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Thermal storage for improved utilization of renewable energy in steam production

Hanne Kauko and Gerwin Drexler-Schmid (AIT)

HighEFF ACM 8.-9.5.2019

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Outline

- Background
  - The problem - steam demand and the way it's produced
  - Fossil-free production of steam & the role of thermal storage
- Relevant thermal storage technologies
- Alternatives for fossil-free steam production
  - Power-to-heat: Results from a case study
  - Concentrated solar power (CSP)
- Summary and on-going/future work in HighEFF

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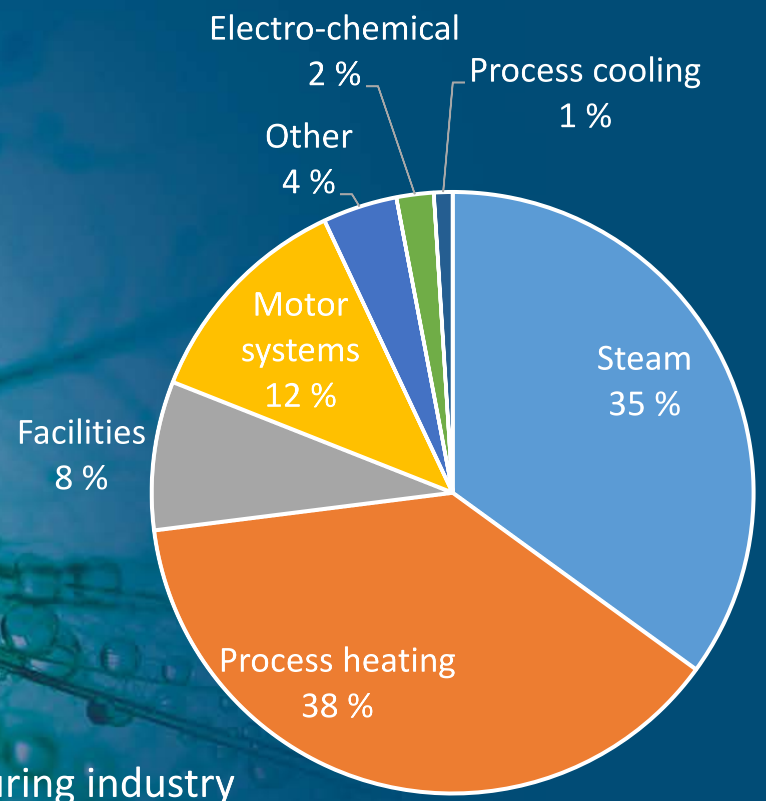
Background



Manufacturing industry energy use by system (US)[2]

- Steam systems are a part of almost every major industrial process, in nearly all industrial sectors
  - Estimated to account for 38 % of global final manufacturing energy use[1] - 9 % of the global final energy consumption
- Steam production primarily based on the use of fossil fuels
  - 37 % of fossil fuel burden in US industry is burned to produce steam[3]
- Huge potential for large reductions in GHG emissions

[1]Banerjee, R. et al. (2012). "Energy end-use: industry." Gobal Energy Assessment-Toward a Sustainable Future: 513
[2]DOE 2004. Energy Loss Reduction and Recovery in Industrial Energy Systems. Prepared by Energetics, Inc., for the U.S. Department of Energy, Washington, DC.
[3]Einstein, D., et al. (2001). Steam Systems in Industry : Energy Use and Energy Efficiency Improvement Potentials, Lawrence Berkeley National Lab (LBNL), Berkeley, CA (United States): **535–547.**

- Fossil-free alternatives for steam production?
  - **Power-to-heat**: Electricity from renewable sources + high-temperature heat pump (HTHP) or electric boiler
  - **Concentrated solar power (CSP)**

In either case – **thermal storage** is the key

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Relevant thermal storage technologies

Thermal storage technologies (1)

