Dissemination workshop: Key elements for the new solar thermal energy plants

Structural design improvements for MSLOOP 2.0

Axel Schweitzer / schlaich bergermann partner

MSLOOP dissemination workshop

Madrid, 9th of July 2019

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Structural design improvements for MSLOOP 2.0

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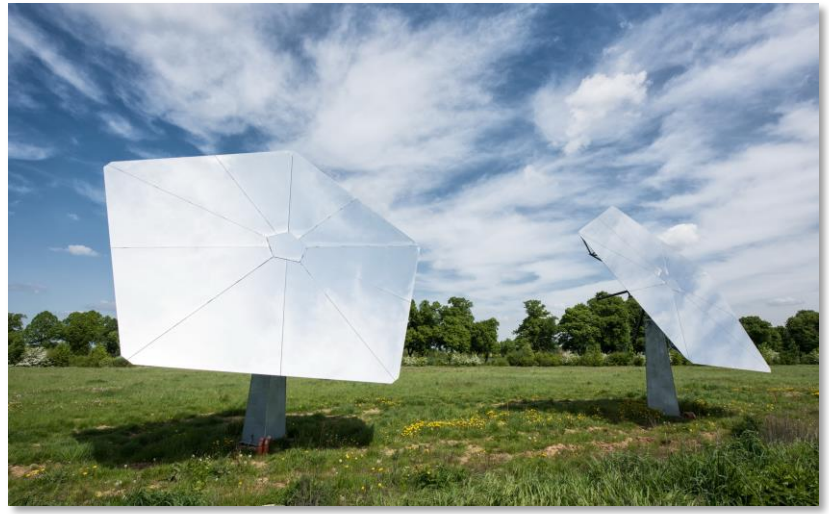
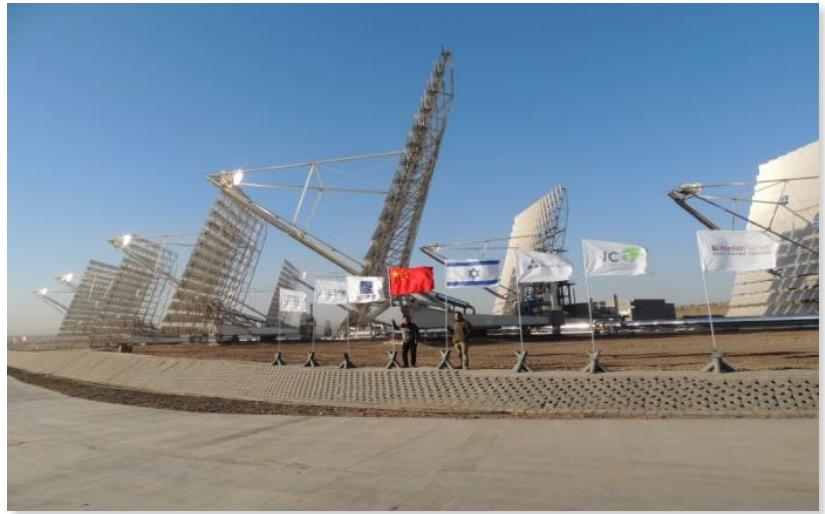
1. **Introduction**
2. General Design Requirements for large Molten Salt Parabolic Trough Collectors
3. MSLOOP Parabolic Trough Collector Design
   - Status Quo before the project
   - Structural Analysis
   - Improvements executed during the project
3. Other Parabolic Trough designs for MS
   - Enel, HT, UT, etc.
4. Outlook and Upscaling from MSLOOP
   - Ilangha, South Africa

Structural design improvements for MSLOOP 2.0








Current Solar Technologies @ schlaich bergermann partner

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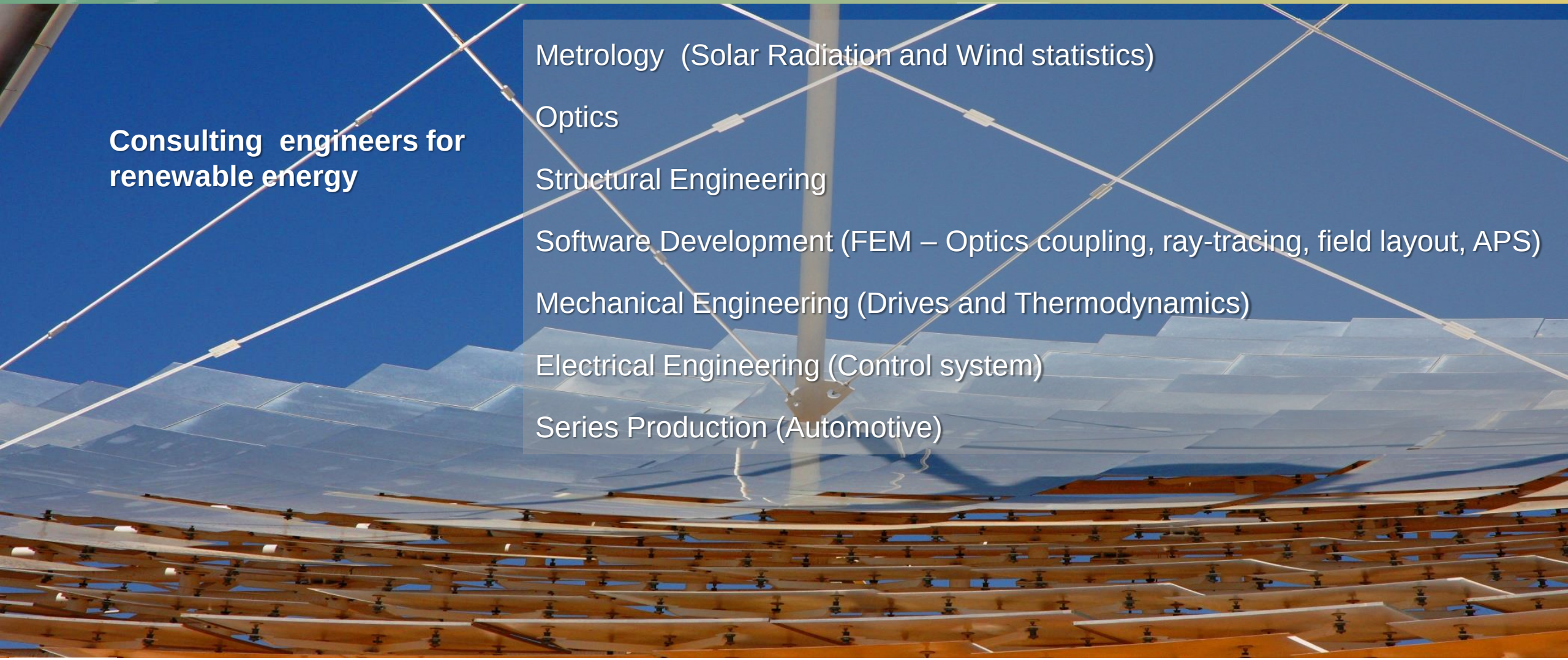

Consulting engineers for renewable energy

- Metrology (Solar Radiation and Wind statistics)
- Optics
- Structural Engineering
- Software Development (FEM – Optics coupling, ray-tracing, field layout, APS)
- Mechanical Engineering (Drives and Thermodynamics)
- Electrical Engineering (Control system)
- Series Production (Automotive)

Structural design improvements for MSLOOP 2.0

sbp role in the MSLOOP project:

- Structural check of the MSLOOP Collector TCP200
- Proposal and implementation of design improvements to make the collector fit for Molten Salt operation
- Monitoring and installation and operation
- Contribution to Commercial scale up and Business model

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Several commercial Parabolic Trough designs are available at present

- Are they appropriate for Molten Salt application?
- What are the design requirements for Molten Salt parabolic Trough Collectors?

