(Reversible) High Temperature Heat Pumps as a Cornerstone for Future Geothermal Heat Supply

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Praxisforum Geothermie Bayern

October 6, 2022

Agenda

01 Motivation

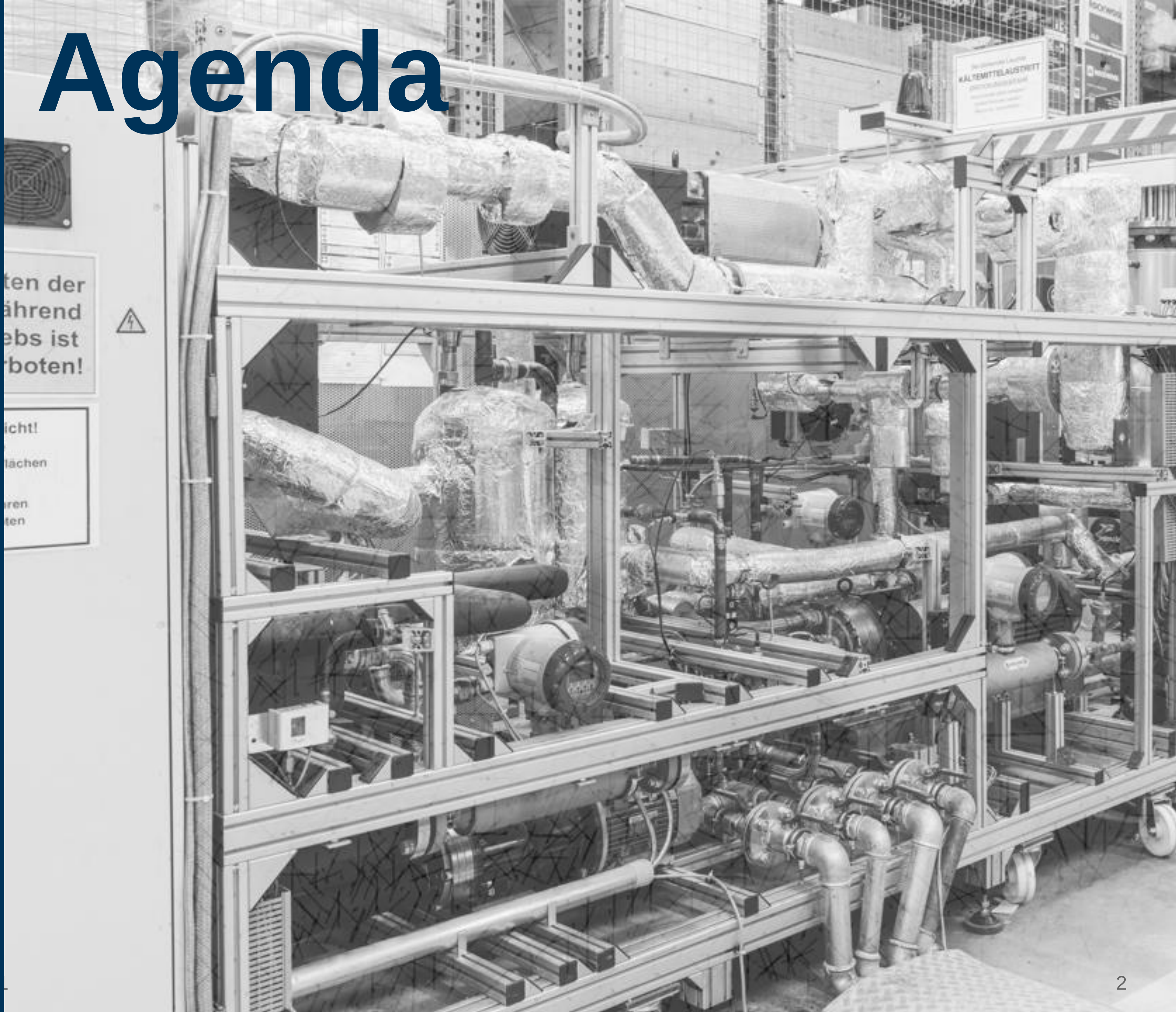
02 Working principle

03 Application scenarios

04 Status of commercial products & real use-case

05 Reversible heat pumps

06 Summary



Motivation and focus of this talk

- Presenting the potential role of high temperature heat pumps (HTHPs) in geothermal heating applications
- Showcasing the performance of current commercial products and a real geothermal application example
- Revealing the role of reversible HTPH/ORC systems in future geothermal CHP (combined heat and power) systems
- This talks focuses only on compression HTHPs

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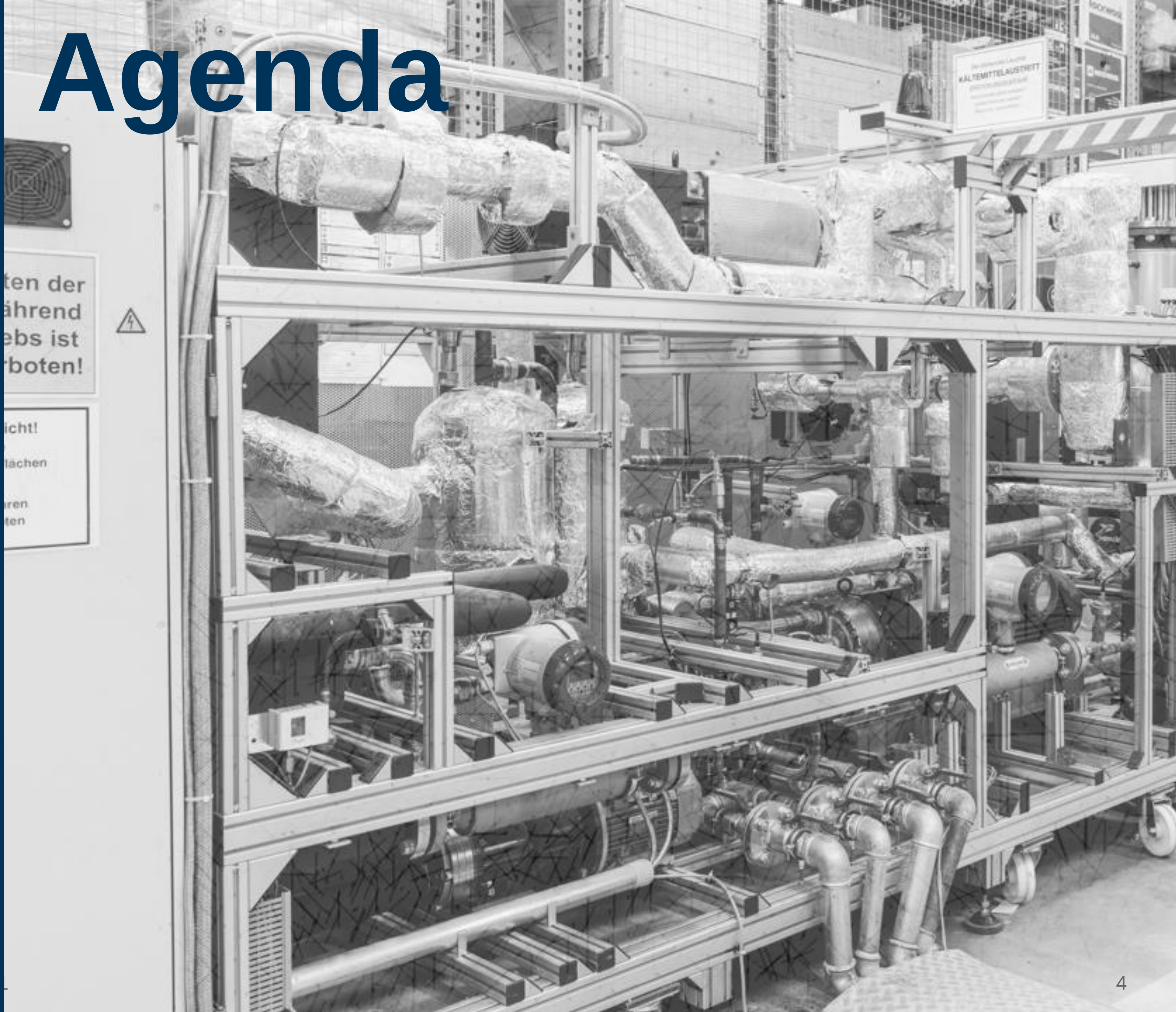