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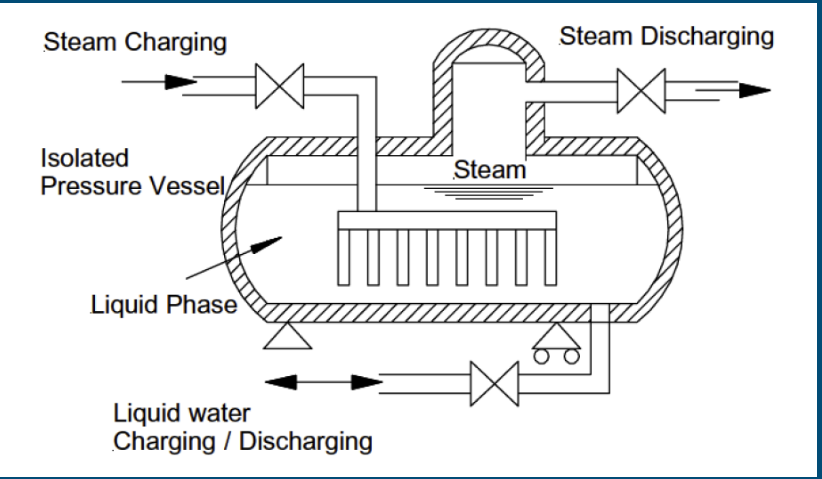
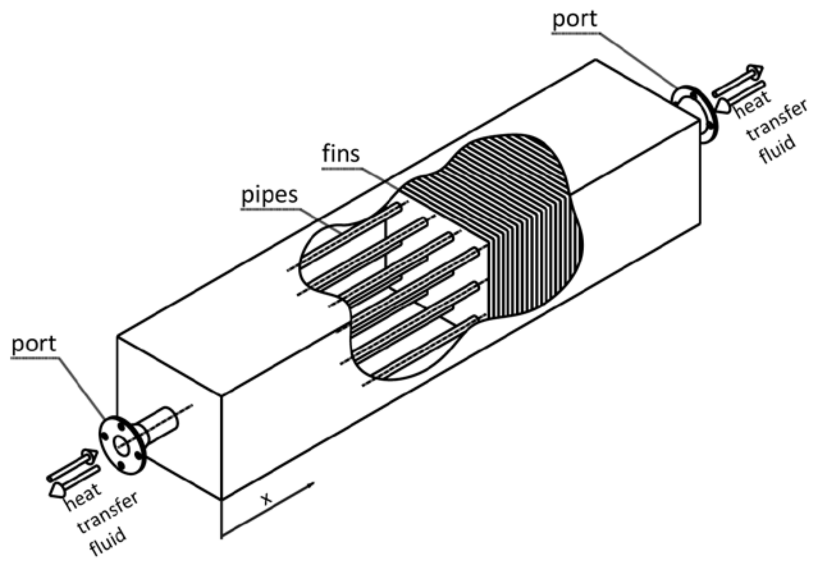
- **Steam accumulator (Ruths steam storage)**
  - High charging/discharging rates
  - Storage medium = heat transfer fluid – no extra heat exchangers
  - Challenge: low energy density – not suitable for large-scale applications, or longer time scales



- **Latent heat storage (LHS)**
  - High energy densities
  - Temperature can be tailored to the application by the choice of material (PCM)
  - Challenges: Low TRL, low thermal conductivity