→ Key parameters explained based on the Ultimate Trough Design

(similar dimensions compared to the MSLOOP TCP 200 Collector)

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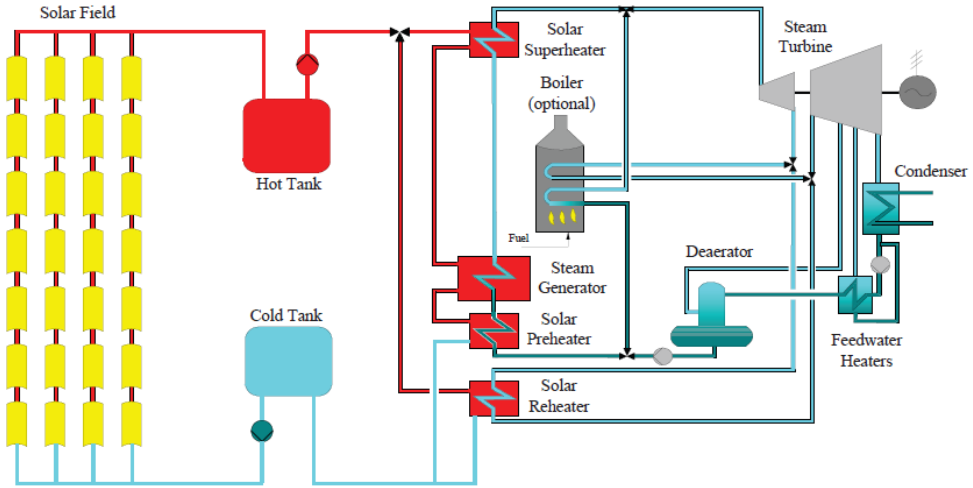
Basic assumptions

- Operation at higher solar field temperatures possible
  - approx. 10 % **higher efficiency of power cycle** due to better steam parameters
- **Direct storage** decreases the cost of storage, simplifies the plant, and makes plant operation easier
  - Turbine can be driven in full load as long as the storage tank is filled
  - almost no “dumping” losses
- Molten Salt has **almost no environmental impact** compared to Thermal Oil

Risk: freeze event due to high melting point



Key Adaptions for Molten Salt parabolic Trough Collectors:

- Optimize concentration factor
  - Reduce HCE diameter?
  - Intercept factor
  - Pressure drop
  - Thermal losses
- Enable Heat Tracing / Preheating
- Enable Molten Salt drainage
- Make HCE supports suitable for higher expansion length due to elevated temperatures

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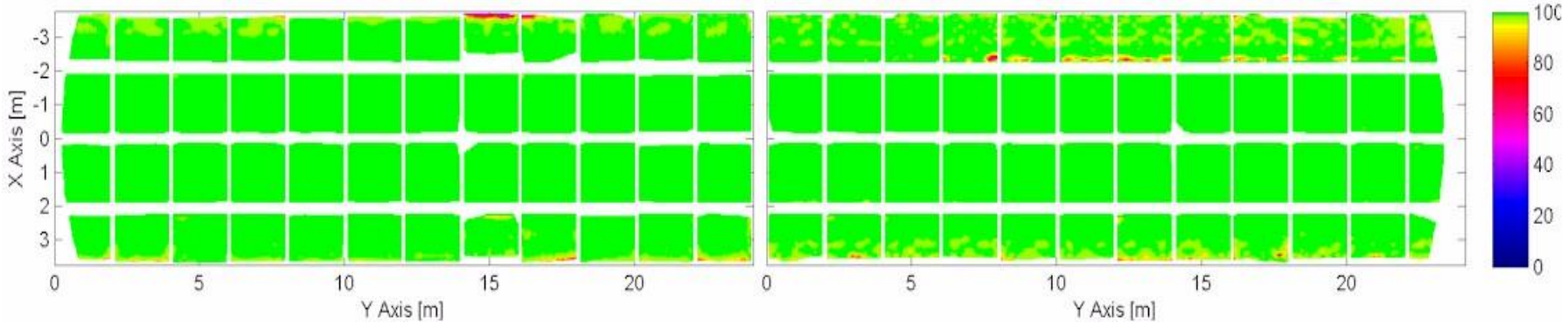
Intercept factor

- The Ultimate Trough has been optically analyzed by photogrammetry and deflectometry methods
- Intercept for standard (oil) absorber pipe (D=90mm): **99.2%** (including sun shape, SCE/HCE alignment errors…)



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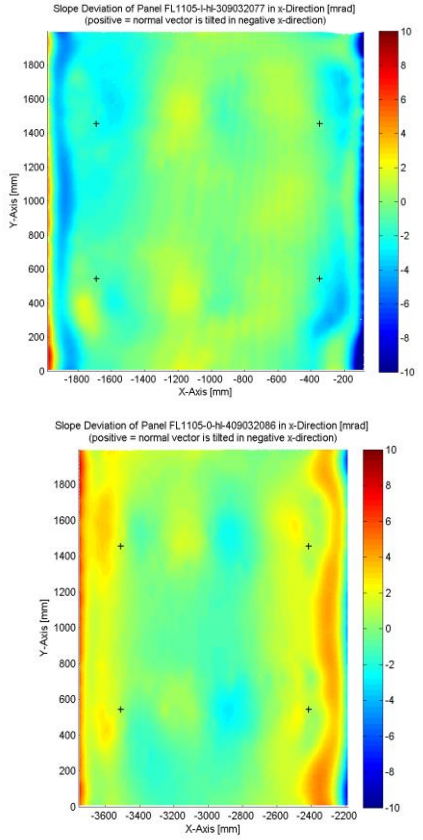
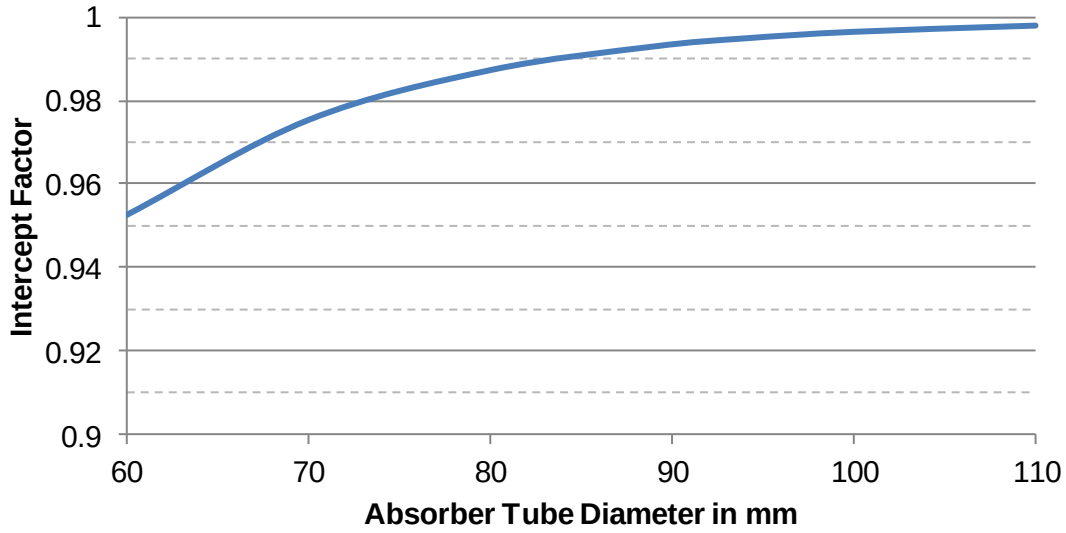
Intercept factor

- Further ray-tracing analysis, based on single RP5 mirror facet evaluations
- Standard slope deviation of representative pair (inner/outer facet): 1.8 mrad (FDx = 8.6 mm)





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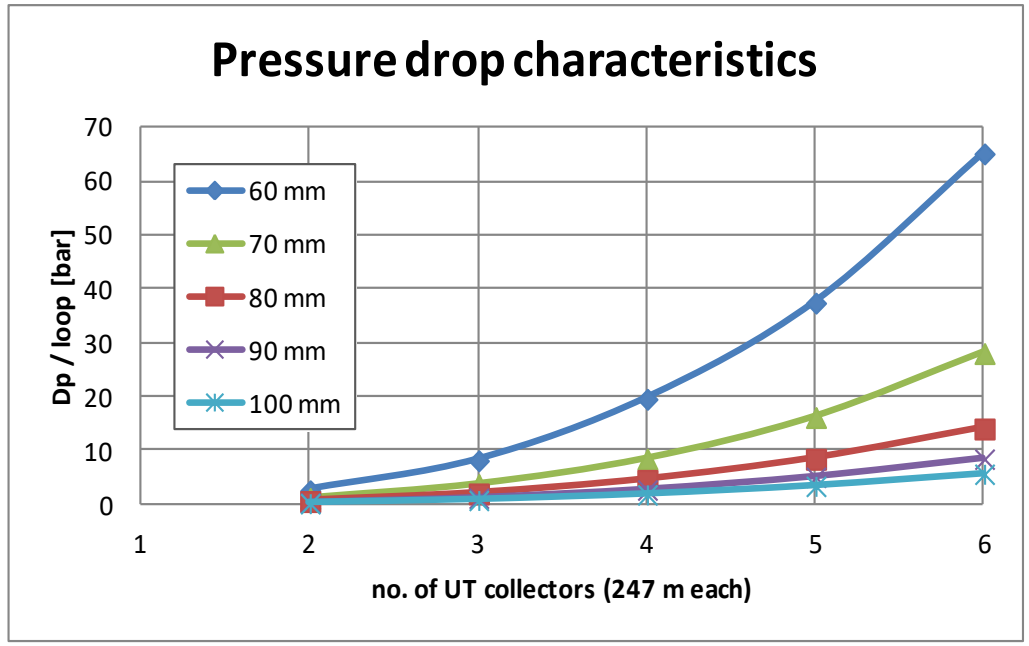
Pressure drop