The general working principle of a heat pump

- Vapour compression cycle including four major process components (see Figure 1)
- “Upgrading” of low temperature heat by means of electricity (see Figure 2)
- The performance is characterized by the Coefficient of Performance (COP)
- The COP describes the ratio between the useful heat that is provided via the condenser of the heat pump and the required electrical power demand.
- The COP depends strongly on the temperature lift that is provided by the heat pump.

$$COP = \frac{\dot{Q}_{use}}{P_{el}}$$

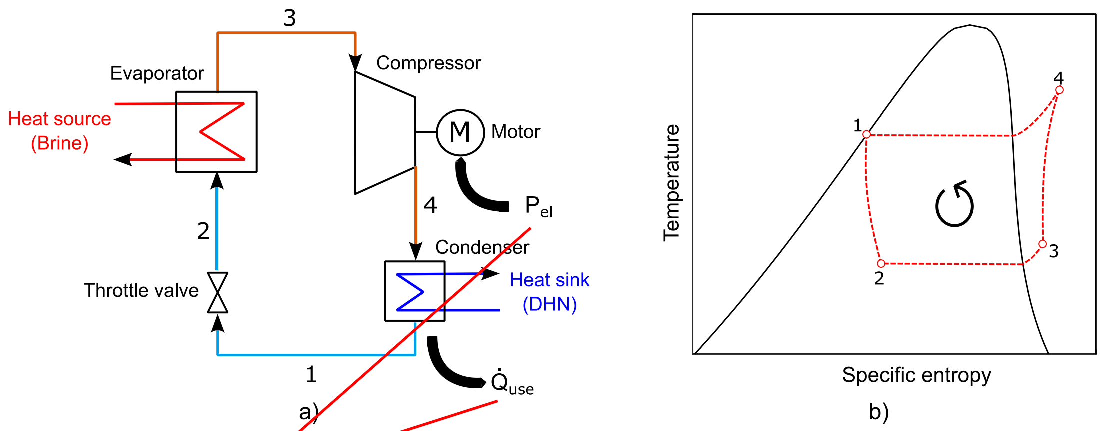

Figure 1: Process flow scheme (a) and T-s-diagramm (b) of a heat pump

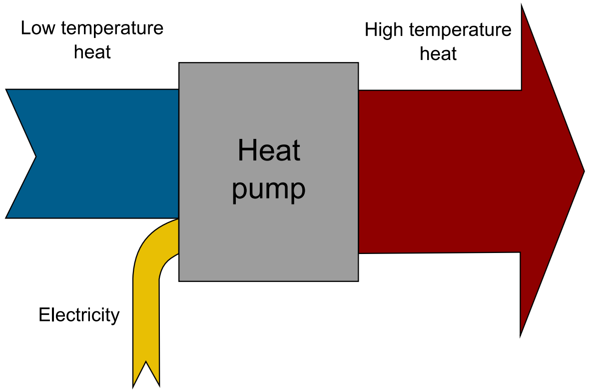

Figure 2: Simplified Sankey diagramm of a heat pump

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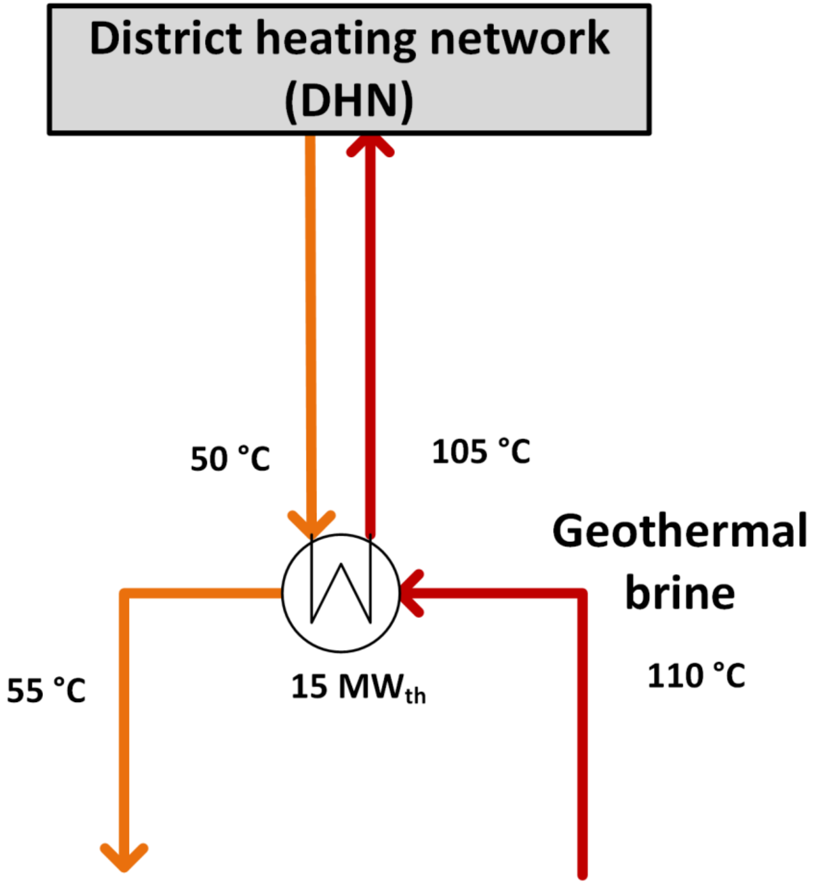
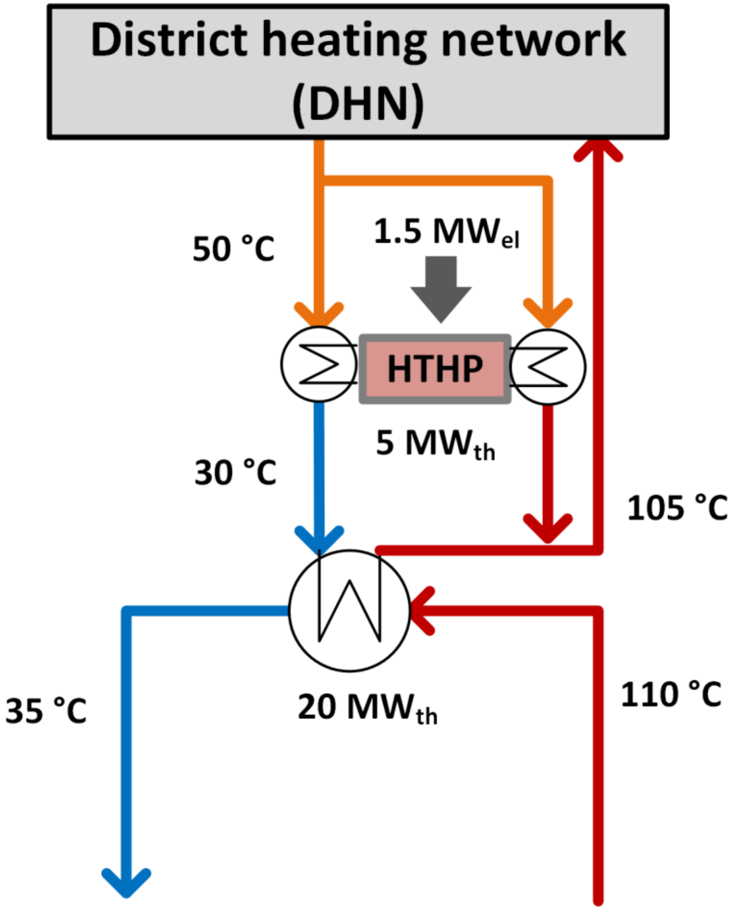
