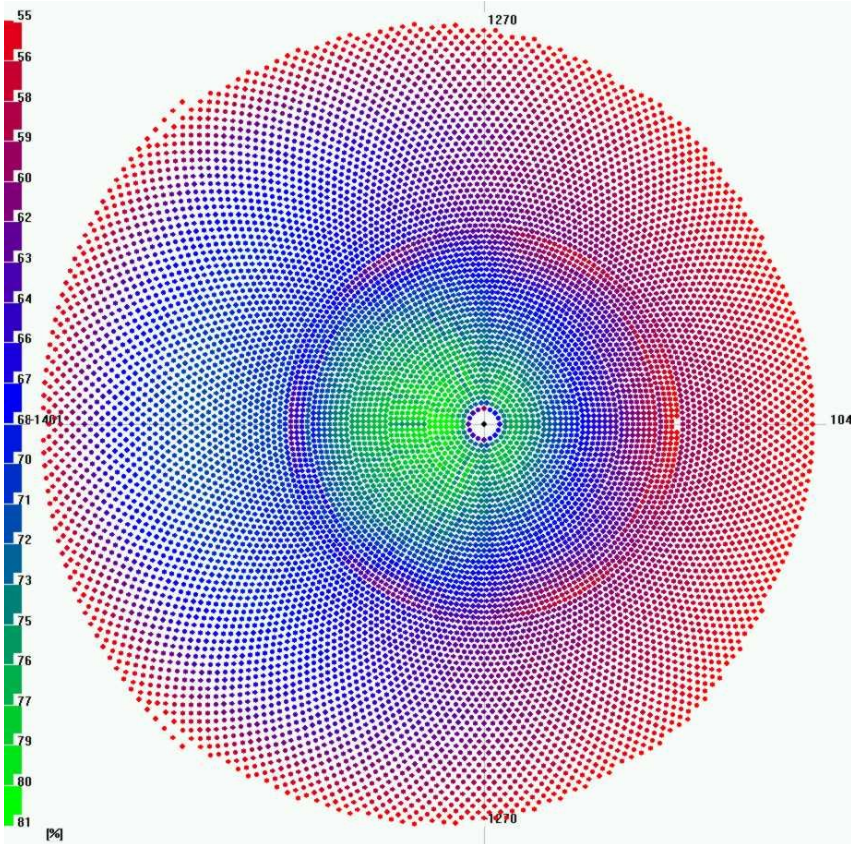
Heliostat designs

Name	Developer	Size	Projects
eSolar Heliostat	eSolar	1.14 m²	Sierra Sun Tower / Alpine Sun Tower / New Mexico Sun Tower
LH-1 Heliostat	Bright Source	7.2 m²	SEDC
LH-2 Heliostat	Bright Source	14.4 m²	Chevron / Ivanpah
HydroHelio	DLR, Cirris Solution, Lehle GmbH	30 m²	Demonstration at Solar Tower in Jülich and PSA planned
Pathfinder 2	Pratt Whitney	62.4 m²	Crescent Dunes Solar Energy Project / Rice Solar Energy Project
Sener Heliostat	Sener	120 m²	Gemasolar
Sanlucar 120SL	Abengoa Solar	121.3 m²	PS10 / PS20 / AZ20
ATS 150	Advanced Thermal Systems	150 m²	Demonstration-Scale
Multi-Facet Stretched-Membrane Heliostat	SAIC	170 m²	Demonstration-Scale

Specification of Sanlucar 120SL heliostat

Item	Unit	Value
Type	-	multi-facetted glass metal with two axis drive
Total reflective surface	m²	121
Surface of one facet	m²	4.33
Height	m	9.45
Width	m	12.84
Height of heliostat centre	m	6
Reflectivity (annual average)	%	87.4
Slope error (incl. sunshape)	mrad	3.664
Canting	-	on-axis
Shut down wind speed	km/h	36
Survival wind speed	km/h	140