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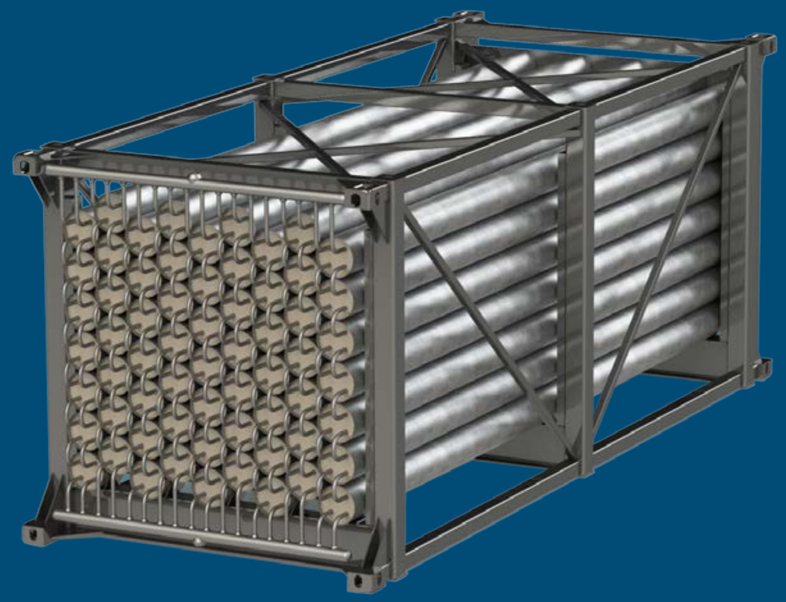
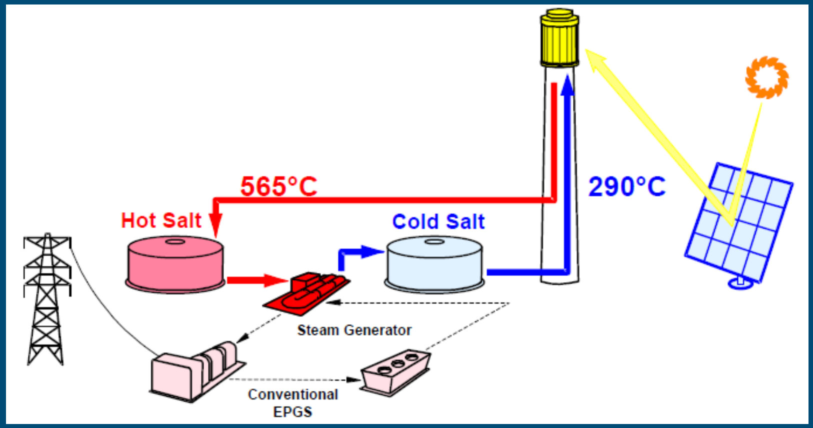
Thermal storage technologies (2)

- **Sensible heat storage in concrete** (e.g. EnergyNest)
  - Cost-efficient, safe and easy-to-use
  - Scalable, modular design
  - Challenges: limited charging/discharging rates

- **Molten salt storage**
  - High thermal conductivities
  - May be used as the heat transfer fluid as well
  - Challenges: keeping the salt in liquid state, corrosivity



https://energy-nest.com/



Pacheco, J. E et al. (2002). "Final test and evaluation results from the solar two project." Report No. SAND2002-0120, Sandia National Laboratories, Albuquerque, NM **45**.

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Fossil-free steam production

Alt. 1: Power-to-heat

Results from a case study

Gerwin Drexler-Schmid and Anton Beck (AIT)

Case study definition

Energy source:

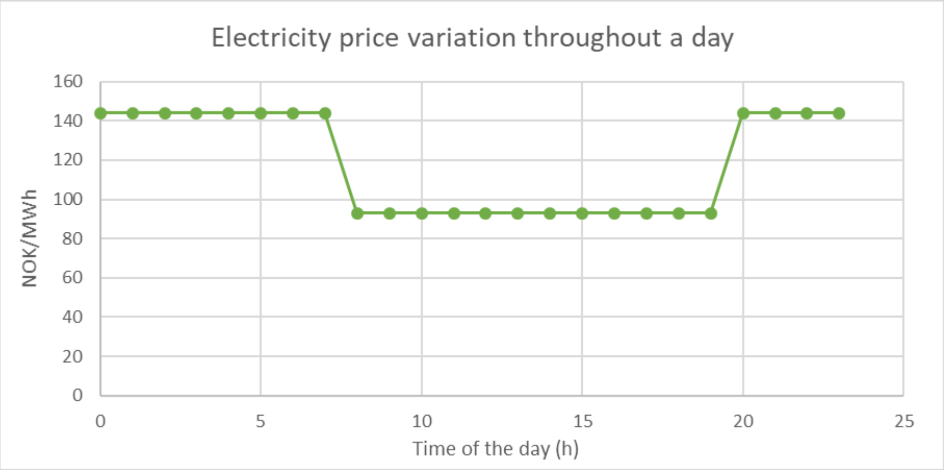
- Electricity market with diurnal price variation, modelled in 2 cases