The standard geothermal heating project without a HTPH



Potential challenges might be:

- ❑ a higher thermal capacity is required during the winter period. Without additional solutions, e.g. fossil-fueled boilers are used
- ❑ the geothermal heat source temperature is lower than the required optimal district heating supply temperature

HTHP application case I: increasing the thermal capacity



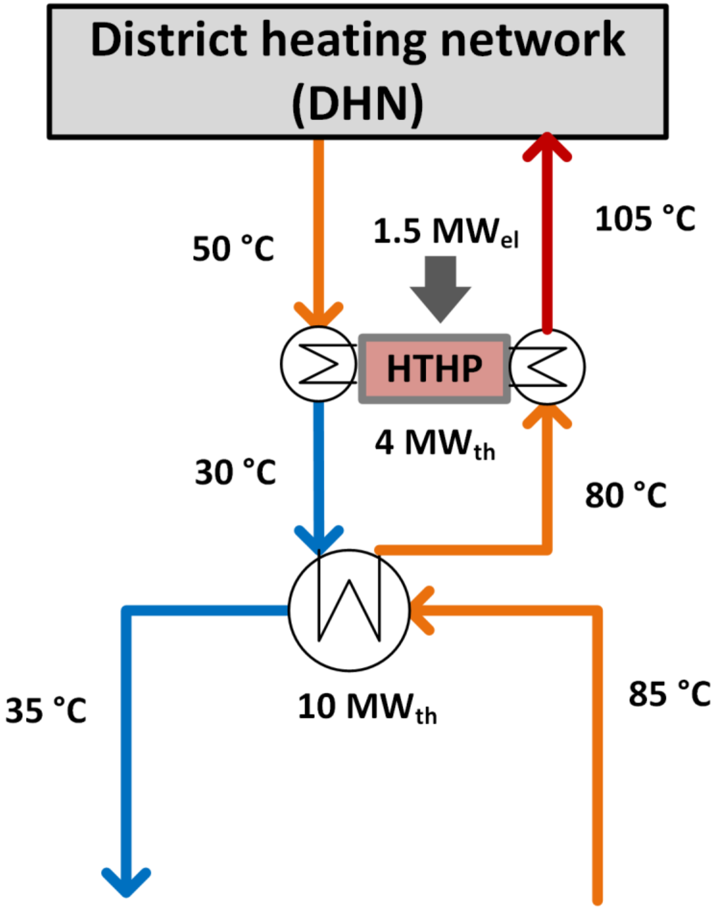
The integration of the HTHP results in:

- ❑ a higher heat extraction from the geothermal brine
- ❑ an additional heat supply by the HTPH

➔ The integration of the HTHP can increase the overall heating capacity of a geothermal project by more than 50 %

➔ The actual possible increase depends on the geothermal source temperature and the DHN supply & return temperatures

HTHP application case II: integrating an insufficient source temp.