Design conditions:

- T_inlet: 300 °C
- T_outlet: 550 °C
- DNI: 900 W/m²
- Solar incidence angle: 20°
- HTF: solar salt eutectic mixture (60% NaNO3, 40% KNO3)



→ Larger diameter reduces pressure drop significantly

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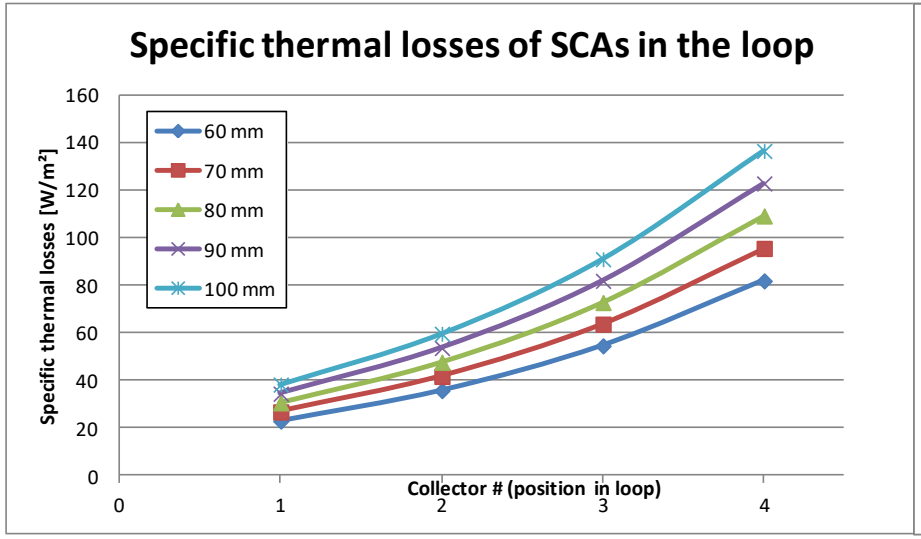
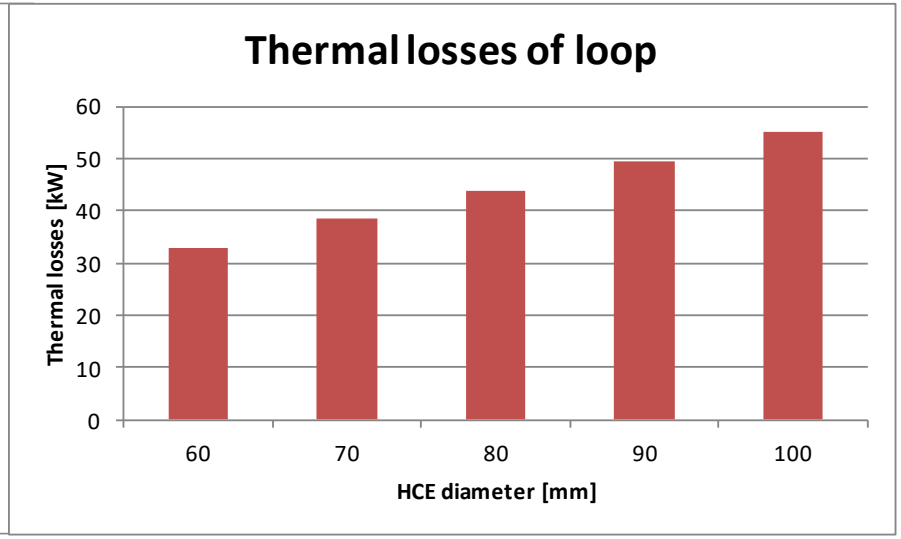
Thermal losses

Design conditions:

- T_inlet: 300 °C
- T_outlet: 550 °C
- DNI: 900 W/m²
- Solar incidence angle: 20°
- HTF: solar salt eutectic mixture (60% NaNO3, 40% KNO3)





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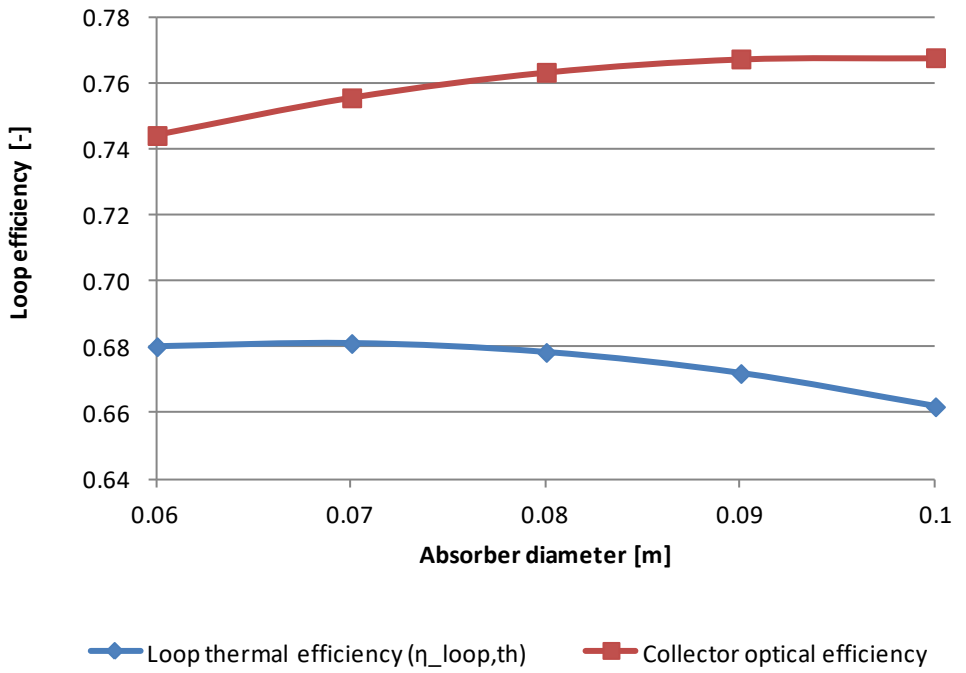
UT Loop efficiency for 60 – 100 mm HCEs

Design conditions:

- T_inlet: 300 °C
- T_outlet: 550 °C
- DNI: 900 W/m²
- Solar incidence angle: 20°
- HTF: solar salt eutectic mixture (60% NaNO3, 40% KNO3)



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Performance results

- Performance model: SAM
- Example: 120 MW plant with 14 hours storage
- Located at Daggett, CA (Annual sum of DNI: 2723 kWh/m²)

	Absorber diameter	mm	60	70	80	90	100
Solar Field	Solar field aperture	m²	1'269'978	1'269'978	1'269'978	1'269'978	1'269'978
	Number of loops	-	188	188	188	188	188
	Collector optical efficiency	%	75.1	77.5	78.7	79.1	79.2
Power Cycle	Conversion efficiency	%	44	44	44	44	44
	Cooling	-	wet	wet	wet	wet	wet
	Availability	%	96	96	96	96	96
Thermal Energy Storage	Thermal Capacity	MWht	3'780	3'780	3'780	3'780	3'780
	Equivalent full load hours	h	13.9	13.9	13.9	13.9	13.9
	Parallel tank pairs	-	1	1	1	1	1
Performance values	Solar Field Thermal Output	GWh	1'645	1'665	1'657	1'632	1'599
	Freeze protection energy	GWh	56	71	83	96	110
	Power Cycle Gross Output (*)	GWh	657.1	656.0	647.6	632.8	615.5
	Net Annual Energy (*)	**GWh**	**607.9**	**608.2**	**601.1**	**587.5**	**571.0**

