HPS2 – High Performance Solar 2

Évora Molten Salts Platform

Dipl.-Ing. Klaus Hennecke
Dr. Michael Wittmann

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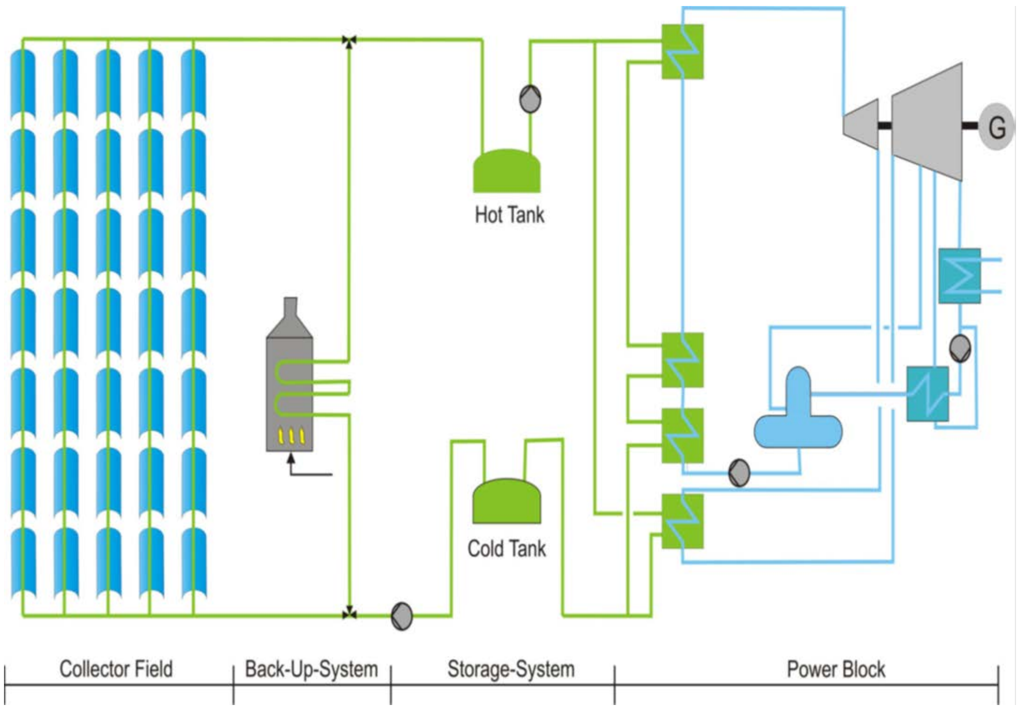
Panorama View HPS, Évora, Portugal

Molten Salt Heat Transfer Fluid in Parabolic Troughs



Advantages

- Direct storage of collected heat
- Full de-coupling of solar field operation from power production
- No unforeseen fluctuations on power block and grid

Challenges

- Freeze protection at 220°C in whole collector and piping system
- Overnight heat losses
- Corrosion / material selection
- Salt mixtures with low melting point

Molten Salt in Parabolic Trough
Current activities

Italy: Archimede Solar

- 2010: 30 MW_{th} Parabolic trough field delivering heat to combined-cycle power plant k
- 2013: 2 MWth molten salt testloop (3.600 m)