➔ The integration of the HTHP enables the integration of a geothermal source temperature which is below the required DHN supply temperature

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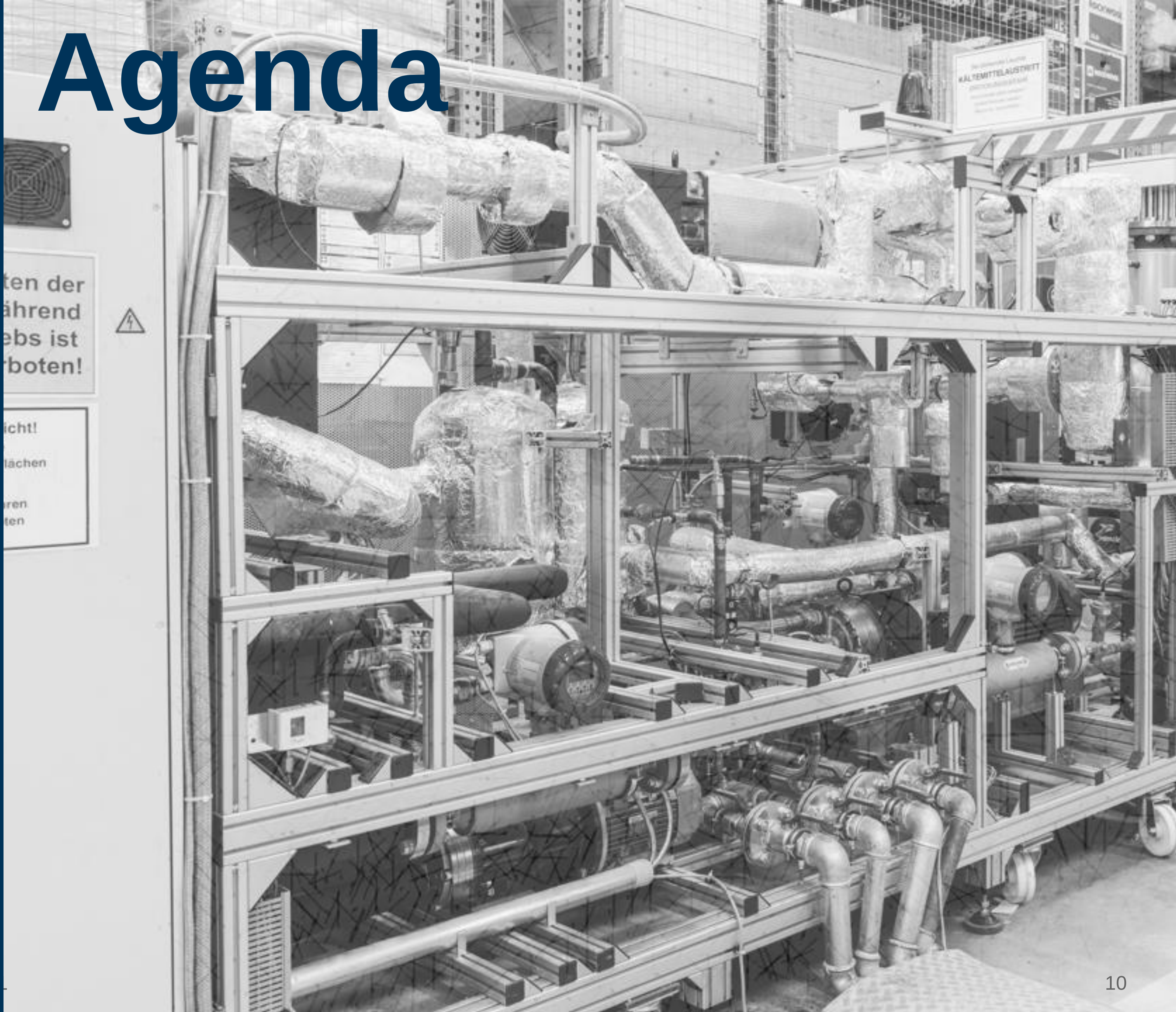


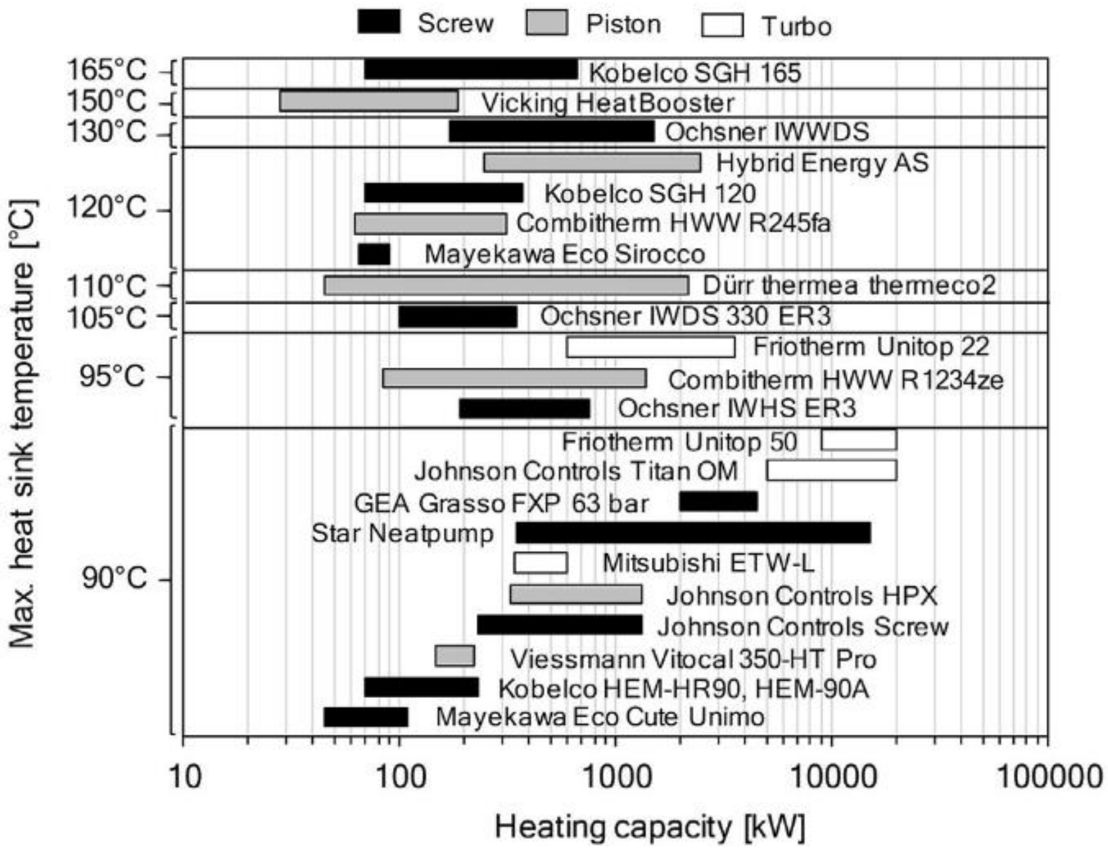
Available commercial large-scale HTHPs

- Increasing number of established available commercial large-scale HTHPs with capacities from a few hundreds kW up to several dozens MW of heating capacity