Heat demand:

- Saturated steam at 15 bar (200 °C)
- Steady volume flow rate: 1200 t/h

Two storage technologies compared:

- Ruths steam storage
- Latent heat storage (LHS)



[USD/MWh]	Case 1	Case 2
High	17	34
Low	11	11

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Existing technology: Ruths steam accumulator

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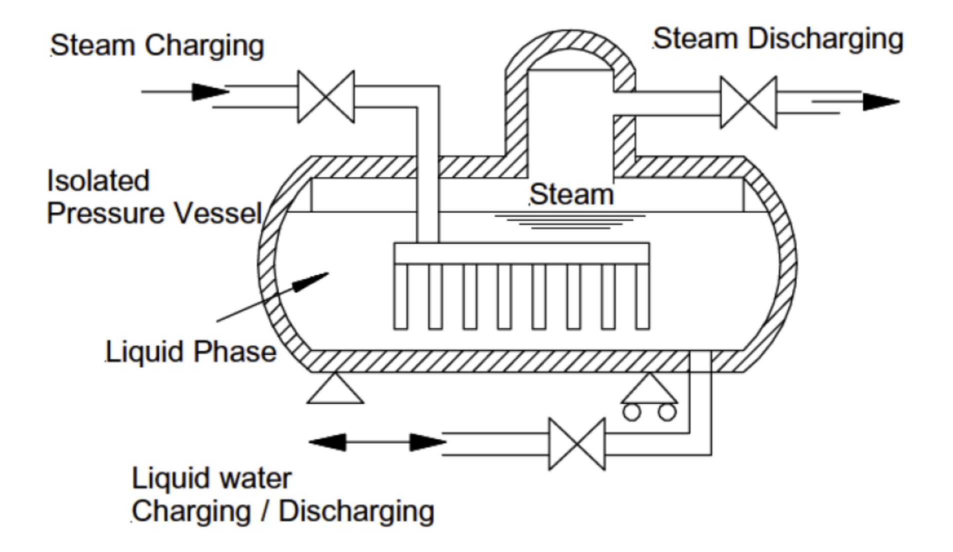
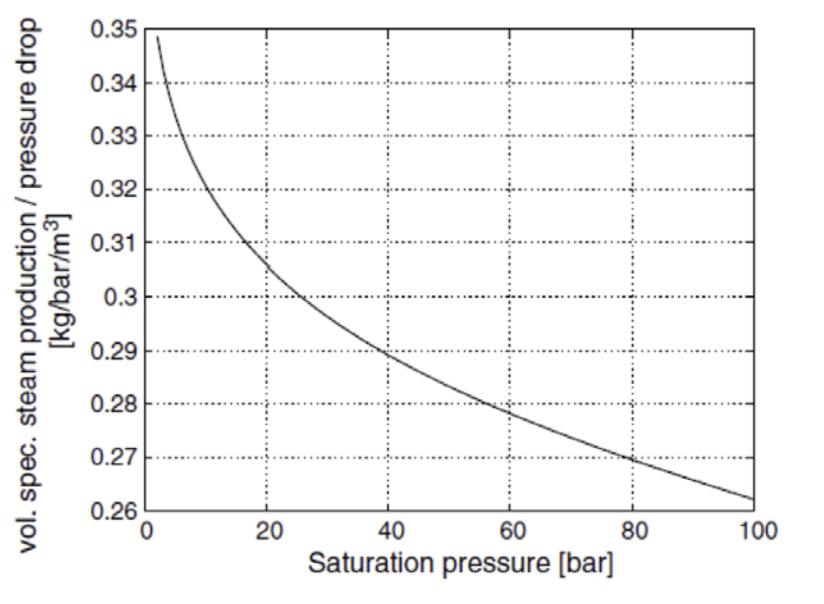
Characteristics