Source: Archimede Solar Energy

Thermal oil (state-of-the-art) vs. Molten Salt Technology

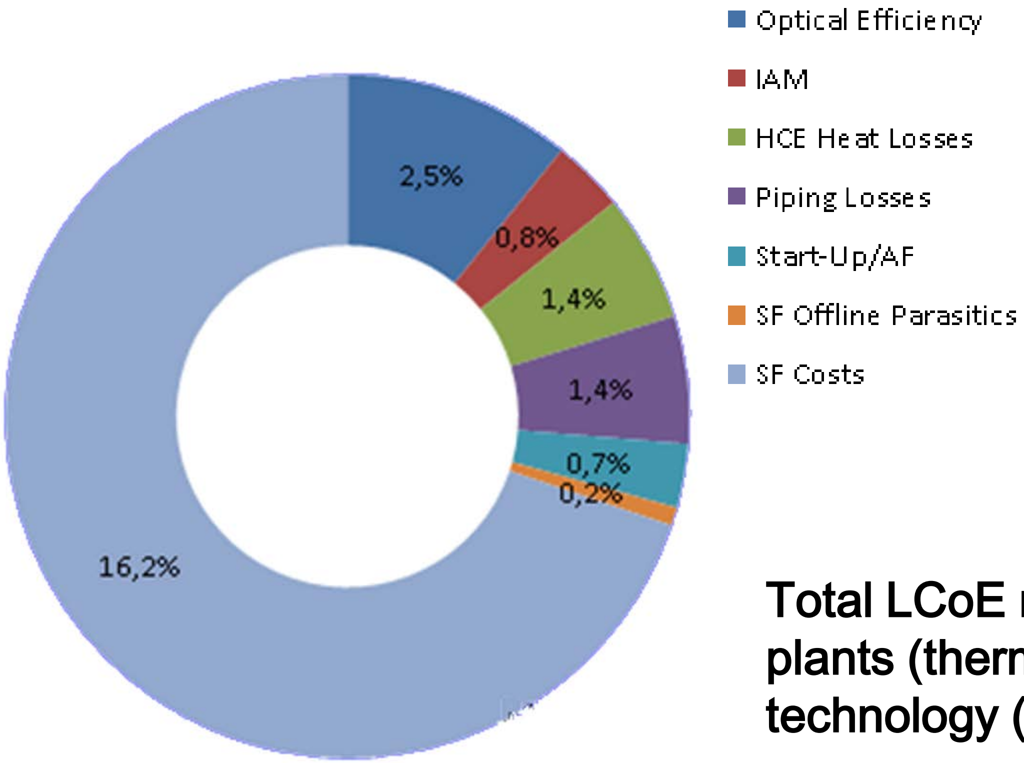
- CSP Solar Power Plants have the purpose to produce CO2-free, renewable and **dispatchable** (in comparison to PV plants) electricity

- Dispatchability is only achieved using a thermal energy storage

- Comparison of state-of-the-art-technology with molten-salt-technology:

  - Life steam parameters and power block efficiency:
    - State-of-the-art: 386 °C / 100 bar: **39,2%**
    - Molten salt: 550 °C / 150 bar: **45,5 %**
  - HTF-pump auxiliary load:
    - State-of-the-art: **6-7 %**
    - Molten salt: **1-2 %**
  - Volume of thermal energy storage at same capacity:
    - State-of-the-art: **100 %**
    - Molten salt @550 °C: **36 %**
  - Direct storage of HTF opens fully independent operability of solar field and power block

Influence of Collector type on Levelized Costs of Electricity



Reference plant in Spain:

- 125 MW
- HTF: NaK-NO3-Technologie@530°C
- 8h-storage
- Collector types:
  - Ultimate Trough (7.5m)
  - Euro Trough (5.6 m)

LCoE-Reduction of UltimateTrough vs. EuroTrough:

23,2 %

Total LCoE reduction potential of state-of-the-art-plants (thermal oil, 5.6 m troughs) and future technology (molten salt, 7.5 m troughs):