- Strong R&D activities regarding heat sink temperatures between 150 and 200°C and the supply of process steam for industry processes

Picture of a 5 MW HTHP

[Source: Figure taken from https://www.star-ref.co.uk]



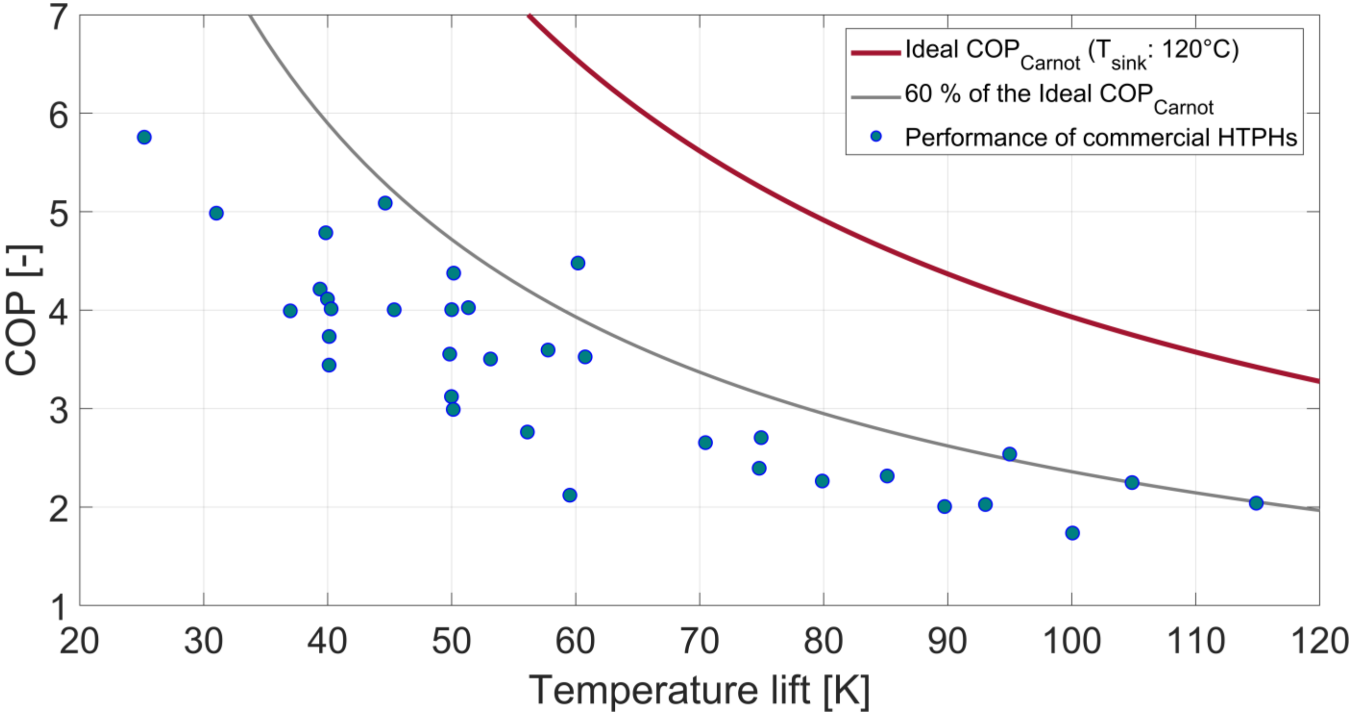
[Source: figure taken from Arpagaus et al. (2018)]

Performance of commercial large-scale HTHPs

- The achievable ideal COP depends mainly on the temperature lift of the HTHP
- Commercial products can currently achieve up to 60 % of the ideal COP

Picture of a 5 MW HTHP

[Source: figure taken from https://www.star-ref.co.uk]



[Source: own figure according based on Arpagaus et al. (2019)]

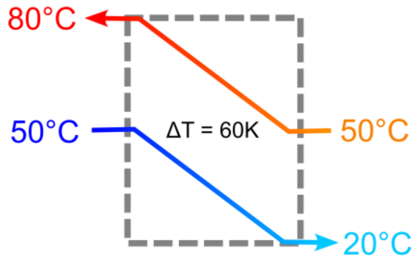
$$COP = \frac{\dot{Q}_{use}}{P_{el}}$$

$$COP_{Carnot} = \frac{T_{sink}}{\Delta T_{lift}}$$

Use-case Schwerin: increasing the COP with a multi-stage concept

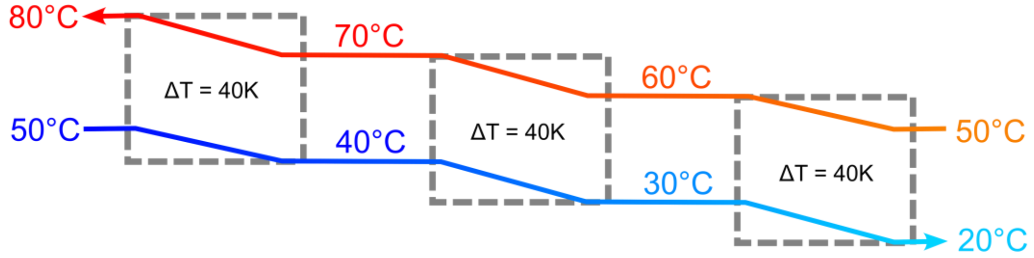
- The geothermal project in Schwerin applies HTHPs in order to lift the geothermal heat source temperature of 55°C to the required district heating supply temperature of 80 – 85 °C
- The final overall thermal capacity of the HTPH system is 6.9 MW_{th} with an expected average COP of 4.2[1]
- Instead of having one single HTPH with a high temperature lift, the overall temperature increase is carried out by several serial HTPHs
- Due to the lower temperature lifts in each HTHP, a higher overall (COP) can be achieved
- Despite higher investment costs and plant complexity, the significant reduction of the electrical power demand makes it favourable considering the long-term operational costs

Temperature lift of a single heat pump



$$COP_{ideal} = 5.89$$

Temperature lift spread on three heat pumps



$$COP_{ideal} = 8.58$$

[1] More information can be found in Mathes (2022)