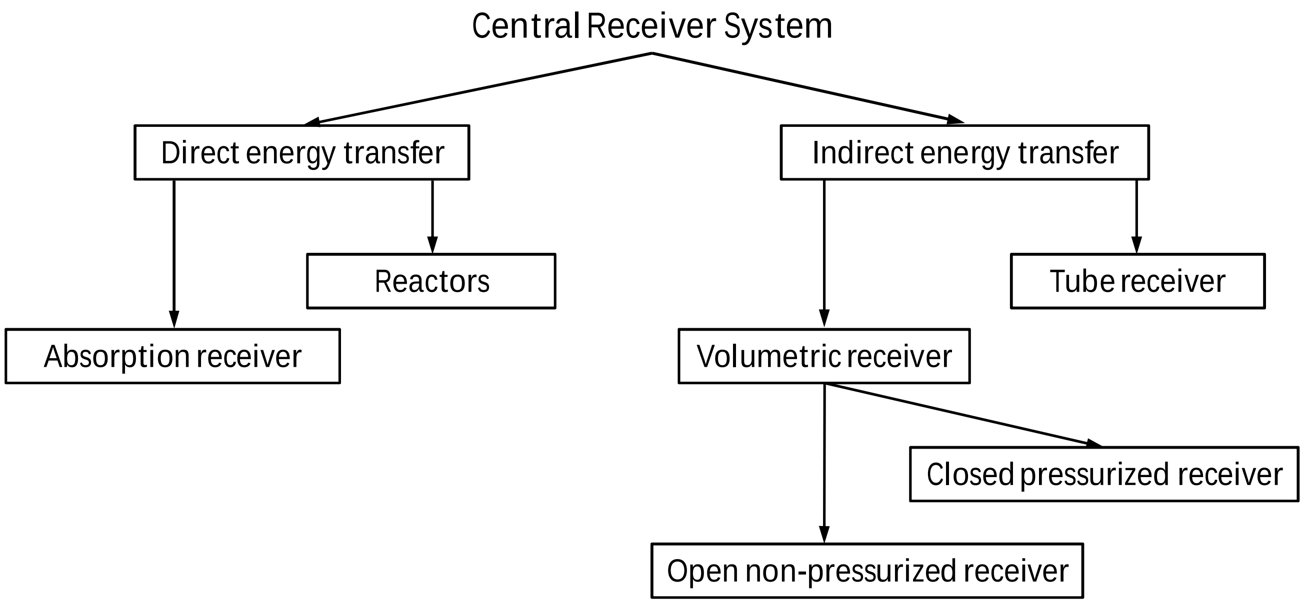
Solar Field Design and Performance

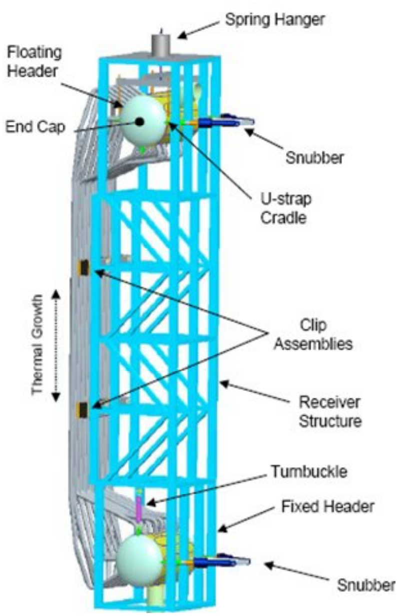


Item	Unit	Option			
		100 MWe			50 MWe
		SM 2	SM 2.5	SM 3	SM 3
Design					
Field arrangement	-	cirular	cirular	cirular	cirular
Heliostat aperture area	m²	121	121	121	121
Number of heliostats	-	7,158	8,978	11,074	5,259
Net aperture area (optical effective mirror surface)	m²	866,118	1,086,338	1,339,954	636,339
North - south dimension	m	1,897	2,110	2,445	1,562
East - west dimension	m	2,030	2,262	2,540	1,790
Total required land area of solar power plant	m²	3,850,579	4,772,310	6,210,007	2,795,566
Factor land area / collector area	-	4.45	4.39	4.63	4.39
Performance					
Heliostat field efficiency at design point	%	66.8	66.6	64.8	68.2
Annual efficiency	%	58.9	58.6	57.4	59.9

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	33.2	25.0	15.7	0.0	0.0	0.0	0.0	0.0	15.7	25.0	33.2	36.1
6	51.9	48.4	41.8	30.1	21.0	17.5	21.0	30.1	41.8	48.4	51.9	52.9
7	58.5	57.7	55.9	50.5	43.9	40.5	43.9	50.5	55.9	57.7	58.5	58.7
8	61.6	61.2	60.2	58.6	56.0	54.1	56.0	58.6	60.2	61.2	61.6	61.7
9	63.9	63.5	62.7	61.3	59.8	58.9	59.8	61.3	62.7	63.5	63.9	63.9
10	65.2	65.0	64.3	62.8	61.3	60.7	61.3	62.8	64.3	65.0	65.2	65.2
11	65.7	65.5	64.8	63.3	61.9	61.2	61.9	63.3	64.8	65.5	65.7	65.7
12	65.2	65.0	64.3	62.8	61.3	60.7	61.3	62.8	64.3	65.0	65.2	65.2
13	63.9	63.5	62.7	61.3	59.8	58.9	59.8	61.3	62.7	63.5	63.9	63.9
14	61.6	61.2	60.2	58.6	56.0	54.1	56.0	58.6	60.2	61.2	61.6	61.7
15	58.5	57.7	55.9	50.5	43.9	40.5	43.9	50.5	55.9	57.7	58.5	58.7
16	51.9	48.4	41.8	30.1	21.1	17.6	21.1	30.1	41.8	48.4	51.9	52.9
17	33.2	25.0	15.7	0.0	0.0	0.0	0.0	0.0	15.7	25.0	33.2	36.1
18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Classification of Receiver Systems





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Specification of tower and receiver

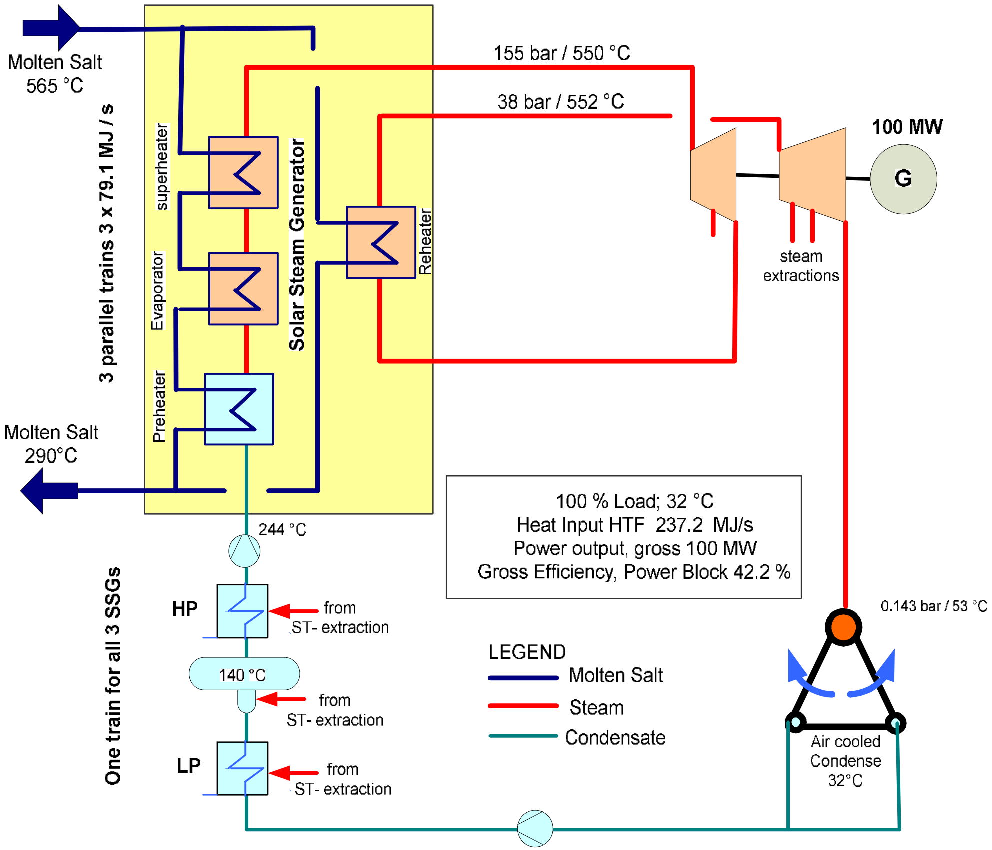
ESMAP Energy Sector Management Assistance Program

Item	Unit	Option			
		100 MWe			50 MWe
		SM 2	SM 2.5	SM 3	SM 3
Tower					
Tower height	m	279	315	320	255
Tower diameter	m	25	25	25	25
Receiver					
Receiver type	-	Zyl.	Zyl.	Zyl.	Zyl.
Receiver aperture	m²	952	1,191	1,428	714
Receiver height	m	19.8	22.2	24.3	17.2
Receiver diameter	m	15.3	17.1	18.7	13.2
Receiver inlet temperature	°C	290	290	290	290
Receiver outlet temperature	°C	565	565	565	565
Absorptivity	-	0.9	0.9	0.9	0.9
Emissivity	-	0.83	0.83	0.83	0.83
Mean flux (incident)	kW/m²	576	575	575	575
Performance					
Receiver thermal power (design point)	MWt	475	594	713	356
Thermal losses (design point)	MWt	63	79	94	47
Receiver efficiency (design point)	%	86.8	86.8	86.8	86.8
Annual efficiency	%	85.4	85.4	85.4	85.4