- Storage medium: Water, steel
- Direct storage
- Variable power to energy ratio
- Storage density:
  - ~ 40 kWh/m³ at 30 bars
  - ~ 31 kWh/m³ at 100 bars
- Costs: 4 €/ton of water, 6000 €/t steel
- Wall thicknesses 3-10 cm





Pros

- Simple
- Commercially available
- Short storage time with high output power

Cons

- Low storage density at high pressures
- High amount of of steel

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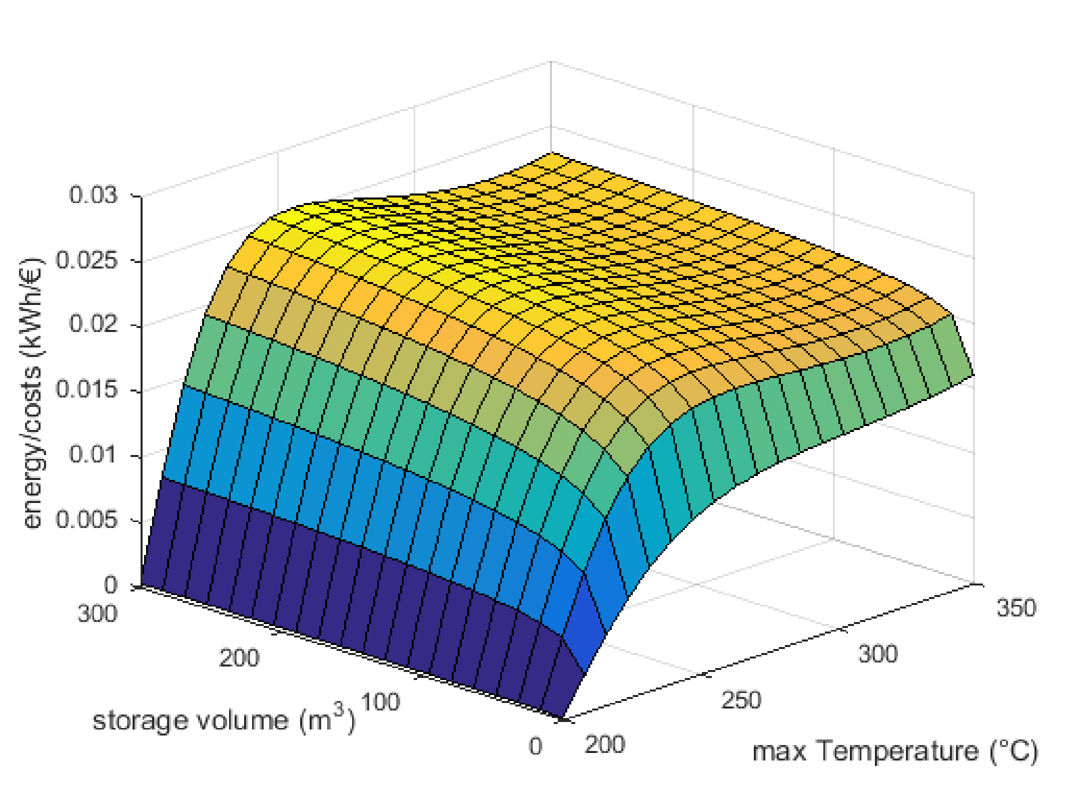
Cost estimates: Ruths steam storage

Ruths steam storage

- Steel: P460NH
- Safety: the required amount of steel depends on the pressure and temperature
- Storage capacity per € increases with storage size – but size limited by manufacturing and transport



Optimal storage unit:

- Chosen max volume: 300 m³
- T_{max} ~255 °C

Cost for kWh of stored energy:

40 €/kWh

Upcoming technology: Latent Heat Storage

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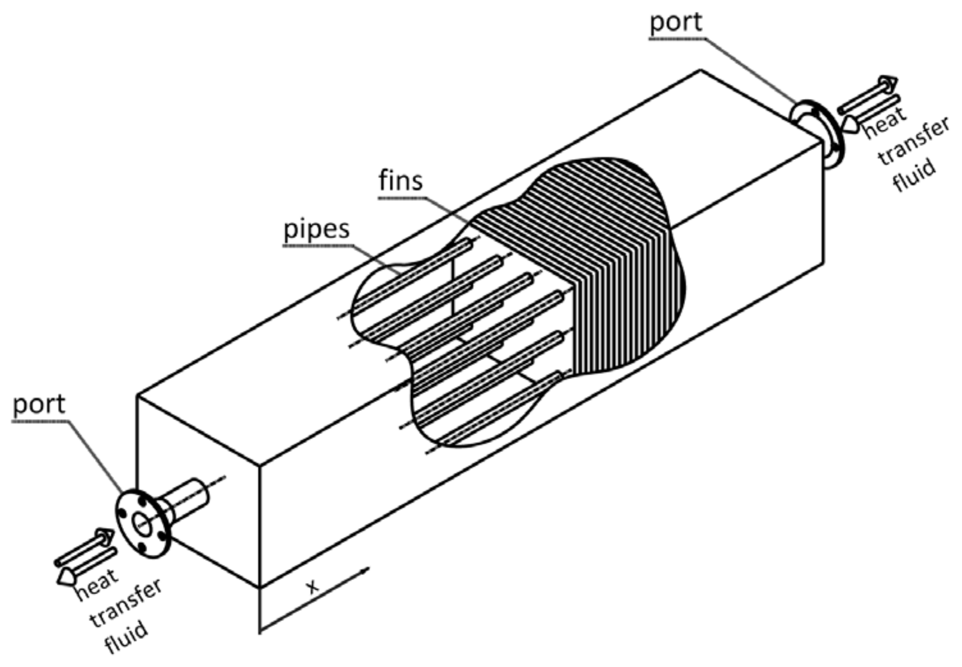
Characteristics

- Storage medium: phase change material (PCM)
- Indirect storage
- Variable power to energy ratio
- Storage density:
  - ~ 100 kWh/m³ at atmospheric pressure
- Unpressurized storage vessel
- Costs: 300-600 €/ton PCM, 6000 €/t steel



Design sketch of the shell and tube latent heat thermal energy storage (Ind. Eng. Chem. Res., 2016, 55 (29), pp 8154–8164)

Pros	Cons
• High energy density	• TRL 5-7
• Low amont of steel	• Low thermal conductivity
• Unpressurized storage vessel	

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Cost estimates: Latent heat storage (LHS)

Assumptions:

- 2 cm diameter piping
- T_{max} ~255 °C
- Effective enthalpy 140 kJ/kg within the applied temperature range
- No additional heat transfer measures
- EUR/USD = 1.14

Results:

- Costs more independent of storage size - mostly affected by pipe diameter
- Cost for PCM/Steel ~50/50

Cost for kWh of stored energy: 24.4 €/ kWh

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Cost estimates for thermal storage technologies: main results

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Electricity prices:

[USD/MWh]	Case 1	Case 2
High	17	34
Low	11	11

Cost estimates:

Tech. type	Steam (t/h)	Thermal storage capacity (MWh)	Number of storage units	Storage tech. costs (mill. EUR)	Payback (yr) Case 1	Payback (yr) Case 2
Ruths	1200	9493 MWh	461	375	20.1	5.2
LHS	1200	9493 MWh	NA	230	12.3	3.2

Payback times should be balanced with the ***cost to access additional power from the power network and cost of additional boilers to charge the TES units****.*

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Conclusions from the case study

Identified limitations

- Additional costs should be taken into account in the case studies (e.g. *additional boilers and access to additional power from network*)
- Large steam accumulators or other TES tech. of **such high scale might not be realisable** for constant steam delivery over 12 hours

Further work

- Feasibility with regards to the large scale of TES
- Evaluation of potential alternative storage technologies
- Techno-economics to evaluate the correct storage and conversion technology for a given application