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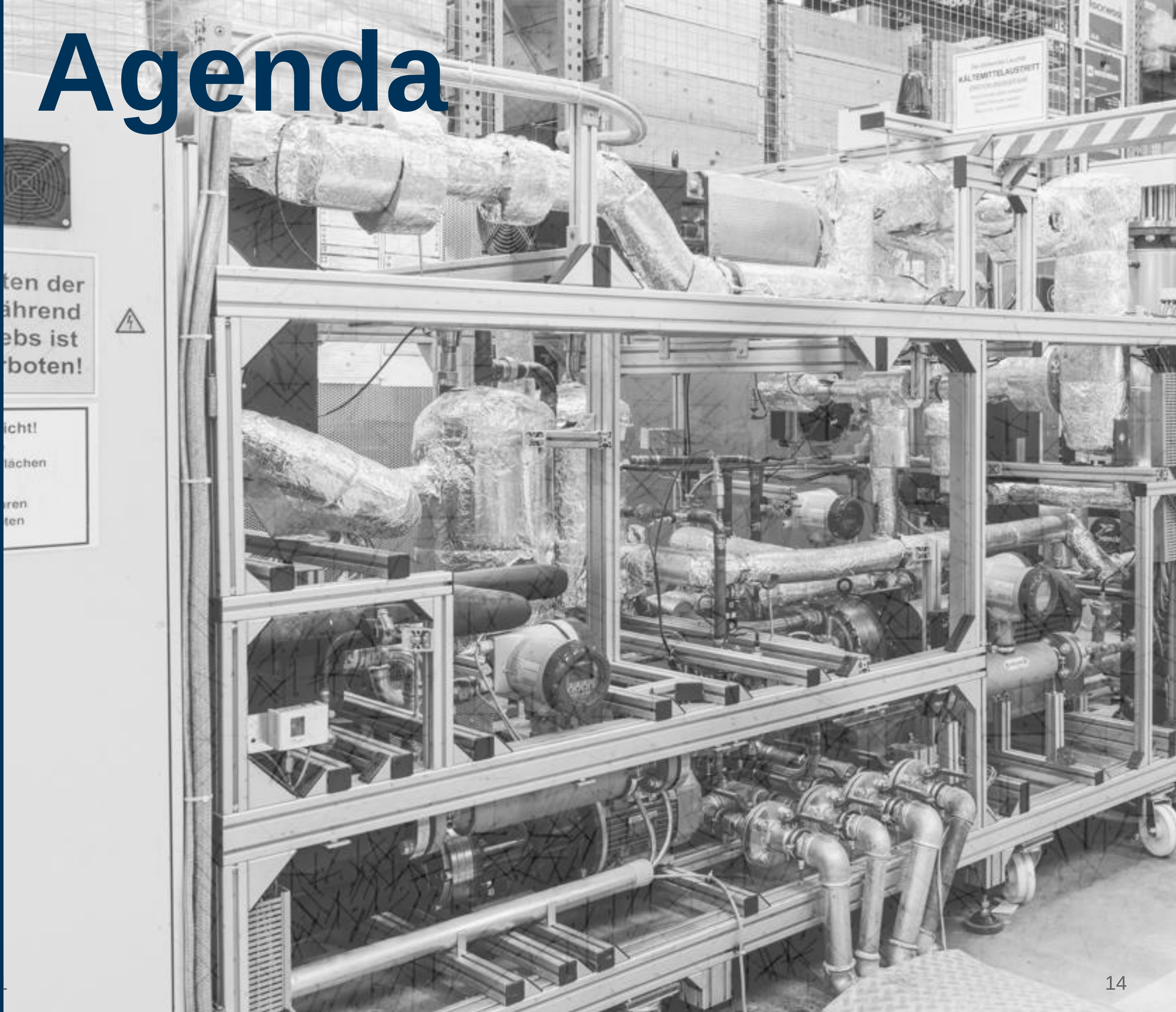
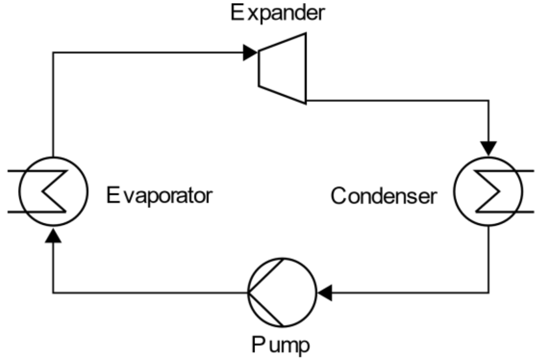
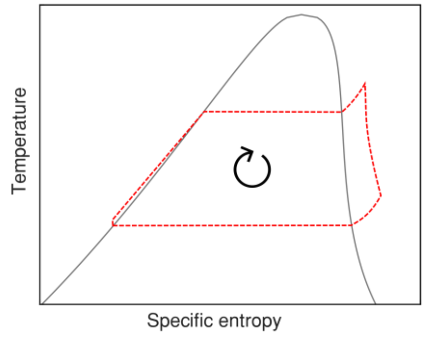


Reversible heat pumps – The idea

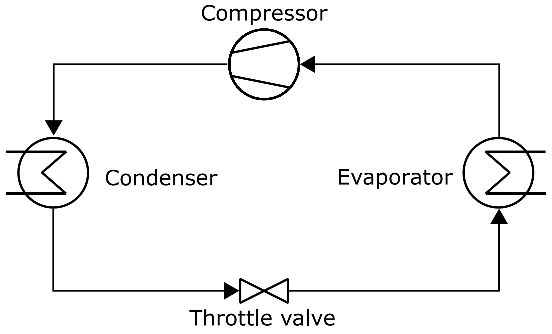
Combination of a heat engine (ORC) and a heat pump (HTHP) in one plant, using similarities of the required components:

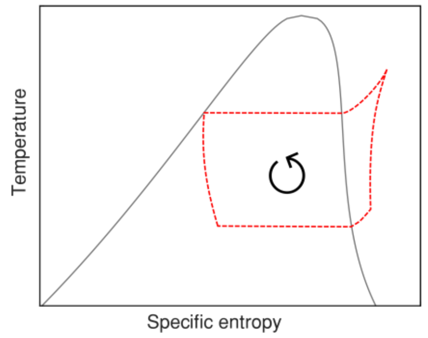
ORC:

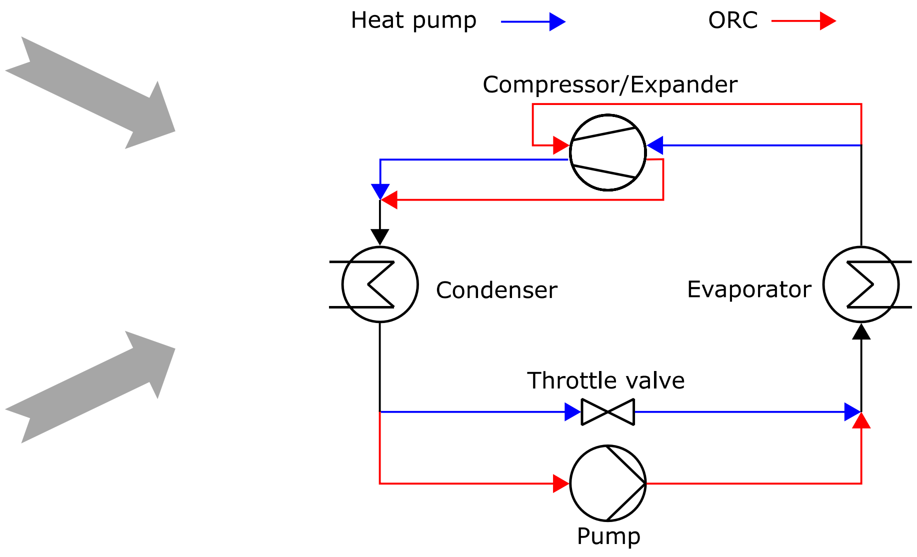




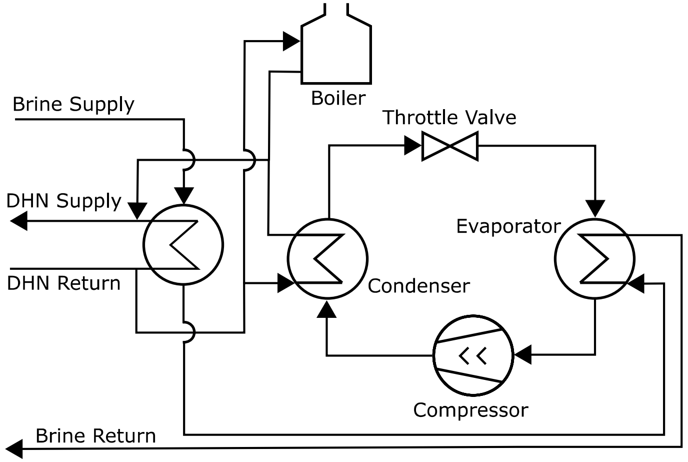
HTHP:



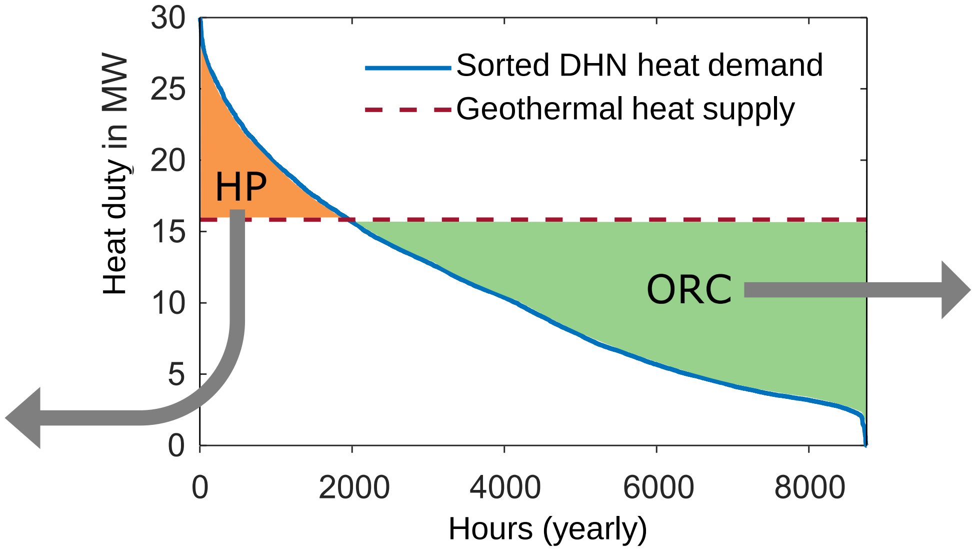


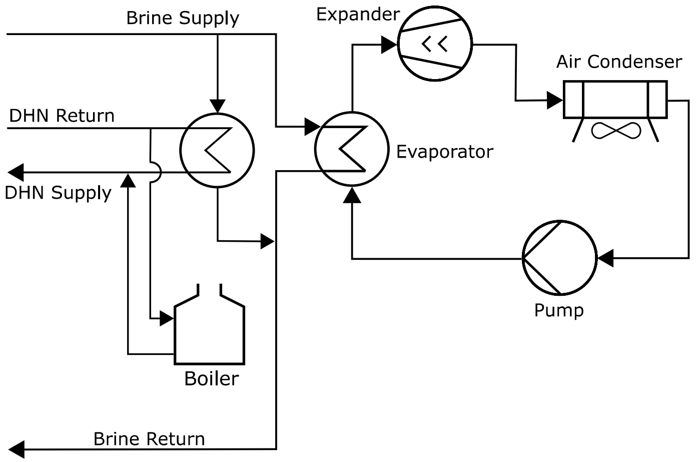


Reversible heat pumps – Geothermal application



Plant configuration of a geothermal CHP in HTHP operation





Plant configuration of a geothermal CHP in ORC operation

Broad potential operating range

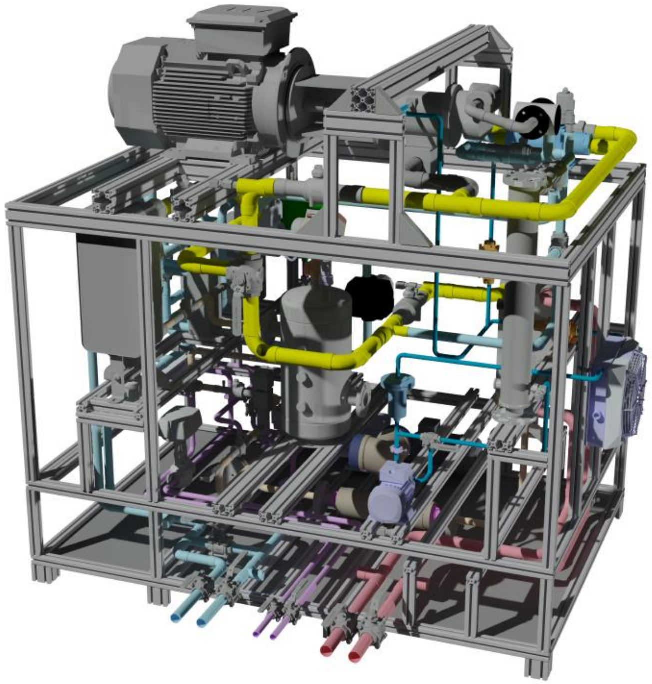
- ➢ Strong mass flow variations
- ➢ Variable *p*- and *T*-levels
- ➢ Complex configuration