Specification of Thermal Energy Storage

Item	Unit	Option				
		100 MWe				50 MWe
		6h	9h	12h	15h	15h
Design						
Type	-	two-tank-molten-salt-storage				
Storage Fluid	-	Solar Salt, 60% NaNO3 + 40% KNO3				
Storage capacity (full load)	h	6	9	12	15	15
Thermal capacity	MWh	1,426	2,138	2,851	3,564	1,782
Salt mass (incl. dead volume)	tons	13,679	20,519	27,359	34,198	17,099
Hot storage tank						
Operating temperature	°C	565	565	565	565	565
Maximum design temperature	°C	593	593	593	593	593
Number of storage tanks	-	1	1	1	2	1
Heat losses (approximation)	kW	574	752	911	1,268	666
Cold storage tank						
Operating temperature	°C	290	290	290	290	290
Maximum design temperature	°C	400	400	400	400	400
Number of storage tanks	-	1	1	1	2	1
Heat losses (approximation)	kW	287	376	455	634	333

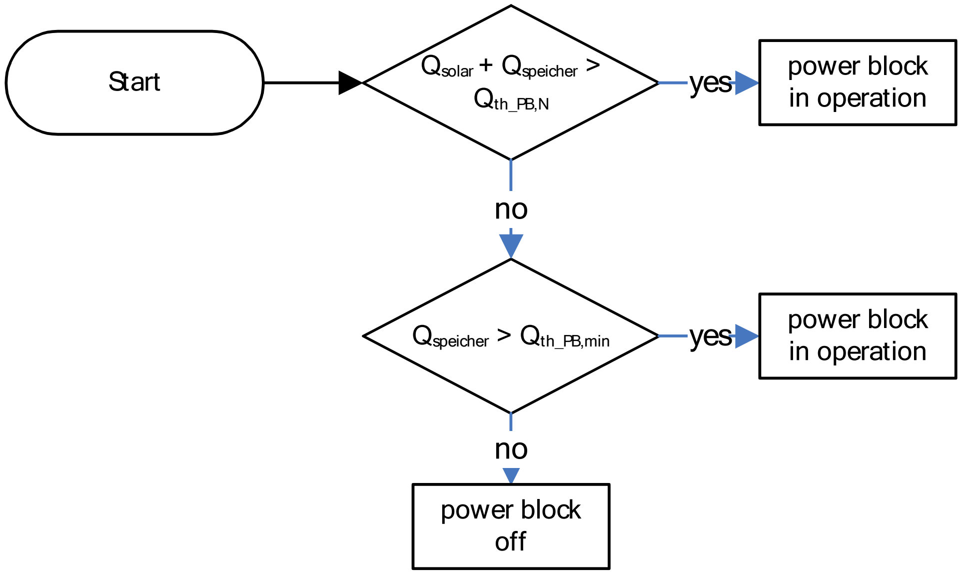
Specification of power block



Item	Unit	Option	
		100 Mwe	50 MWe
Steam generator (design point)			
Number of trains	°C / bar	3	2
Steam condition (outlet SH)	°C / bar	552 / 160	
Reheat steam condition (outlet RH)	°C / bar	552 / 31.5	
Feed water temperature	°C	238	
Salt inlet temperature	°C	565	
Salt outlet temperature	°C	290	
Pressure loss in salt path	bar	5	
Steam turbine and feed-water system			
Type	-	re-heat condensing	
Capacity (gross)	MWe	100	50
Gross efficiency	%	42.09	42.09
Number of LP-preheaters	-	6	
Number of HP-preheaters	-	1	
Number of deaerators	-	1	
Live steam conditions	°C / bar	552 / 155	
Reheat steam conditions	°C / bar	552 / 31.5	
Exhaust steam conditions	°C / bar	53.0 / 0.143	
Feedwater pump	MWe	2.04	1
Condenser			
Type	-	direct air cooled	
Heat load	MWt	237.6	118.8
Condensing temperature	°C	53	53
Power demand at design conditions	MWe	1.4	0.7

Operation Strategy

- Solar-only operation: operation of the power plant when sufficient power can be provided by the receiver and the storage, respectively. No possibility of fossil co-firing is given.
- The power block of the plant will – if possible – always be run at full load.
- The solar field generally uses all its heliostats. If the maximal power of the receiver is exceeded by 15 % an adequate number of heliostats will be defocused in order to keep the receiver power within its operation limits, thus, a certain amount of solar energy is dumped.



Performance at Design Point

Item	Unit	Option			
		100 MWe			50 MWe
		TES 9.0 h	TES 12.0 h	TES 15.0 h	TES 15.0 h
Solar Field General Layout Data					
Solar multiple	-	2	3	3	3
Net aperture area (optical effective mirror surface)	1000 m²	866,118	1,086,338	1,339,954	636,339
Solar Field Design Data (at Reference Site					
Design point solar field efficiency	%	66.8	66.8	66.8	66.8
Receiver thermal power	MJ/s	475	594	713	320.7
Solar Heat to Power Block (day mode)	MJ/s	237.2	237.2	237.2	118.6
Solar Heat to TES	MJ/s	238.1	356.9	475.7	202.1
Power Block Design Data					
Solar heat to power block	MJ/s	237.2	237.2	237.2	118.6
Steam turbine gross efficiency	%	42.16	42.16	42.16	42.16
Rated gross electric power output day mode	MWe	100	100	100	50
Net electric output day mode	MW	90.6	88.7	87.2	44.2
Condeser cooling system	-	Air cooled	Air cooled	Air cooled	Air cooled
Cooling load (including auxiliary cooling system load)	MJ/s	140.5	141.2	141.7	70.6
Plant efficiencies, at design point					
Design / Reference DNI	W / m²	950	950	950	950
Heliostat field efficiency	%	66.8	66.6	64.8	68.2
Receiver efficiency	%	86.8	86.8	86.8	86.8
Solar to heat efficiency	%	58.0	57.8	56.2	59.2
Power plant efficiency at design point, gross	%	42.2	42.2	42.2	42.2
Solar to electricity efficiency, gross	%	24.4	24.4	23.7	24.9