Pressure drop: **20 bars** **8 bars**

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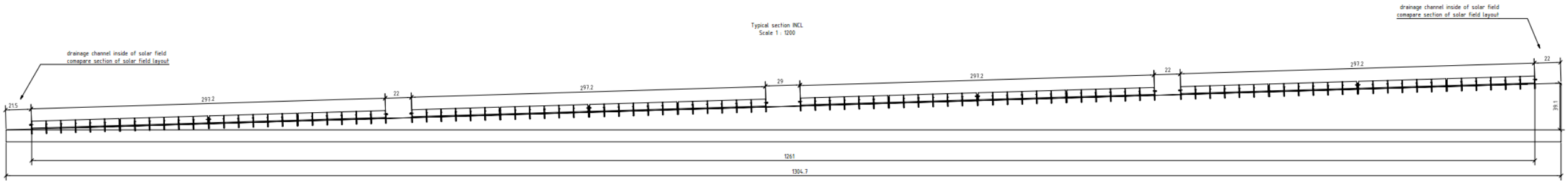
Molten Salt Drainage

- Drainage by gravity towards drainage tanks
- Sloped Collector field (Ultimate Trough can be installed directly on sloped ground up to 2 %)

Preheating of HCE and Header system

- Solar heating or air/N2



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MSLOOP Parabolic Trough Configuration
Collector TCP200 (ACS Cobra)

Solar Collector Element

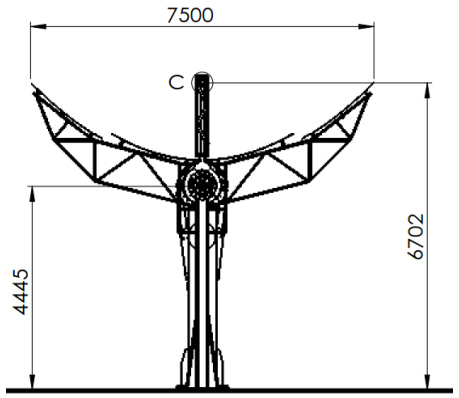
SCE key figures

- Length: 20.4 m
- Aperture width (gross): 7.51 m
- Aperture area (net): 151 m²
- Torque tube design
- 5 (D=70) HCE/SCE
- 10 x 4 = 40 refl. Panels

Solar Collector Assembly

SCA key figures

- 12 SCE/SCA
- Length: 246 m
- Aperture area: 1812 m²
- Hydraulic drive system



Commercialization of TCP200 design is not foreseen by ACS at present

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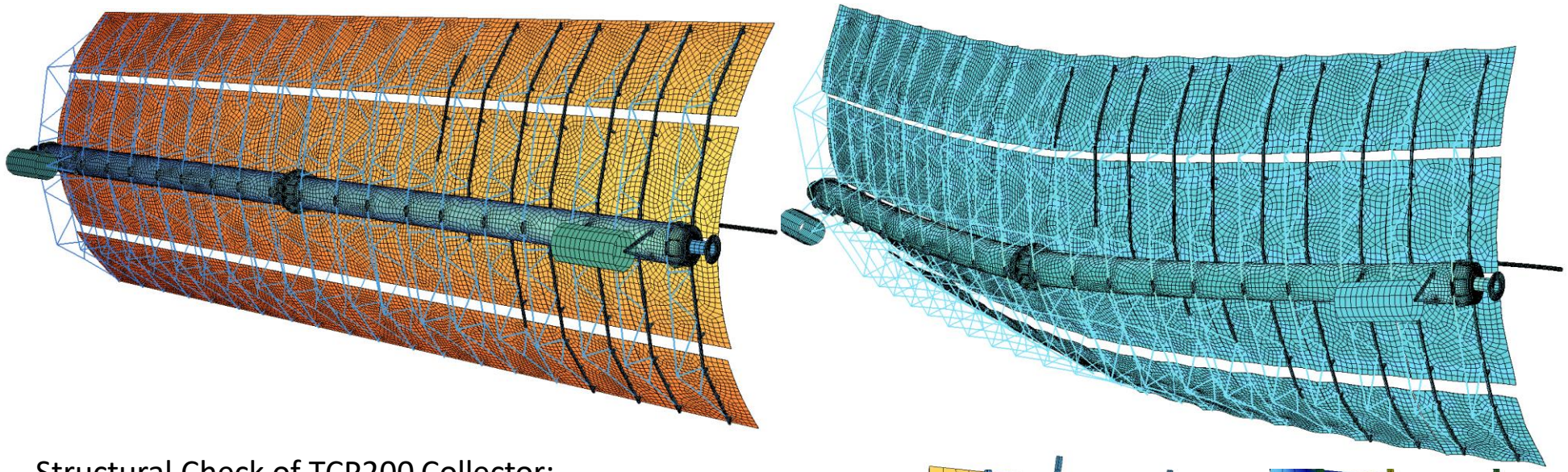
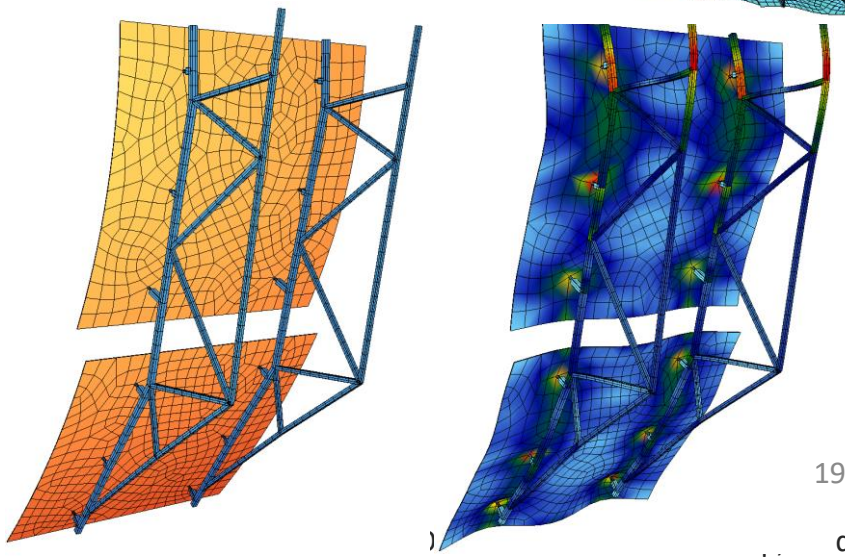


Structural Check of TCP200 Collector:

- Safeties and load combination according to EC Code
- Loads according to Spanish Code SE-AE-2009