33,2 %

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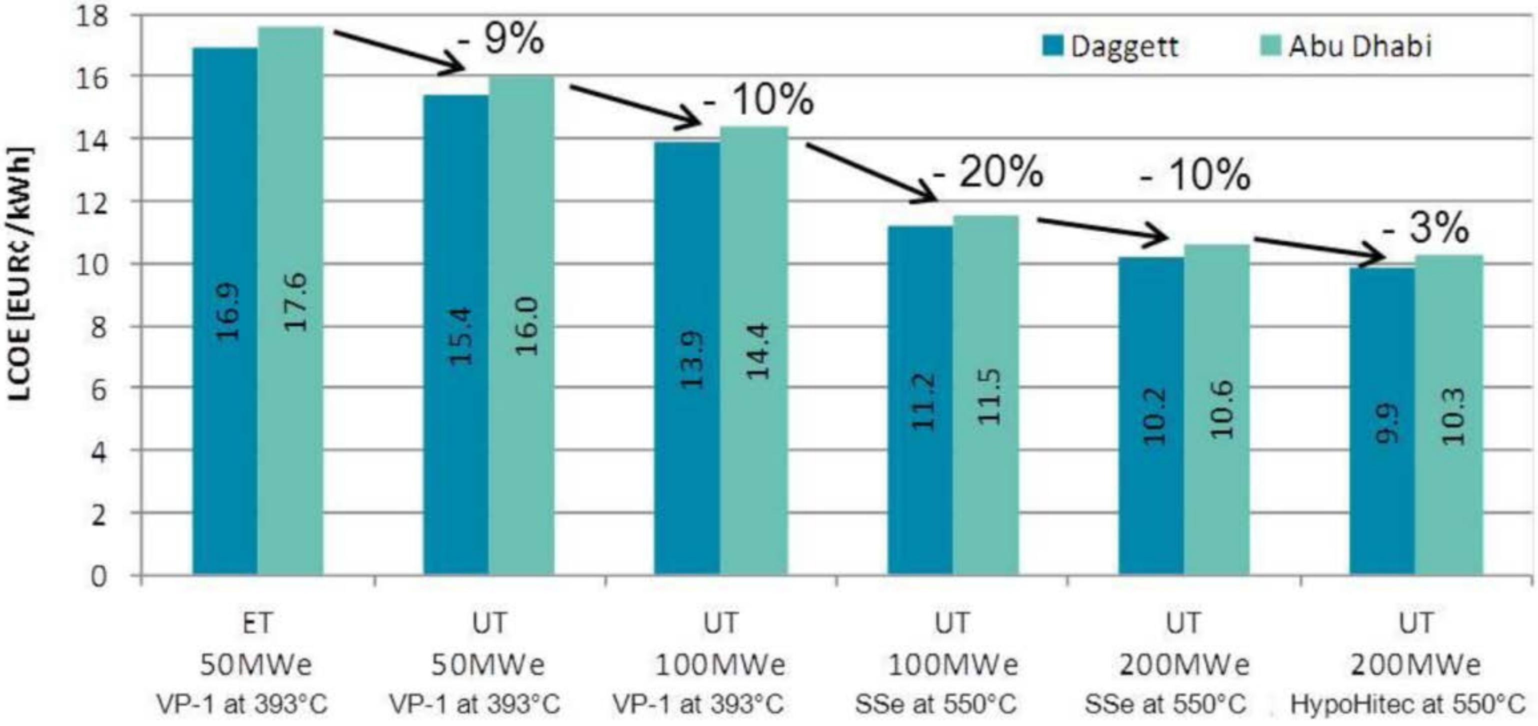
Potentials (LCoE – Roadmap)



LCoE evaluation over technologies

Ruegamer, T., H. Kamp, et al. (2014). "Molten Salt for Parabolic Trough Applications: System Simulation and Scale Effects." Energy Procedia **49**(0): 1523-1532.

Potentials of Molten Salt Technology
What do other people say?

Kearney et al. (2003):

LCoE Potential between **14,2 and 17,6%**
VP1 vs. NaK or HiTec XL

Kelly et al. (2007)

LCoE Potential **up to 25 %**
VP1 vs. NaK with 8m aperture

Kolb, Diver (2008)

LCoE Potential between **6 to 25 %**
VP1 vs. NaK and 2X-Trough (high aperture)

Turchi et al. (2008)

LCoE potential of **21 up to 45 %**
VP1 with 6h-storage vs. NaK with 6h-TES and 450 °C vs. NaK with 12h-TES and 500 °C

Riffelmann et al. (2011)

LCoE potential **of 11,6%**
EuroTrough (5,7 m) vs. UltimateTrough (7,5 m) (both mit VP-1)