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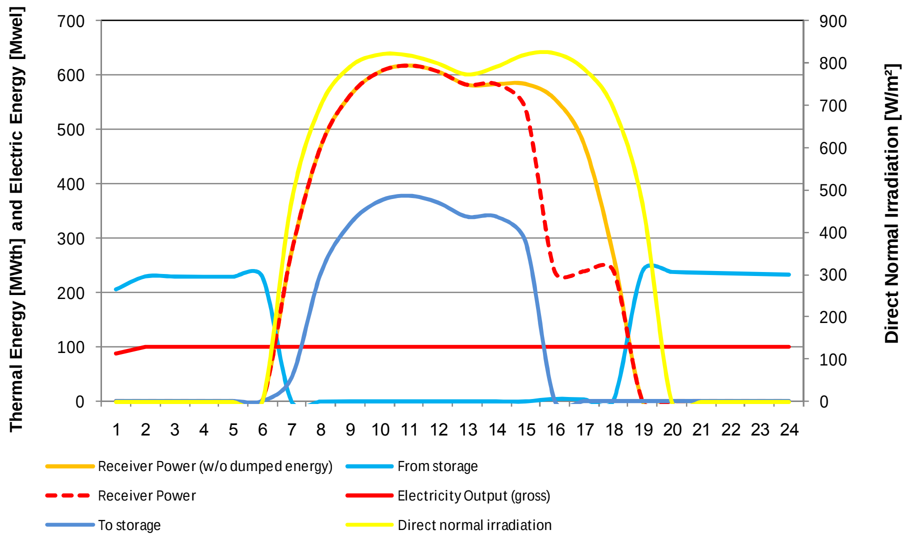
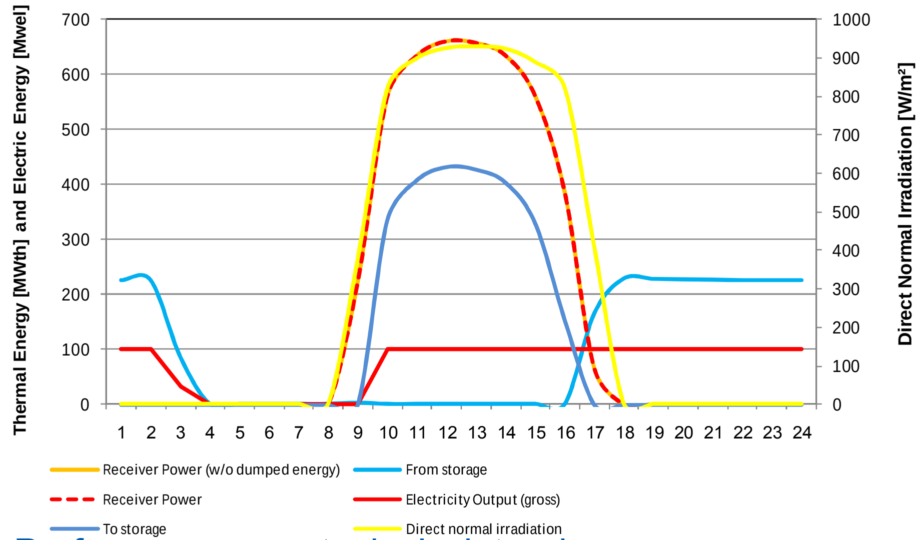
Performance - Typical Summer & Winter Day

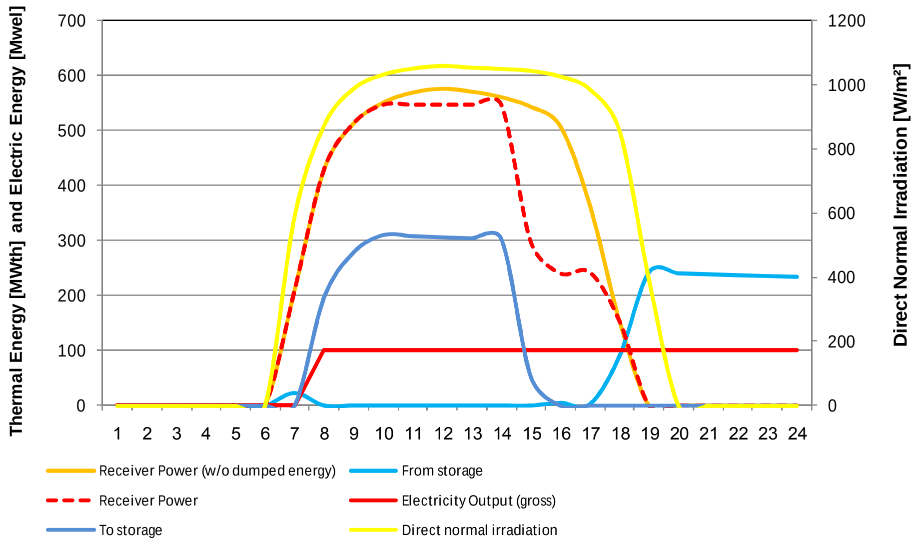
ESMAP Energy Sector Management Assistance Program



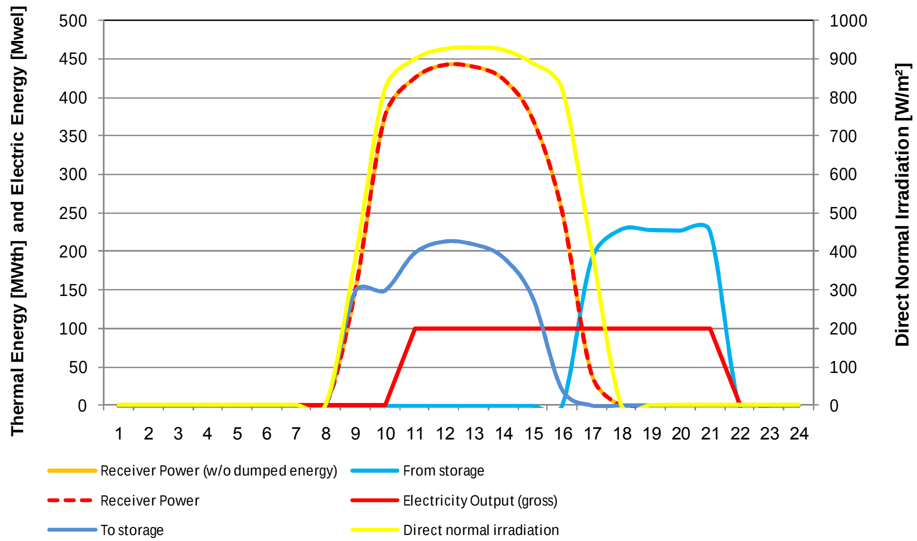
Performance on a typical summer day
(SM 3 - 15h storage)



Performance on a typical winter day
(SM 3 - 15h storage)



Performance on a typical summer day
(SM 2 - 9h storage)



Performance on a typical winter day
(SM 2 - 9h storage)

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Central Receiver – Annual Performance

Item	Unit	Option Central Receiver			
		100 MWe			50 MWe
		TES 9.0 h	TES 12.0 h	TES 15.0 h	TES 15.0 h
Solar Field General Layout Data					
Solar multiple	-	2	3	3	3
Heliostat aperture area	m²	121	121	121	121
Number of heliostats	-	7,158	8,978	11,074	5,259
Net aperture area (optical effective mirror surface)	1000 m²	866,118	1,086,338	1,339,954	636,339
Annual plant performance					
Annual solar irradiation	kWh / m^2 a	2,806	2,806	2,806	2,806
Solar energy (optical)	GWh_t / a	1,391	1,736	2,095	1,040
Solar heat (receiver)	GWh_t / a	1,186	1,480	1,787	887
Solar heat to power block	GWh_t / a	1,176	1,443	1,659	829
Gross electricity generation, total	GWh_e / a	474	592	692	345
Own consumption (total)	GWh_e / a	43	54	63	30
Net electricity generation, total	GWh_e / a	431	538	630	315
Capacity factor	-	0.54	0.68	0.79	0.79
Equivalent full load operating hours	h / a	4,738	5,924	6,923	6,907
Annual plant efficiencies					
Annual average solar to heat efficiency (incl. dumping)	%	48.9	47.8	44.6	46.9
Average annual steam turbine efficiency, gross	%	40.3	41.0	41.7	41.7
Own consumption/Gross electricity generation	%	9.1	9.1	9.1	8.6
Annual solar to electricity efficiency, gross	%	19.7	19.6	18.6	19.5
Avoided CO2 emissions	t CO2 /a	**483**	**604**	**706**	**352**