→ **Nove Emerging Concept (NEC) application**

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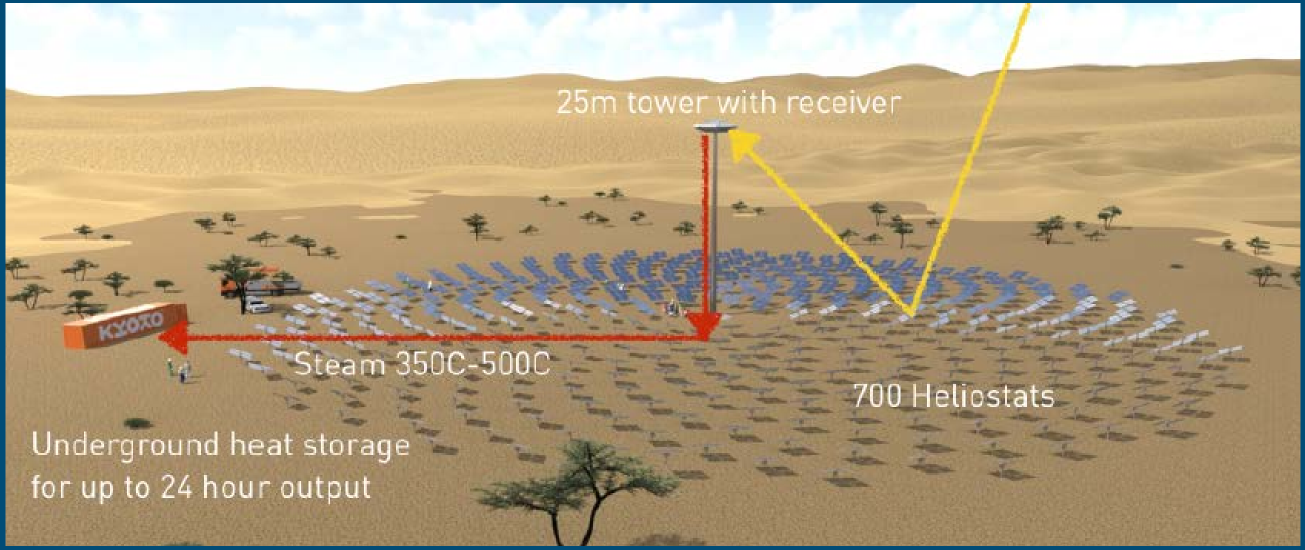
Fossil-free steam production

Alt.2: Concentrated solar power (CSP)

Concentrated solar power (CSP)

- Concentrating the sunlight to heat up a heat transfer fluid to high temperatures to produce steam or electricity
  - Parabolic trough (150–350 °C)
  - Solar tower (500–1000 °C)
- Kyoto Group
  - Modular CSP systems for the demands of the industry
    - Cost-efficient
    - Fast to build
  - Thermal storage: Novel molten salt developed by Yara
    - Lower melting point
    - Cheaper
    - Less corrosive