Giostri et al. (2012)

Increase of annual energy output of **6 %**
VP1 vs. NaK without storage

Kearney, D., U. Herrmann, et al. (2003). "Assessment of a Molten Salt Heat Transfer Fluid in a Parabolic Trough Solar Field." Journal of Solar Energy Engineering 125(2)
Kelly, Bruce, H. Price, D. Brosseau , D. Kearney , "Adopting Nitrate/Nitrite Salt Mixtures as the Heat Transport Fluid in Parabolic Trough Power Plants," Proceedings of the Energy Sustainability 2007 Conference, June 27-30, 2007, Long Beach, CA.
Kolb, G. and R. B. Diver (2008). Conceptual Design of an advanced Trough Utilizing a Molten Salt Working Fluid. SolarPACES 2008, Las Vegas, NV.
Turchi, C., M. Mehos, et al. (2008). Current and Future Costs for Parabolic Trough and Power Tower Systems in the US Market. SolarPACES 2008, Perpignan, France.
Giostri, A., M. Binotti, et al. (2012). "Comparison of different solar plants based on parabolic trough technology." Solar Energy 86: 1208-1221.
Riffelmann, K.-J., D. Graf, et al. (2011). Ultimate Trough - the New Parabolic Trough Collector Generation for Large Scale Solar Thermal Power Plants. ASME - 5th International Conference on Energy Sustainability, Washington DC.

What hinders the technology?

Or the „10 major concerns“:

1. Filling and draining of the plant
2. High thermal effort during anti-freeze operational mode (added costs for the required heating)
3. Danger of freezing during various operation modes
4. Blackout scenarios
5. Material requirements, high corrosion
6. Performance of the SCA / HCE
   a. thermal performance, b. optical performance, c. mechanical properties
7. Flexible connection: Proof of functionality and tightness
8. Steam Generating System: internal leakage due to defect of heat exchanger tubes
9. Maintenance procedures, Handling of disturbances (e.g. complete draining and re-filling)
10. Stability of salt mixtures (time stability, thermal stability)

History of the HPS-Project

In 2010 a consortium of industry and research institutes joined to set up a demo plant under the funded project HPS.

The partners were Siemens (as project leader), DLR, Steinmüller Engineering, K+S and Senior Flexonics.

View on construction site of HPS, Évora, Portugal

In 2012 Siemens decided to step out of the solar business. A total volume of approx. 5 Mio € was invested.

The plant was overtaken by University of Évora in 2013

Co-operation agreement between University of Évora and DLR to jointly complete and operate the Evora Molten Salt Platform

Plant Layout

DCS/PCC/MCC

Steam Generating System

W/S-Cycle

Wind Fence

Thermal Energy Storage

Solar Field Site

Drainage Tank with Melting Unit

Civil Works, Site power and Water Treatment
Plant fully completed

Objectives of HPS2 project

The project HPS2 aims to erect, operate and demonstrate

- a parabolic trough system with an aperture of 6.8 m
- two-tank storage systems
- once-through vessel (design 550 °C/150 bars)

with the technology fully based on Molten Salt as heat transfer medium

HelioTrough in US with workers

This set-up will be a **first-of-its-kind demo plant world wide**

Technical Specifications

Remark: Specs according to design layout with Solar Salt

Helio Trough

• Solar Field Design Power	2.8 MW
• Aperture Width	6.8 m
• Length of single collectors	191 m
• Number of Collectors	4
• Thermal Efficiency	~70 %

Once-Through SGS

• Steam Generating System	1.6 MW
• Life Steam Design Temperature	560 °C
• Life Steam Design Pressure	140 bar