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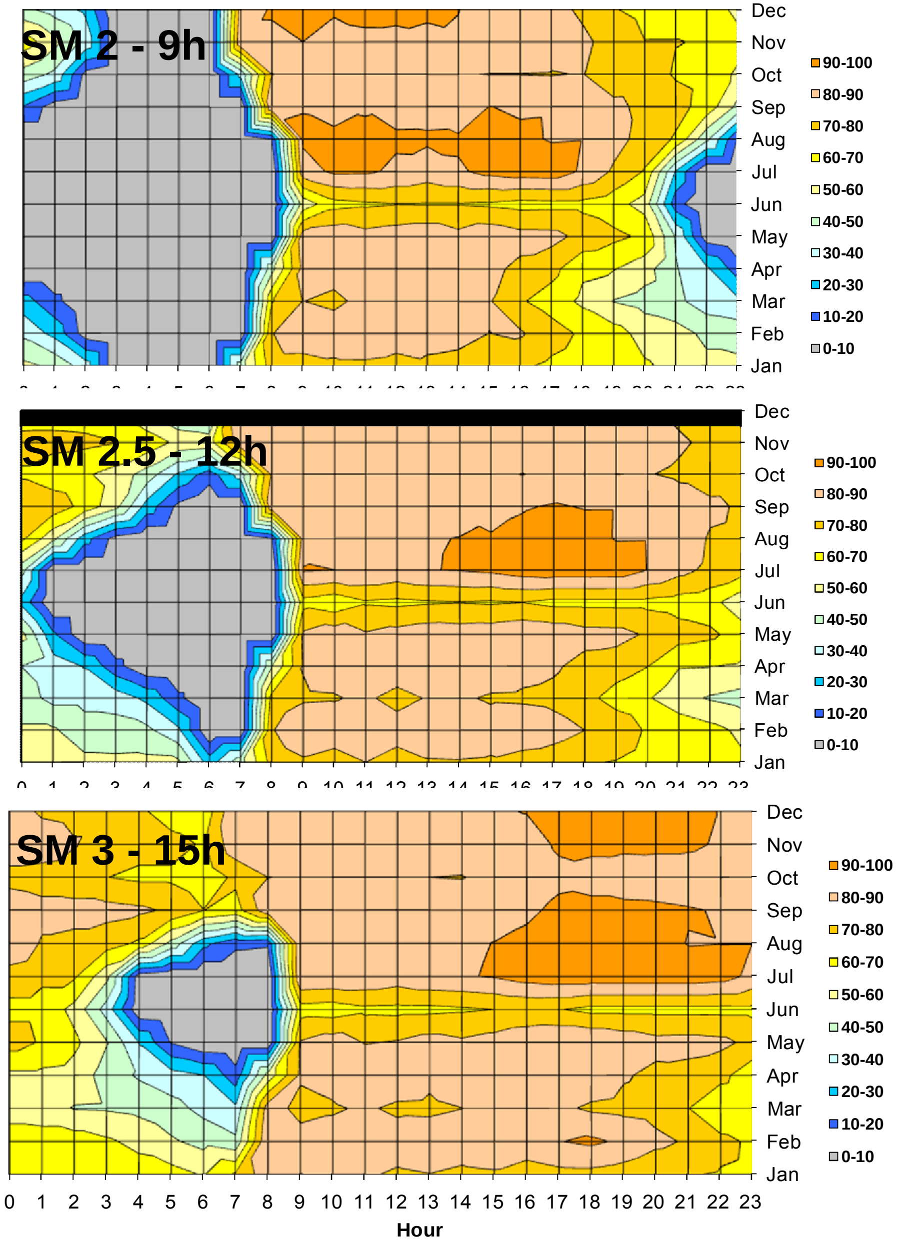
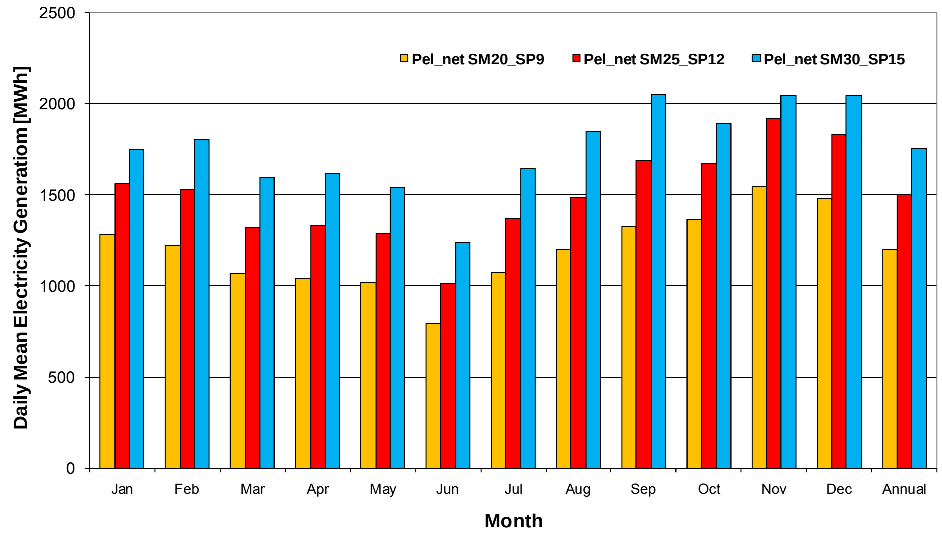
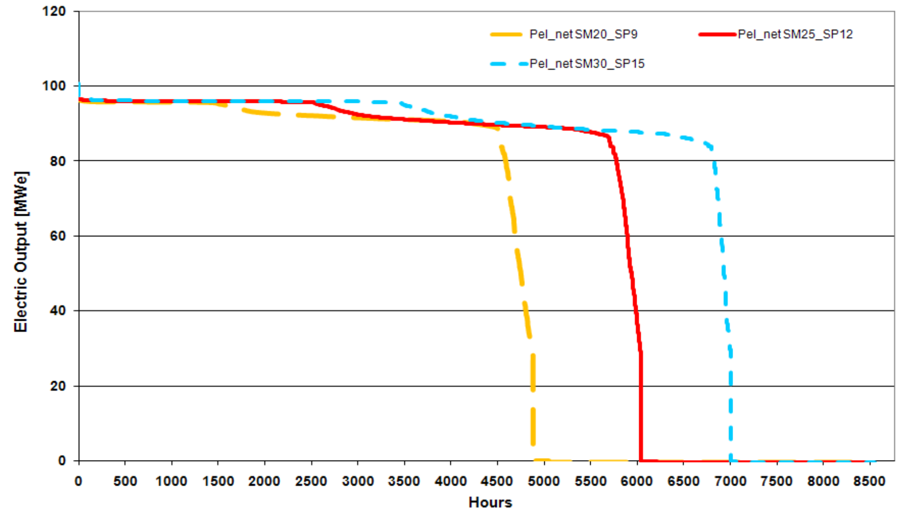
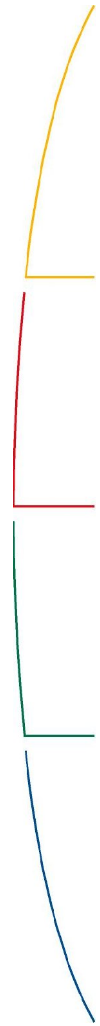
Central Receiver – Annual Performance