Checking for Loop configuration as built in Manchasol



Structural design improvements for MSLOOP 2.0

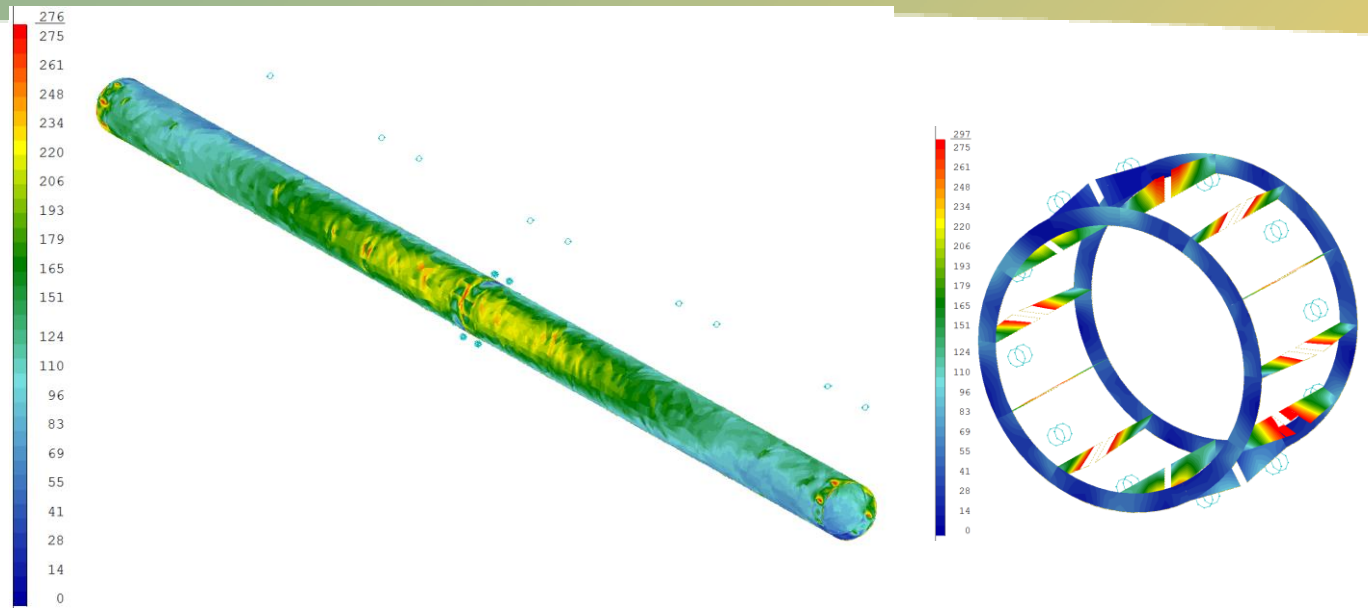
Structural Check of TCP200 Collector

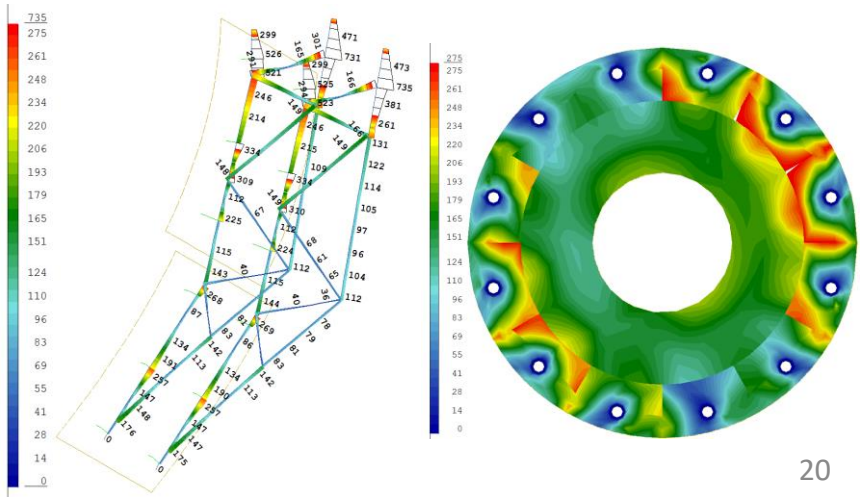
- Slip checks for bolt connections partly not fulfilled (torque tube flange + cantilever connection)
- Several parts suffer from very high stress and show unacceptable large zones of plastification (Flanges, Torque Tube, Cantilever)
- No imminent danger of collapse, but likelihood of plastic deformations / glass breakage

Conclusion:

Several structural improvements recommended to be improved:

- Improvement of structural stability at Ultimate Limit State
- Optical performance through structural stiffness under dead and operation wind load





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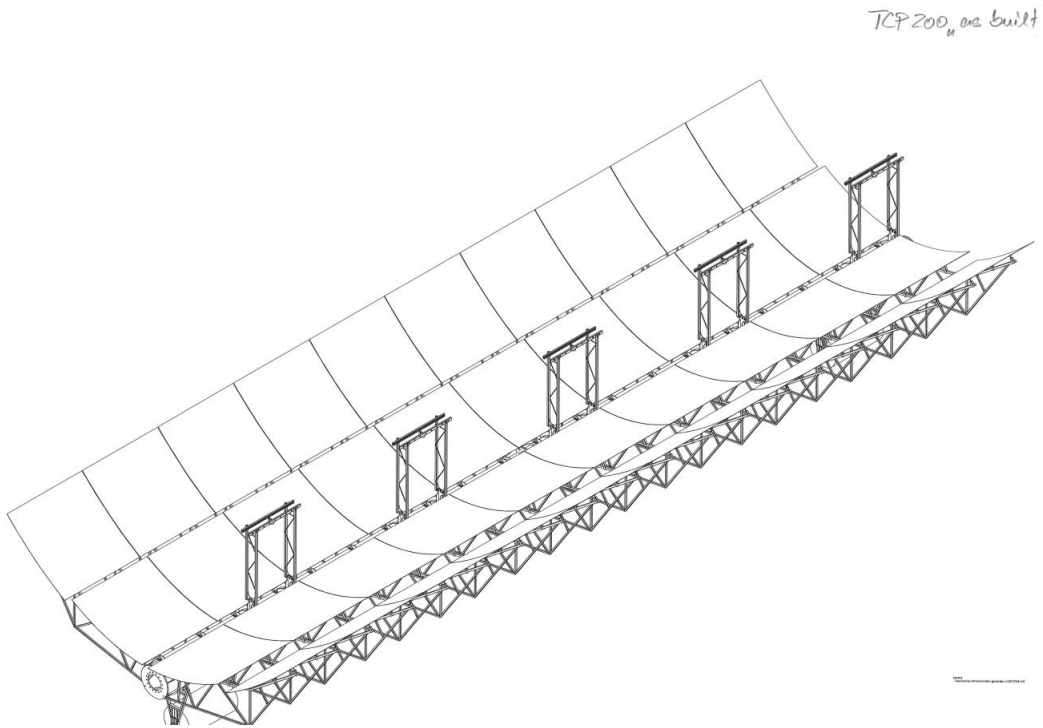
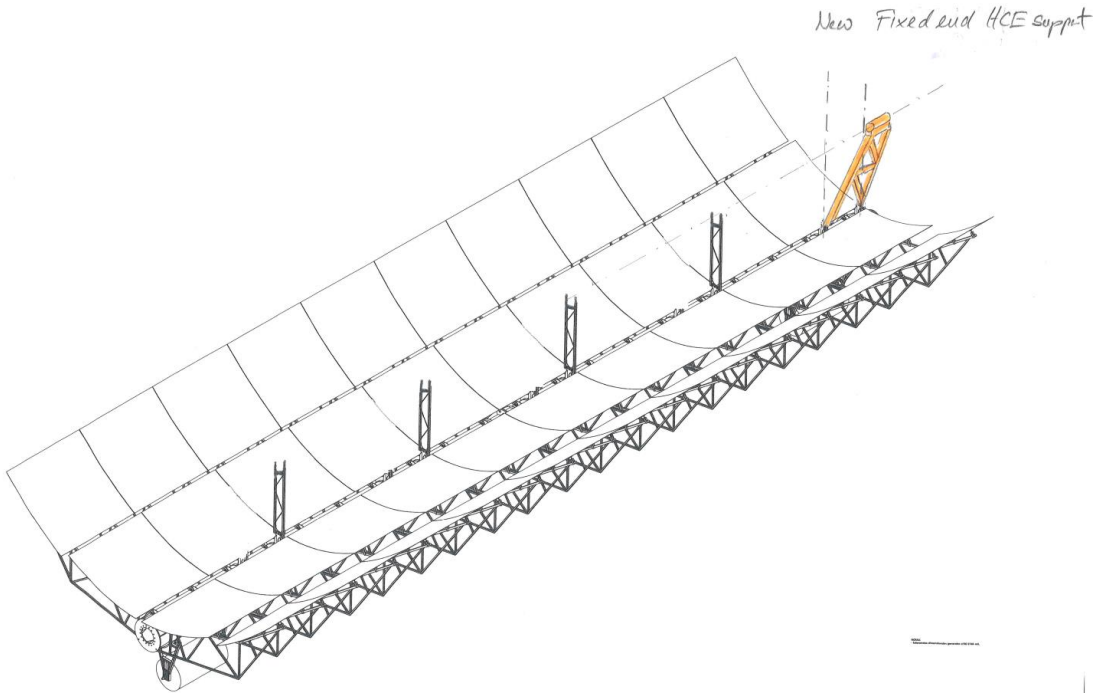
Structural design improvements for MSLOOP 2.0

Make HCE supports suitable for higher expansion length due to elevated temperatures

Rigid sliding HCE supports replaced by → Hingeable HCE supports





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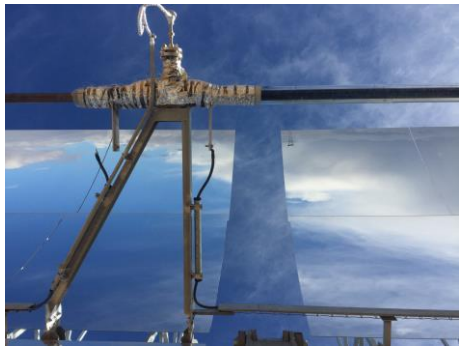
Existing Design:

North End

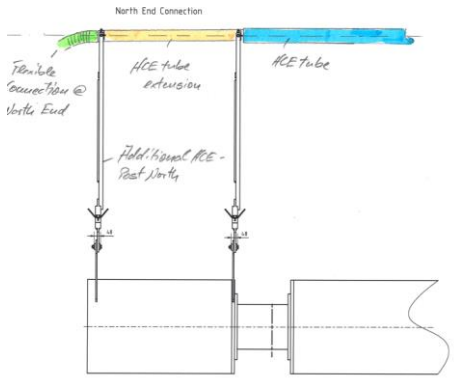
Standard HCE Support

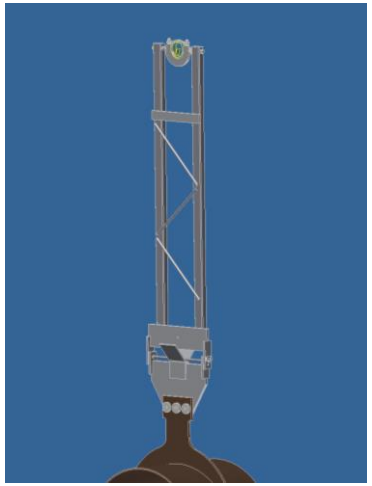
Fixed HCE Support

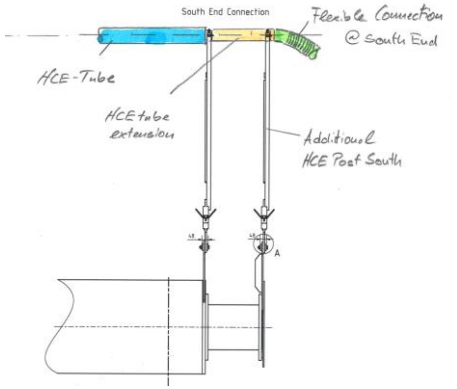


South End

New Design:







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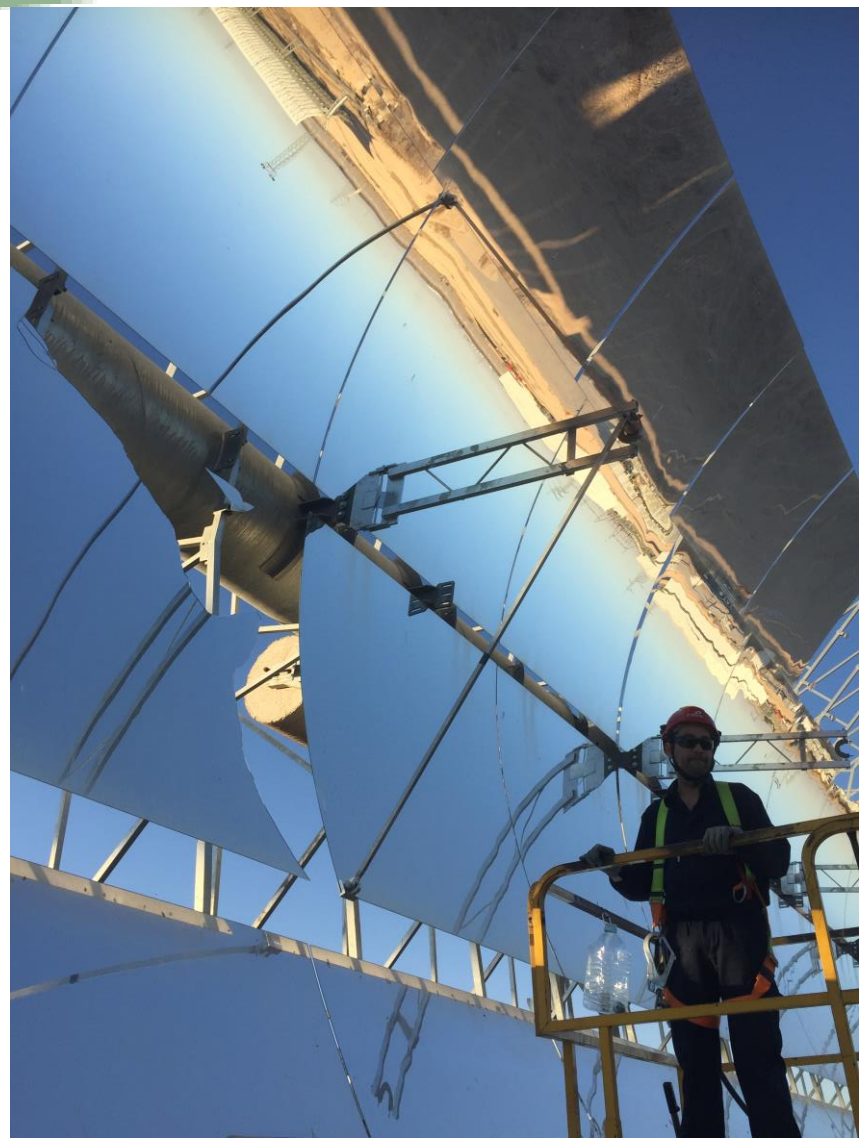
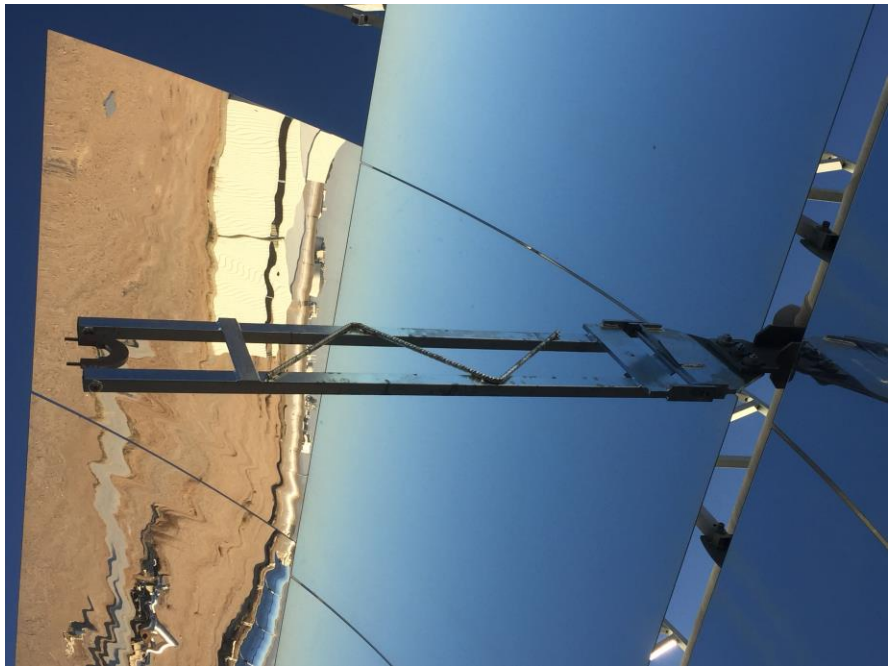
Installation of the HCE posts

- Pre-Installation
- Alignment with template





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Structural design improvements for MSLOOP 2.0

Archimede solar plant - 5 MW Priolo Gargalo, Sicily

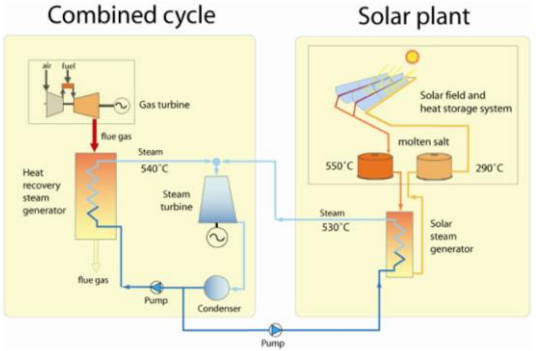
General data:
- ENEL collector, 9 Loops with 6 x 100 m collectors each
- Roughly 30'000 m² aperture area
- Design power: 5 MWe
  (12 MW t steam generator, 530°C, 100 bar)

Storage:
- Capacity: 80 MWht
- Hot tank design operation temp.: 270 - 550 °C
- Cold tank design operation temp.: 270 - 400 °C

Salt:
- Solar salt (60%/40% Na/K NO_3)

San Quirico consortium (sbp, Flabeg, M+W, Bertrams-Heatec) had access to the plant (workshop with ENEL) in 2013

General: plant working well (commissioning, normal operation, ….), but:
- Low collector efficiency
- Problems to reach 530 °C
- Leakages at flexible connections, valves



Source: Falchetta et al., 2009

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Archimede Solar Energy Demo plant – Massa Martana, Italy

General data:

- Archimede collector, 1 Loop with 6 x 100 m collectors each
- Roughly 3'400 m² aperture area
- Design power:
  (2 MW_{th} steam generator, 530°C, 100 bar)

Storage:

- Capacity: 4,3 MWh_{th}

Salt:

- Solar salt (60%/40% Na/K NO_3)

Archimede consortium (Chiyoda Corporation, Archimede Solar

General: Start of operation 2013

- Performance not published
- Thin glass mirrors on sandwich elements

Solar Collector Element

SCE key figures

- Length: 12 m
- Aperture width (gross): 6.0 m
- Aperture area (net): 72 m²
- Torque tube design
- 3 (D=70) HCE/SCE
- 10 x 4 = 40 refl. Panels