Thermal Energy Storage

• Storage Capacity @ ΔT=280 K	2 hours
• Tank Height	5,0 m
• Tank Diameter	3,1 m

Testing options

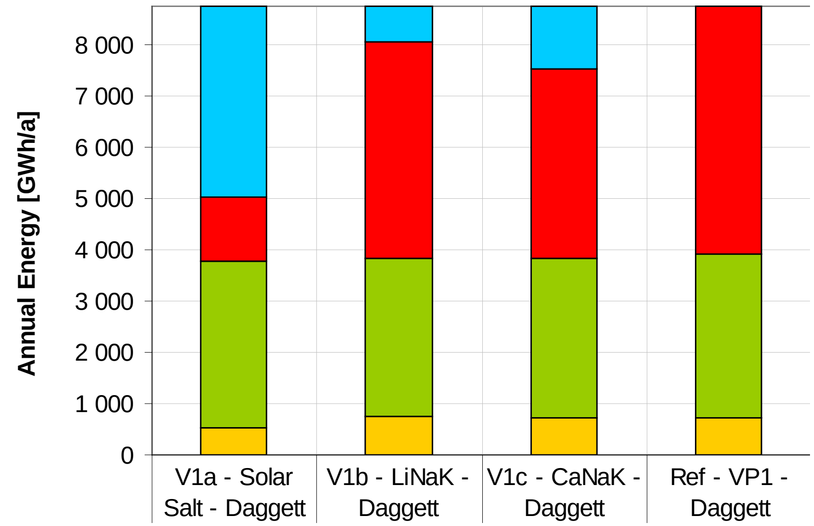
1. Filling and draining of the plant

Drainage Tank designed to accept total content
Solar field piping and steam generator

Drainage options and foreseen tests:

- Drainage of horizontal piping: self-draining
- Drainage supported by pressurized air system
- Partly drainage and subsequent re-melting by trace heating
- Drainage points in-between collectors
- Drainage mass flow measurements
- Pneumatic Valves in solar field and storage system
- System prepared for „Salt Dilution“

Testing options



2. High thermal effort during AF operation

Complete protection of salt piping and equipment with trace heating.

Anti-Freeze-Options and foreseen testing:

- Several different options of trace heating implemented
- Storage design enables complete night operation from storage
- Solar-driven convective anti-freeze operation
- Electric-powered anti-freeze operation
- Drainage for freeze protection
- Monitoring of energy demands of subcomponents

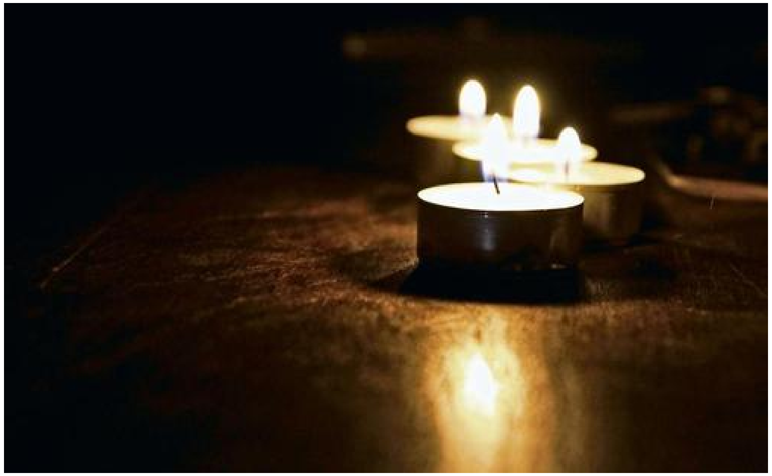
Testing options

3. Danger of freezing during various operation modes

- Numerous temperature measurements in all system
- Heat loss measurements in storage foundations
- Sufficient and redundant trace heating
- Insolation and heating based on analysis of operating modi
- Avoiding of stagnating liquid salt in all operating conditions
- Automatic operation of trace heating systems
- Instrumentation to analyse heat losses of all individual subcomponents

Testing options

4. Blackout scenarios



- System design and operation close to upper temperature ensuring operational flexibility in case of emergency
- Uninterrupted power supply with battery und diesel-generator
- Simulation of scenarios within T3000-controlsystem (Single components as well as complete system, including different back-up power systems)
- Automatisation of blackout procedures