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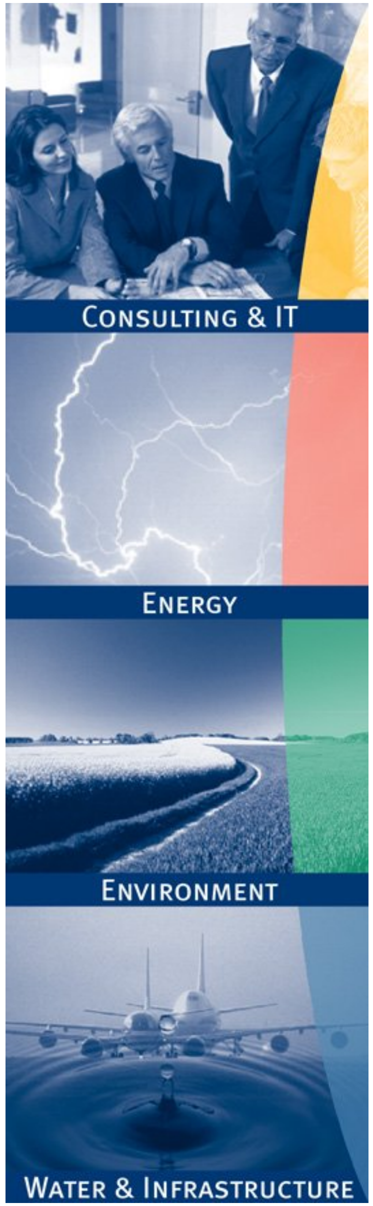
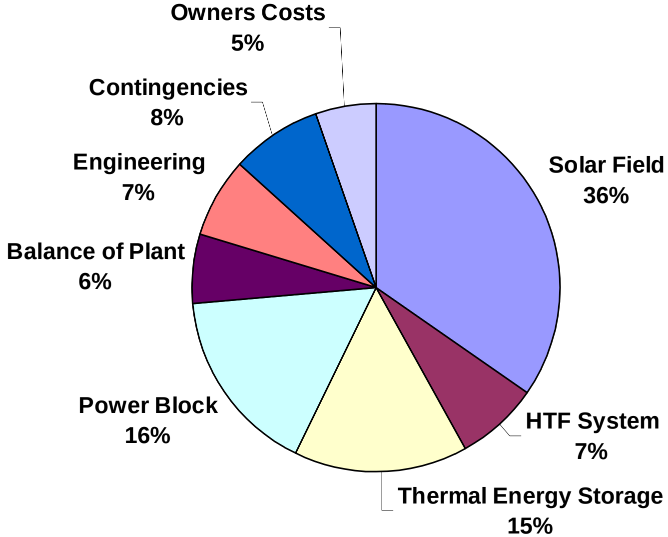
- CSP technology description
- CSP market assessment
- CSP technology selection
- Solar resource and site assessment
- Parabolic trough power plant design and performance
- Central receiver power plant design and performance
- Techno-economic evaluation



Parabolic Trough – CAPEX Estimate

Item	Unit	Option Parabolic Trough			
		100 MWe			50 MWe
		TES 4.5 h	TES 9.0 h	TES 13.4 h	TES 9.0 h
Nominal plant size					
Exchange rate	Euro / US$	1.40	1.40	1.40	1.40
Rated electric power, gross	MW_e	100	100	100	50
EPC Contract Costs	**mln US$**	**704.2**	**721.1**	**872.7**	**388.8**
Solar Field	mln US$	323.6	284.4	334.2	142.5
HTF System	mln US$	68.1	59.9	70.3	30.0
Thermal Energy Storage	mln US$	62.7	123.6	184.4	62.7
Power Block	mln US$	107.7	107.7	107.7	67.3
Balance of Plant	mln US$	45.0	46.0	55.7	24.2
Engineering	mln US$	36.4	37.3	45.1	29.4
Contingencies	mln US$	60.7	62.2	75.2	32.7
Owners Costs	**mln US$**	33.4	34.2	41.4	21.6
CAPEX Grand Total ± 20%	**mln US$**	**737.6**	**755.3**	**914.1**	**410.4**
Specific CAPEX	**$ / kW**	**7,376**	**7,553**	**9,141**	**8,207**

CAPEX Break-Down - Total 914 mln US$
Opiton Parabolic Trough
100 MW - 13.4 h TES



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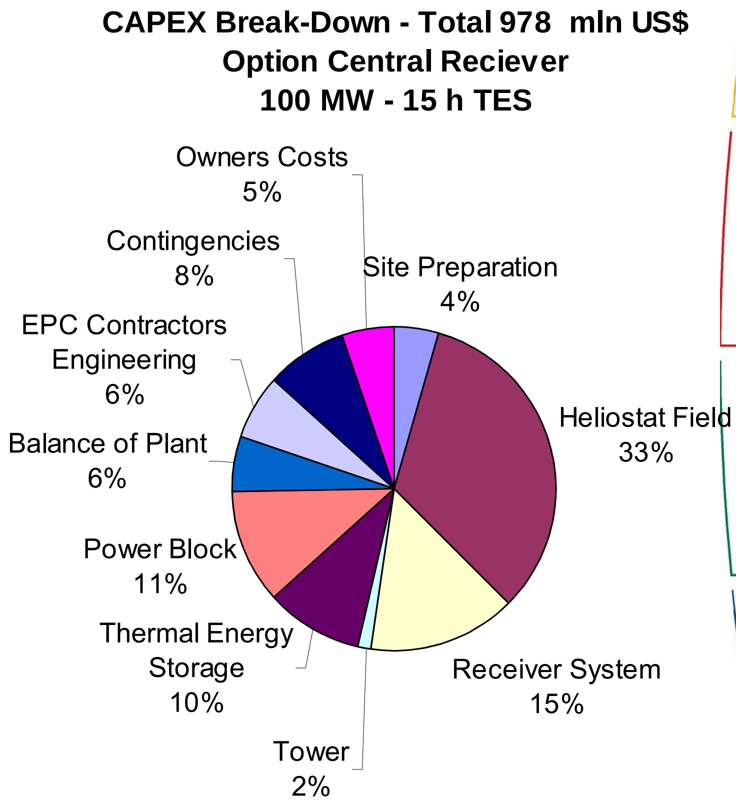
Central Receiver – CAPEX Estimate