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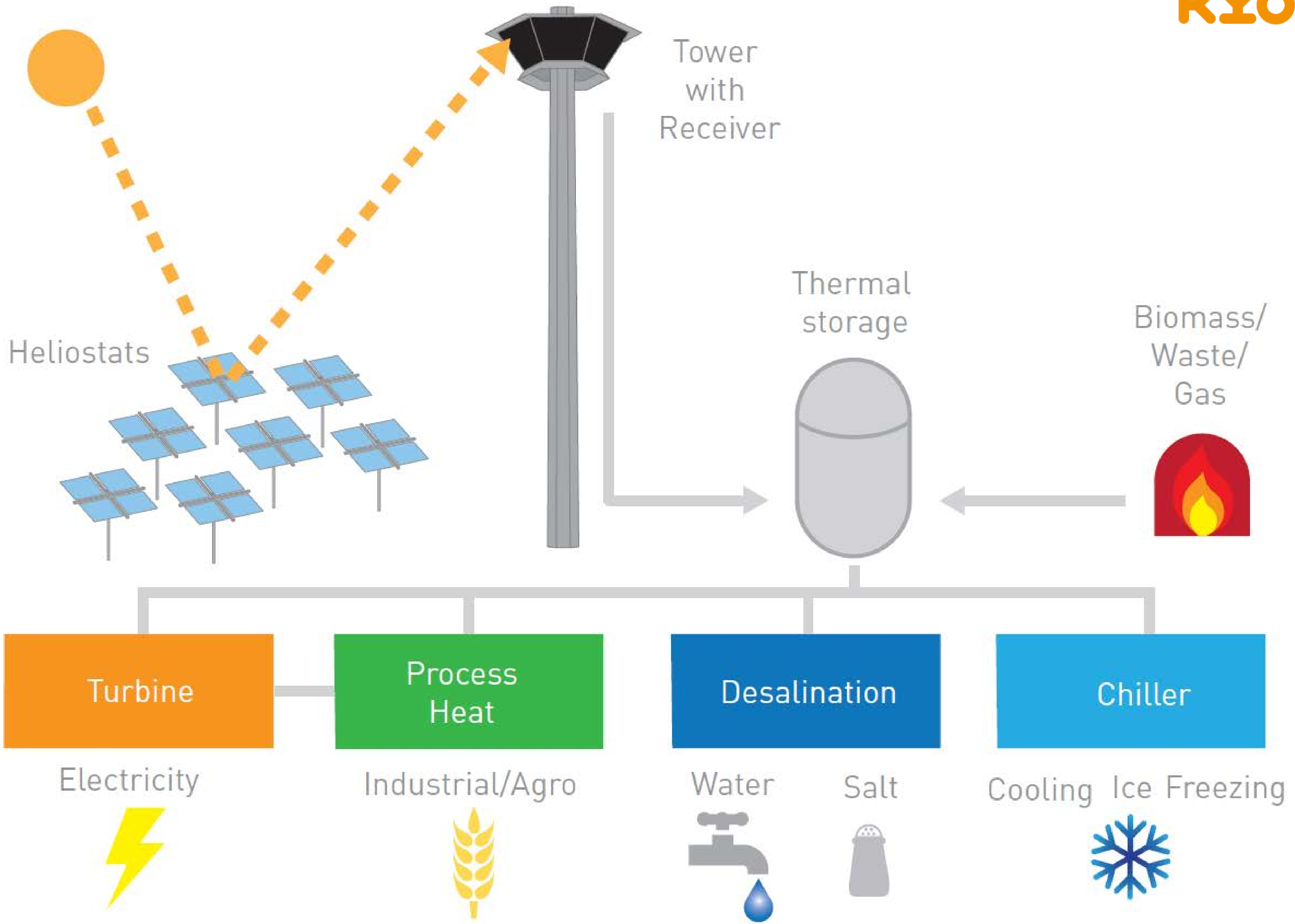

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Summary
and on-going/future work in HighEFF

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Summary

- Steam demand is huge + the production is still largerly based on the use of fossil fuels
    - **Switching to renewable-based production can allow fast and large reduction in GHG emissions**
- Fossil free alternatives for steam production
    1. Power-to-heat – using high-temperature heat pumps or electric boilers
    2. Concentrated solar power
- In either case – thermal storage is required
    1. To enable the use of renewable power when prices are low
    2. To enable continuous output from CSP plants

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On-going and future work in HighEFF

HighEFF

- D3.3_2019.01: Thermal storage for improved utilization of renewable energy in steam production
  - Description and comparison of relevant storage technologies
  - Integration of HTHPs

- NEC application: Cost-efficient thermal energy storage for increased utilization of renewable energy in industrial steam production
  - Power-to-heat
  - Development of methodology to find the correct storage and conversion technology for a given application
  - Conversion technologies: HTHP, electric boiler

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Reference group meeting: Energy Storage

- Wish to affect the research work within Energy Storage in HighEFF?
- Join the reference group meeting tomorrow at 13:30 (KJL21)!

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Thank you for your attention.

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