Solar Collector Assembly

SCA key figures

- 8 SCE/SCA
- Length: 100 m
- Aperture area: 576 m²
- Hydraulic drive system

Commercialization of collector in Akesai, China plant Project aborted

Source: Archimede Solar 2013

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Structural design improvements for MSLOOP 2.0

HPS2 Molten Salt Test Loop, Evora, Portugal

General data:
- HelioTrough collector, 1 Loop with 2 x 171 m collectors each
- Roughly 4'630 m² aperture area
- Design power:
  12 MW_{th} steam generator, 565°C, 70-140 bar)

Storage:
- Capacity: 6 MWh_{th}
- Hot tank design operation temp.: 270 - 565 °C
- Cold tank design operation temp.: 270 - 400 °C

Salt:
- CaNaK-NO3

HPS2 consortium (TSK, eltherm, Yara, Steinmüller, DLR
-- Sponsored by BMWi Germany

2019 under commissioning

Structural design improvements for MSLOOP 2.0

HPS2 Molten Salt Test Loop, Evora, Portugal

Solar Collector Element

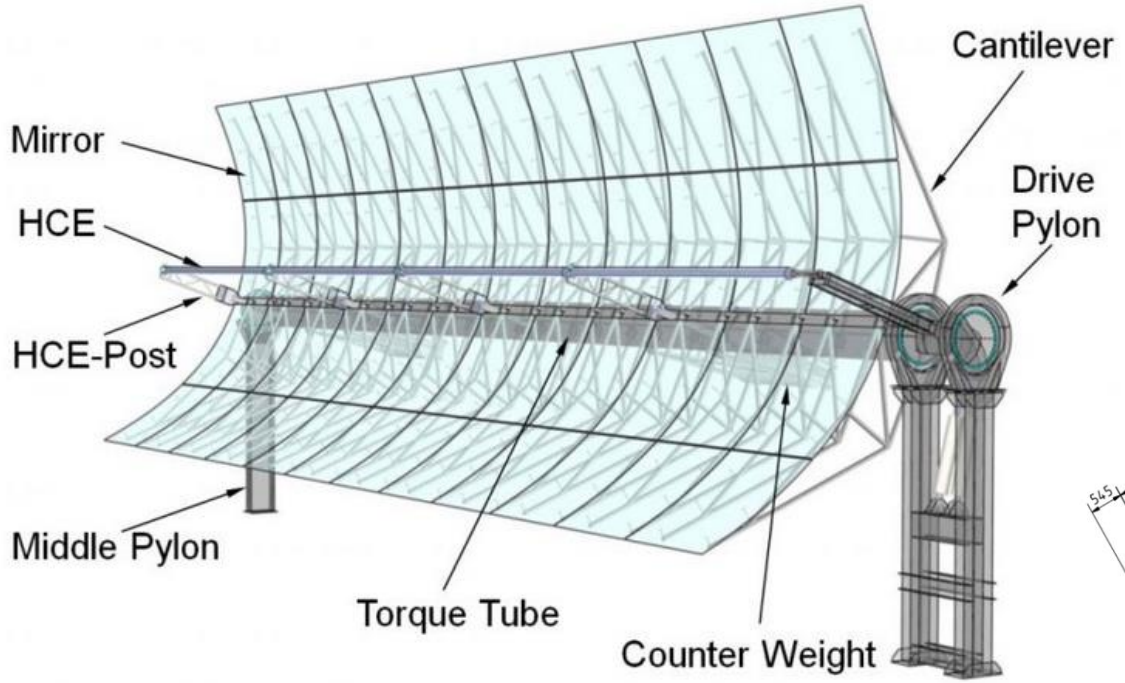
SCE key figures

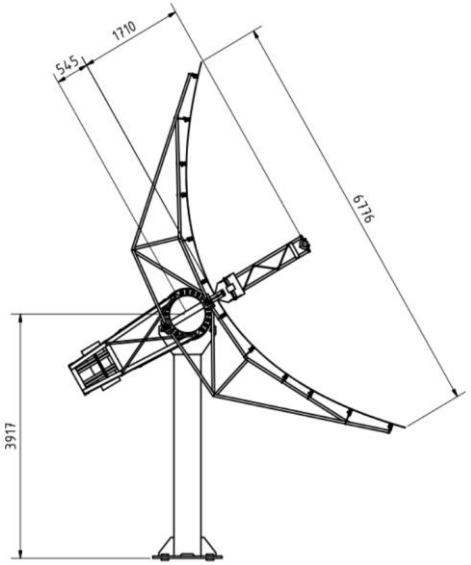
- Length: 19 m
- Aperture width (gross): 6,7 m
- Aperture area (net): 127 m²
- Torque tube design
- 5 (D=70) HCE/SCE
- 12 x 4 = 48 refl. Panels

Solar Collector Assembly

SCA key figures

- 10 SCE/SCA
- Length: 191 m
- Aperture area: 1270 m²
- Hydraulic drive system





Structural design improvements for MSLOOP 2.0

12 MWel GELA plant - Ultimate Trough Collector for MSLOOP Molten Salt Application

General data:
- Ultimate Trough collector, 16 Loops with 4 x 200/240 m collectors each
- Roughly 124’000 m² aperture area
- Design power: 12 MWel

Storage:
- 400 MWth
- Capacity: 12h
- Additional Gas Heater

Salt:
- Solar salt (60%/40% Na/K NO3)
- or MSLOOP configuration

CLP project, Italy

2018 Tender stage / No EPC awarded so far

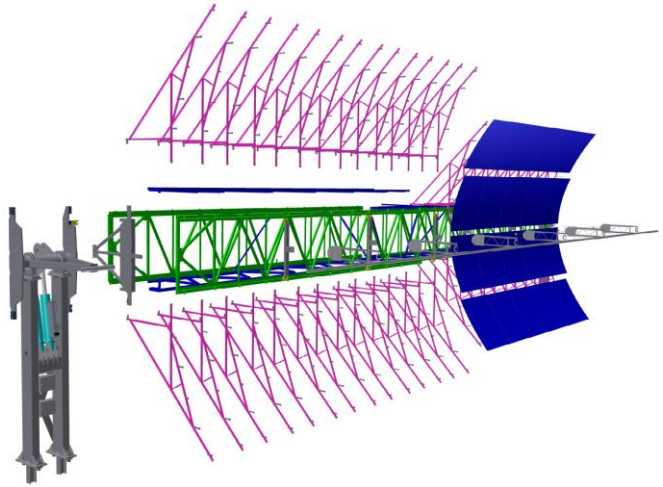
Structural design improvements for MSLOOP 2.0

Ultimate Trough Collector for MSLOOP Molten Salt Application

Solar Collector Element

SCE key figures

- Length: 24 m
- Aperture width (gross): 7.51 m
- Aperture area (net): 171 m²
- Torque box Design
- 6 (D=70) HCE/SCE
- 12 x 4 = 48 refl. Panels



Solar Collector Assembly

SCA key figures

- 10 SCE/SCA
- Length: 243 m
- Aperture area: 1170 m²
- Hydraulic drive system

Commercial application:
50 MW DUBA Green ISCC, DUBA, Saudi Arabia, 2017

50 MW DUBA Green ISCC, DUBA, KSA, 2017

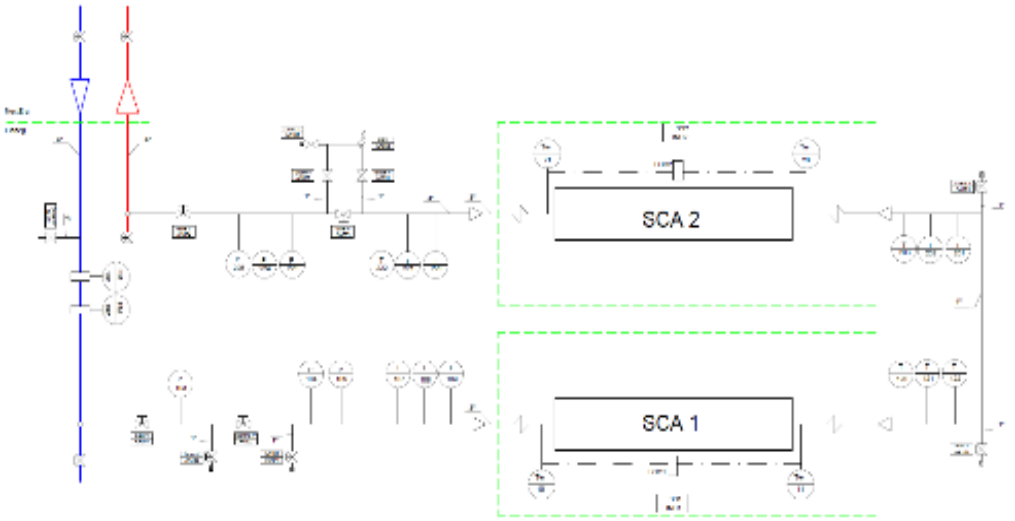
Structural design improvements for MSLOOP 2.0

Ultimate Trough for MSLOOP Scaleup

- Test Loop equipped with calibrated flow meter, temperature and pressure sensors
- Meteo station (DNI, GHI, ambient temp., wind speed)

- Validated intercept factor: 99.2% (with 94 mm absorber)
- Calculated intercept: 99.0% (with 88.9 mm), 97% (with 70 mm)
- Value is valid for the whole SCA, not only one SCE!