Item	Unit	Option Central Receiver			
		100 MWe			50 MWe
		TES 9.0 h	TES 12.0 h	TES 15.0 h	TES 15.0 h
Nominal plant size					
Exchange rate	Euro / US$	1.40	1.40	1.40	1.40
Rated electric power, gross	MWe	100	100	100	50
EPC Contract Costs	**mln US$**	**679.7**	**798.0**	**926.7**	**501.0**
Site Preparation	mln US$	27.0	33.0	42.4	19.9
Heliostat Field	mln US$	218.3	267.6	323.3	165.4
Receiver System	mln US$	106.4	125.8	144.3	85.8
Tower	mln US$	15.0	15.0	15.0	8.8
Thermal Energy Storage	mln US$	58.7	77.1	95.3	49.3
Power Block	mln US$	110.0	110.0	110.0	65.4
Balance of Plant	mln US$	40.7	47.6	55.0	30.0
EPC Contractors Engineering	mln US$	46.1	54.1	62.8	34.0
Contingencies	mln US$	57.6	67.6	78.5	42.5
Owners Costs	**mln US$**	37.4	43.9	51.0	27.6
CAPEX Grand Total ± 20%	**mln US$**	**717.1**	**841.9**	**977.7**	**528.6**
Specific CAPEX	**US$ / kW**	**7,171**	**8,419**	**9,777**	**10,572**



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Parabolic Trough – OPEX Estimate

Item	Unit	Option Parabolic Trough			
		100 MWe			50 MWe
		TES 4.5 h	TES 9.0 h	TES 13.4 h	TES 9.0 h
Technical- financial constraints					
Exchange rate	EURO / US$	1.4	1.4	1.4	1.4
Power generation	GWh / a	441.1	492.4	583.8	237.2
Number of operating staff	-	60	60	75	45
Manpower cost (average)	1000 $ / a	58.8	58.8	58.8	58.8
Price diesel fuel	$ / liter	1.1	1.1	1.1	1.1
Fuel consumption	1000 Liter / a	200	200	200	120
Raw water	US$ / m^3	0.70	0.70	0.70	0.70
Annual raw water consumption	1000* m^3 / a	132,330	147,720	175,140	71,160
HTF Consumption	t / a	61	54	64	26
HTF price	US$ / t	3,000	3,000	3,000	3,000
Annual OPEX (costs as 2009)					
Fixed O&M Costs:	**mln US$**	**13.4**	**13.6**	**16.5**	**8.0**
Solar field & storage system	mln US$	4.5	4.7	5.9	2.4
Power block	mln US$	2.3	2.3	2.5	1.4
Personnel	mln US$	3.5	3.5	4.4	2.6
Insurance	mln US$	3.0	3.1	3.8	1.6
Variable O&M Costs (Consumables**):**	**mln US$**	**1.2**	**1.2**	**1.4**	**0.6**
Fuel	mln US$	0.2	0.2	0.2	0.1
Water	mln US$	0.1	0.1	0.1	0.0
HTF	mln US$	0.2	0.2	0.2	0.1
Other consumables & residues *)	mln US$	0.7	0.7	0.9	0.4
Total OPEX	**mln US$**	**14.6**	**14.9**	**17.9**	**8.6**
In percent of CAPEX	**%**	**1.97%**	**1.97%**	**1.96%**	**2.10%**

Central Receiver – OPEX Estimate

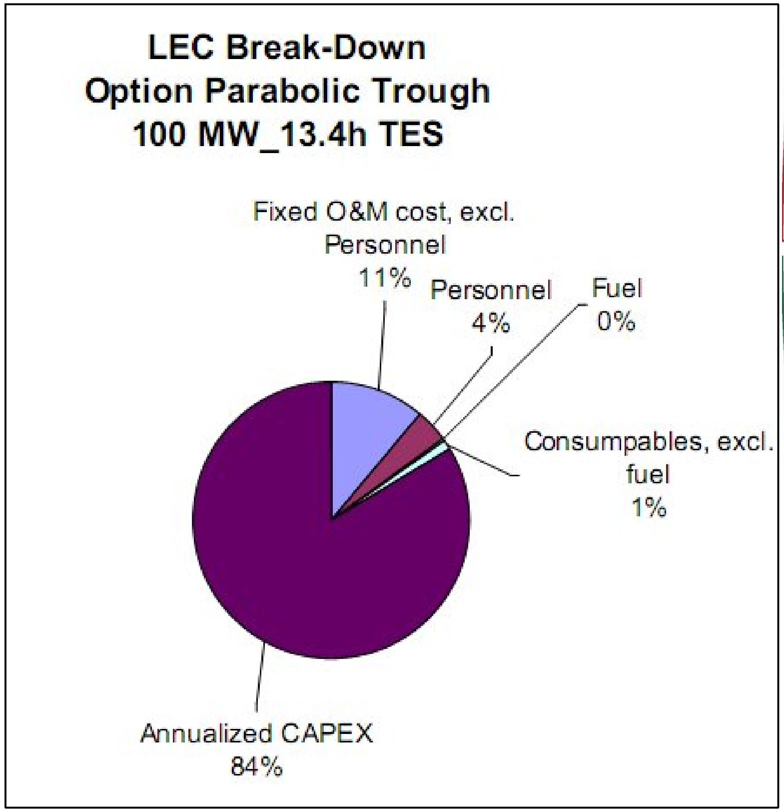
Item	Unit	Option Central Receiver			
		100 MWe			50 MWe
		TES 9.0 h	TES 12.0 h	TES 15.0 h	TES 15.0 h
Technical- financial constraints					
Exchange rate	EURO / US$	1.4	1.4	1.4	1.4
Power generation (net)	GWh / a	430.8	538.3	629.6	315.5
Number of operating staff	-	60	68	77	52
Manpower cost (average)	1000 $ / a	59	59	59	59
Price diesel fuel	$ / liter	1.1	1.1	1.1	1.1
Fuel consumption	1000 Liter / a	300	300	300	150
Raw water	US$ / m^3	0.7	0.7	0.7	0.7
Annual raw water consumption	1000* m^3 / a	116,323	145,340	169,982	85,183
Annual OPEX (costs as 2009)					
Fixed O&M Costs:	**mln US$**	**12.29**	**14.19**	**16.24**	**9.47**
Solar field & storage system	mln US$	3.83	4.71	5.63	3.00
Power block	mln US$	2.26	2.37	2.48	1.43
Personnel	mln US$	3.53	3.98	4.50	3.06
Insurance	mln US$	2.67	3.14	3.64	1.98
Variable O&M Costs (Consumabl	**mln US$**	**1.32**	**1.57**	**1.78**	**0.89**
Fuel	mln US$	0.34	0.34	0.34	0.17
Water	mln US$	0.08	0.10	0.12	0.06
Other consumables & residues *)	mln US$	0.90	1.13	1.32	0.66
Total OPEX	**mln US$**	**13.6**	**15.8**	**18.0**	**10.4**
In percent of CAPEX	**%**	**1.90%**	**1.87%**	**1.84%**	**1.96%**