Testing options

5. Material requirements, high corrosion

- Corrosion tests with external specialists
- Appropriate material selection
- Good access to all components and piping to enable sampling

Testing options

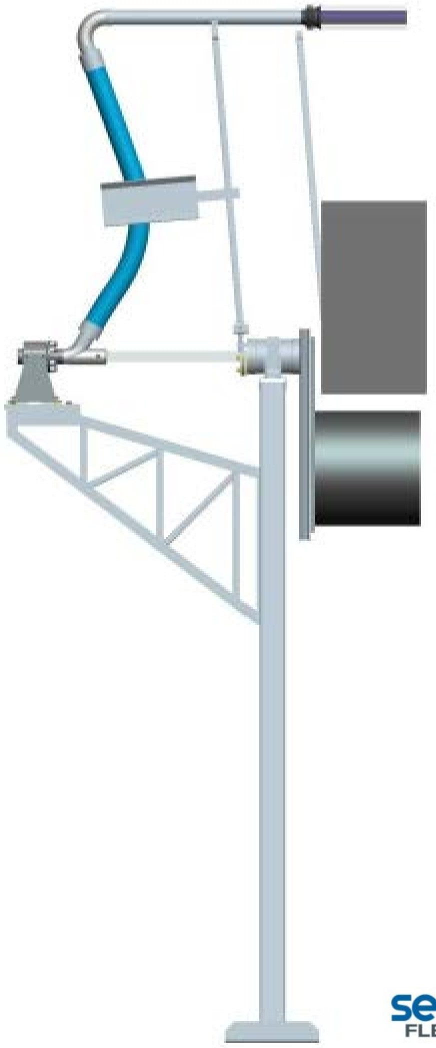
6. Performance of the SCA

- Loop instrumentation with numerous flow- and temperature measurements
- Optical and thermal qualification tests and documentation during acceptance
- Central data acquisition system, data storage over whole project period
- Redundant instrumentation at sensible points
- Weather station including cloud camera system

Testing options

7. Flexible connection

- Test of flexible connection to compensate thermal expansion and rotation
- Decentral drainage option
- Proof of reliable trace heating to avoid freezing
- Alternative solution without rotational joint
- Torsion measurements



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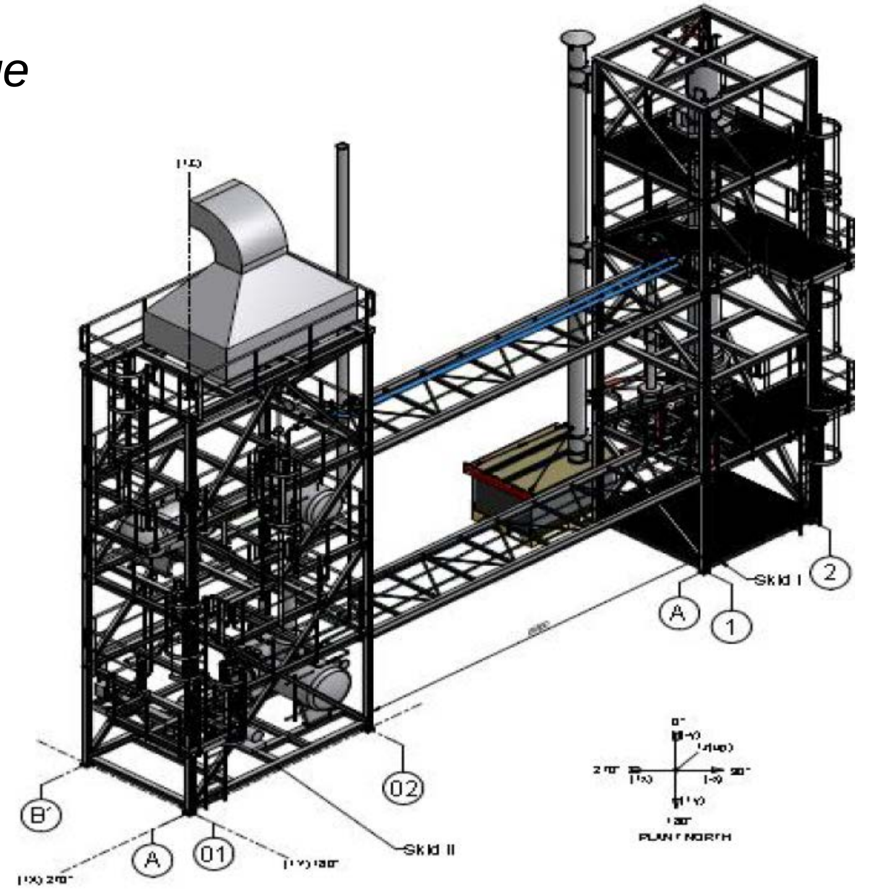
Testing options