Construction of a reversible heat pump test rig to

- **prove feasibility,**
- **improve thermodynamic efficiency and**
- **economic viability**

Recent research at the TUM chair of energy systems

- ❑ Reversible HP connected to a 200 kW_{th} heating circuit
- ❑ Modified reversible twin-screw compressor
- ❑ Flexible operation as ORC or HTHP



Research questions addressed:

I. Design and construction of a fully reversible HTHP
   - Cost efficient design using as many components as possible reversibly
   - Design for a wide operational range aiming for good part-load performance

II. Demonstration of both operation modes
   - Electricity production from exccess geothermal brine (ORC)
   - Additional heat supply to a DHN in times of high demand (HTHP)

III. Thermo-economic evaluation of rev. HPs
   - Yearly simulations based on real plant & weather data
   - Analysis of new plants and retrofit plants
   - Sensitivity analysis on energy prices

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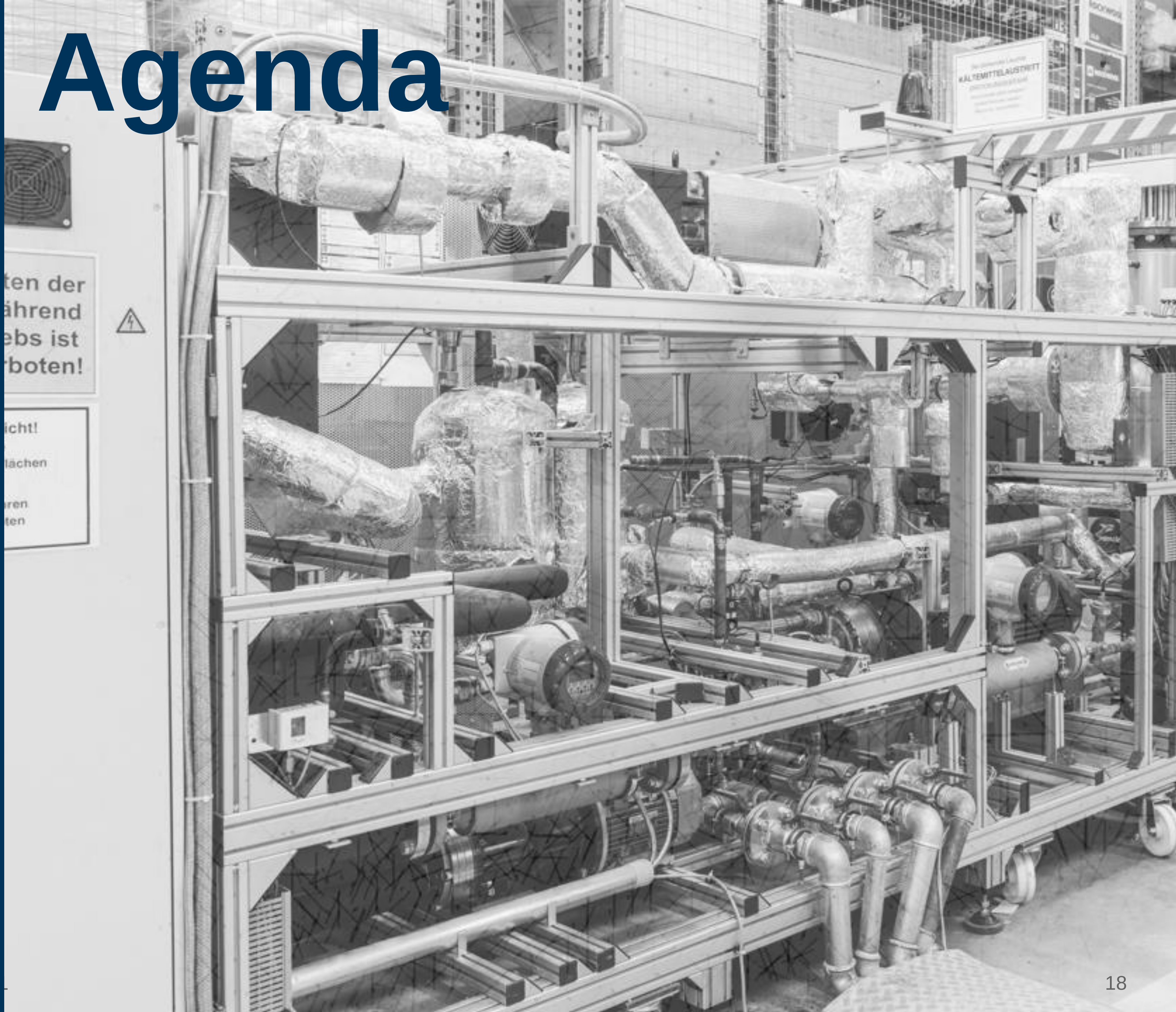

Summary / Key take-aways

Highlights

01 Heat pumps can enhance the utilization of low-temperature heat sources using electricity

02 HTHPs can supply additional heat to avoid fossil support firing in district heating plants

03 HTHPs can increase the DHN supply temperature for low heat source temperatures

04 Increasing number of commercial HTHPs available from the kW to the MW range

05 Achievable COP depends on temperature lift, with up to 60% of the ideal COP achieved in commercial plants

06 First economically viable projects are realized with multi stage HTHPs

07 Reversible HTHPs could significantly increase plant utilization and reduce carbon emission in future geothermal CHP

(Reversible) High Temperature Heat Pumps as a Cornerstone for Future Geothermal Heat Supply

Thank you for your attention!

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References

- Arpagaus, C. et al.: High temperature heat pumps: Market overview, state of the art, research status, refrigerants, and application potentials. Energy, 152, (2018), 985-1010.
- Arpagaus, C.: Hochtemperatur-Wärmepumpen - Marktübersicht, Stand der Technik und Anwendungspotenziale. VDE Verlag (2019).
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