*) Electricity import, HTF, nitorgen, chemicals

Parabolic Trough – LEC Calculation

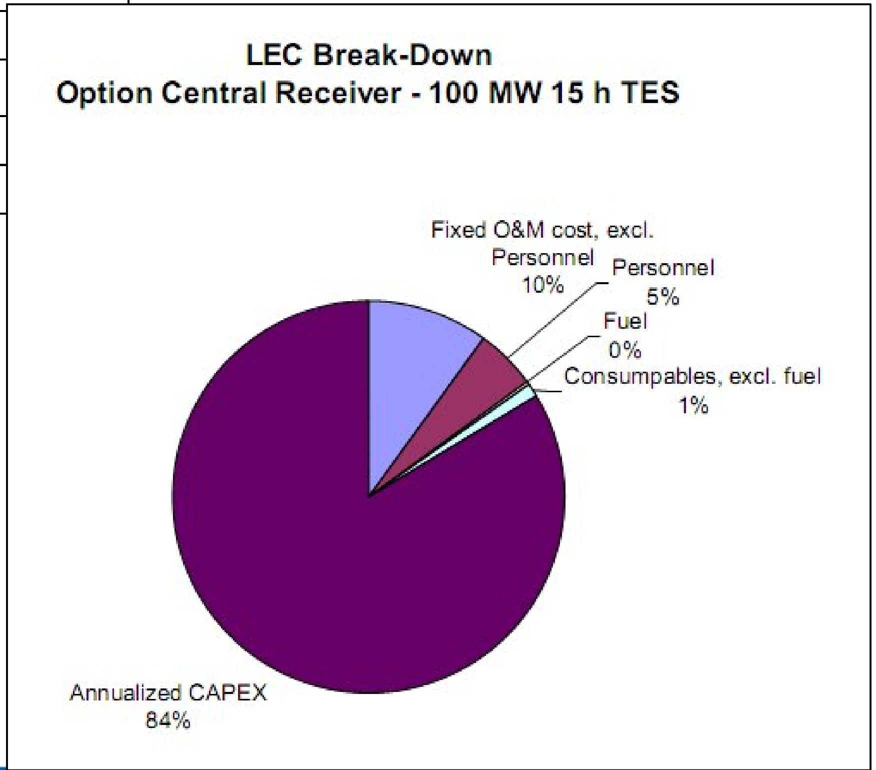
Item	Unit	Option Parabolic Trough			
		100 MWe			50 MWe
		TES 4.5 h	TES 9.0 h	TES 13.4 h	TES 9.0 h
Basic Data					
Net electricity production	GWh / a	377.4	421.8	502.4	206.6
Total CAPEX ± 20%	mln US$	737.6	755.3	914.1	410.4
Total annual costs without carbon credit					
Discount rate 8%	mln US$ / a	88.9	91.0	110.1	50.0
Discount rate 6% (reduced risk) *)	mln US$ / a	76.6	78.4	94.9	43.2
Avoided CO_2 emissions	1000 t / a	384.9	430.2	512.4	210.7
Carbon credit certificate	US$ / t CO_2	14.00	14.00	14.00	14.00
Carbon credit (if applicable)	mln US$ / a	5.39	6.02	7.17	2.95
Levelized electricity costs					
Discount rate 8%, no carbon credit	Cent / kWh	23.6	21.6	21.9	24.2
Discount rate 8%, with carbon credit	Cent / kWh	22.1	20.1	20.5	22.8
Discount rate 6%, no carbon credit *)	Cent / kWh	20.3	18.6	18.9	20.9
Discount rate 6%, with carbon credit *)	Cent / kWh	18.9	17.2	17.5	19.5

*) Lower discount rate considering reduced risk against central receiver technology



Central Receiver – LEC Calculation

Item	Unit	Option Central Receiver			
		100 MWe			50 MWe
		TES 9.0 h	TES 12.0 h	TES 15.0 h	TES 15.0 h
Basic Data					
Net electricity production	GWh / a	430.8	538.3	629.6	315.5
Total CAPEX ± 25%	mln US$	717.1	841.9	977.7	528.6
Total annual costs without carbon credit	mln US$ / a	85.9	100.6	116.6	63.6
Avoided CO_2 emissions	1000 t / a	439.4	442.7	511.1	549.1
Carbon credit certificate	US$ / t CO_2	14.00	14.00	14.00	14.00
Carbon credit (if applicable)	mln US$ / a	6.15	6.20	7.16	
Levelized electricity costs, discount rate 8%					
Discount rate 8%, no carbon credit	Cent / kWh	19.9	18.7	18.5	
Discount rate 8%, with carbon credit	Cent / kWh	18.5	17.5	17.4	



Thank You!

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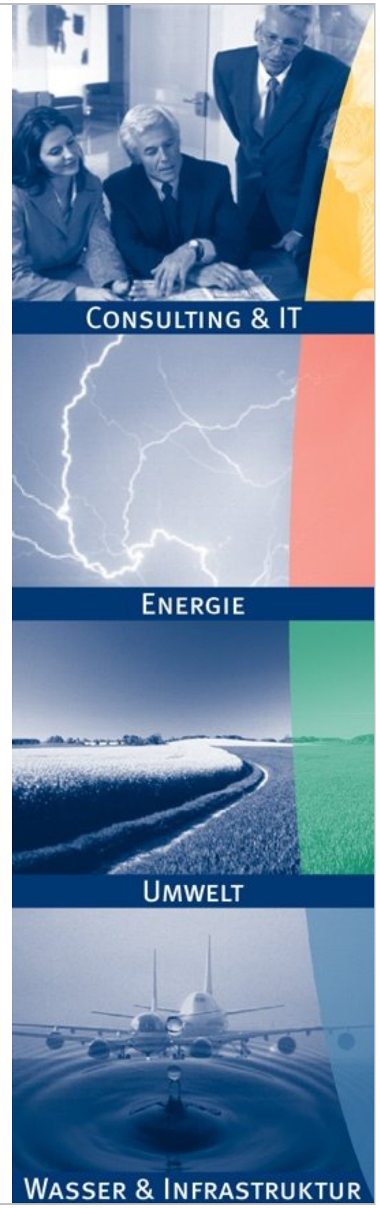

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