8. Steam Generating System: internal leakage due to defect of heat exchanger tubes



- Salt-heated
  Benson boiler (150 bar/550 °C)
- Background from Solar Two
- Adapted design and operation
- Safety system implemented

Testing options

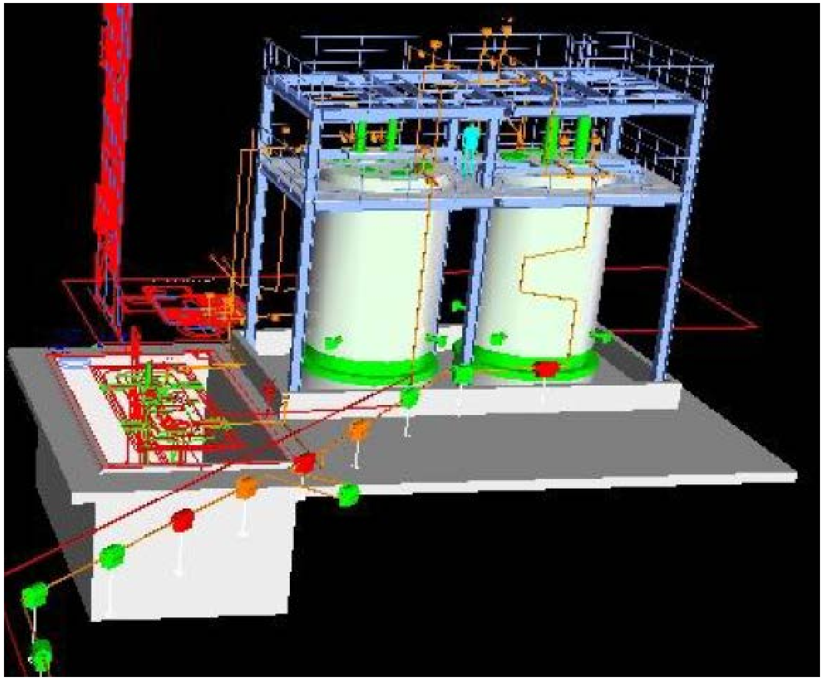
9. Maintenance procedures,

Handling of disturbances

- Draining options for all subcomponents independent from operating modus
- Single storage tank volume designed to accept total system volume: Salt management options
- De-mineralised water production on site (steam generator and mirror washing)
- Highly flexible control system with automatisation options
- Redundant design of main pumps and important control instruments and actuators

Testing options

10. Stability of salt mixtures



- Full accessibility to storage tanks
- Laboratories for salt analyses available at project partners
- Redundant level measurements with different methods in all tanks
- NOx-measurements in the gas blanket

Summary
Evora Molten Salt Platform

- Unique infrastructure to demonstrate solutions to all major concerns against molten salt in parabolic trough systems
- Options for test of innovative solutions for design or operation e.g. optimized drainage or freeze protection operations
- Demonstration of ability of project consortium to provide advanced technology for first commercial implementation
- Extension potential for implementation and test of alternative technologies
- Chance to collect operational knowledge and create competitive advantages

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