- IAM curve deviated from measurements



Structural design improvements for MSLOOP 2.0

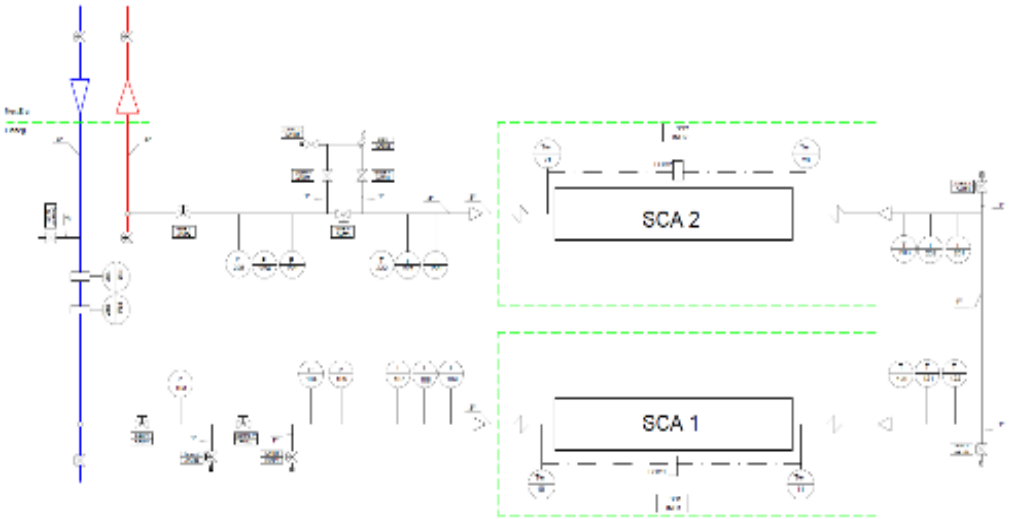
Ultimate Trough for MSLOOP Scaleup

- Test Loop equipped with calibrated flow meter, temperature and pressure sensors
- Meteo station (DNI, GHI, ambient temp., wind speed)

- Validated intercept factor: 99.2% (with 94 mm absorber)
- Calculated intercept: 99.0% (with 88.9 mm), **97% (with 70 mm)**
- Value is valid for the whole SCA, not only one SCE!

- IAM curve deviated from measurements

Best suitability for
Large Scale Molten Salt Plants !



Structural design improvements for MSLOOP 2.0

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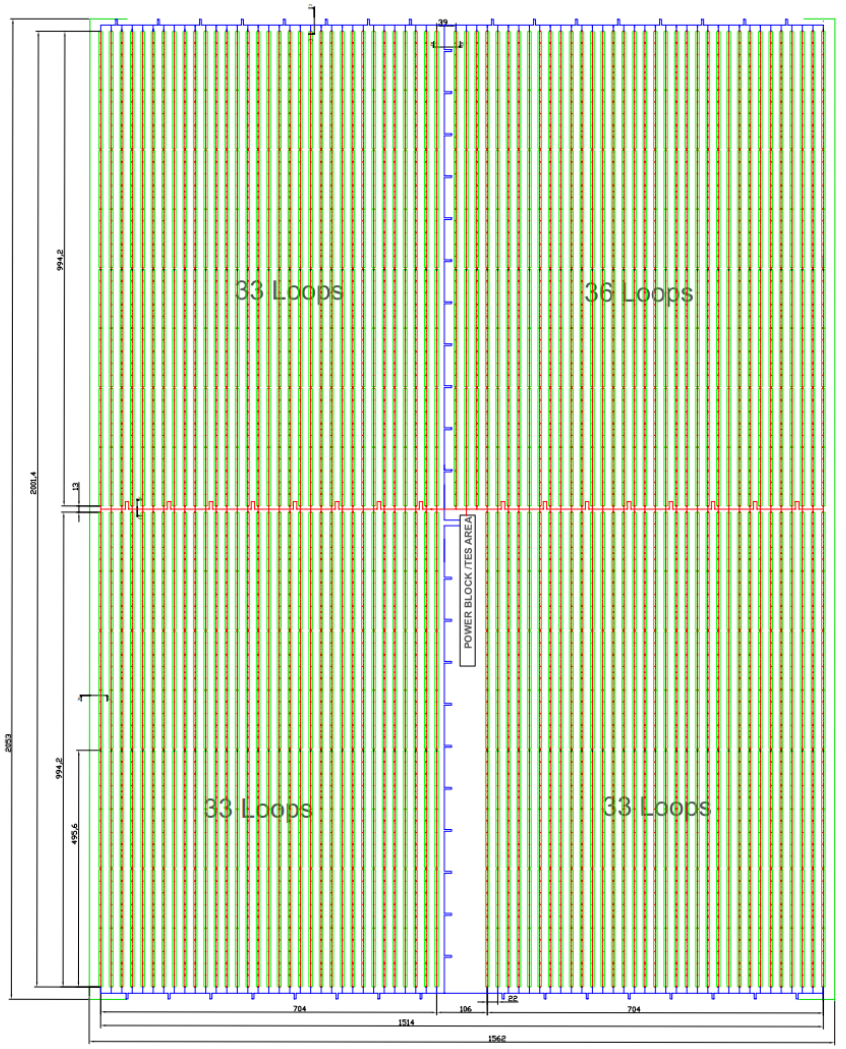
2. General Design Requirements for large Molten Salt Parabolic Trough Collectors
3. MSLOOP Parabolic Trough Collector Design
   - Status Quo before the project
   - Structural Analysis
   - Improvements executed during the project
3. Other Parabolic Trough designs for MS
   - Enel, HT, UT etc
4. **Outlook and Upscaling from MSLOOP**
   - Ilangha, South Africa

Structural design improvements for MSLOOP 2.0

Ultimate Trough for MSLOOP Scaleup / Outlook
Illangha, Northern Cape, South Africa

	COMMERCIAL CASE with MSLOOP RESULTS
Location	ILANGA (South Africa)
MOLTEN SALT SYSTEM	
MS type	Ternary (53%KNO3 - 7%NaNO3 - 40NaNO2)
SOLAR FIELD*	**Acc. to SBP proposal (with some changes)*
Inlet MS Temperature	290ºC
Outlet MS Temperature	500ºC
Collectors	Ultimate Trough
Solar multiple	2,6
Solar field slope (optimun drainage of MS)	0,5%
POWER BLOCK**	
Power block output (gross power)	80 MWe
Thermal power	190,5 MW
TOTAL GROSS POWER OUTPUT	
Power block + Co-firing output (gross power)	80 MWe
STORAGE	
Capacity	2400 MW·h
Equivalent full hours	12,6 h



For Levelized Cost of Energy see MSLOOP 2.0 Final Report

80 MWel plant designed to minimize LCOE (large TES / No restrictions for time of delivery / load curve)

sbp
schlaich bergermann partner

Structural design improvements for MSLOOP 2.0

Ultimate Trough for MSLOOP Scaleup / Outlook
Illangha, Northern Cape, South Africa

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Equivalent full hours	12,6 h

Possibly < 1

> 200MWel (depending on PV input)

Increased (depending on PV input)

Alternative PV integrated configuration (Time of delivery only 6 h evening e.g.)
Identical field Size → Significantly larger Power Block (>200 Mwel)
CSP-LCOE a little bit higher than minimum, value of electricity maximized

sbp
schlaich bergermann partner

Ultimate Trough for MSLOOP Scaleup / Outlook
Illangha, Northern Cape, South Africa

MSLOOP

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THANK YOU FOR YOUR ATTENTION

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