DLR Institute of Low-Carbon Industrial Processes

NEXT GENERATION HIGH TEMPERATURE HEAT PUMPS

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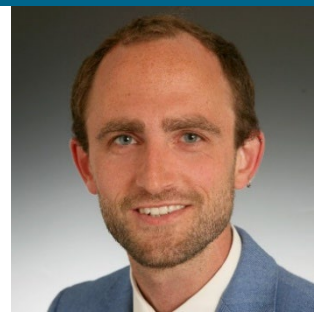
Institute for low carbon industrial processes
Department of high temperature heat pumps

DLR

The presented work is a result of collaboration with…

Johannes Oehler



Phong Tran

Matteo Pettinari

Lorenzo Ferrari

DLR 2023

Research Organisation
8.350 employees

Project Management Agency
1.400 employees

Space Administration
250 employees

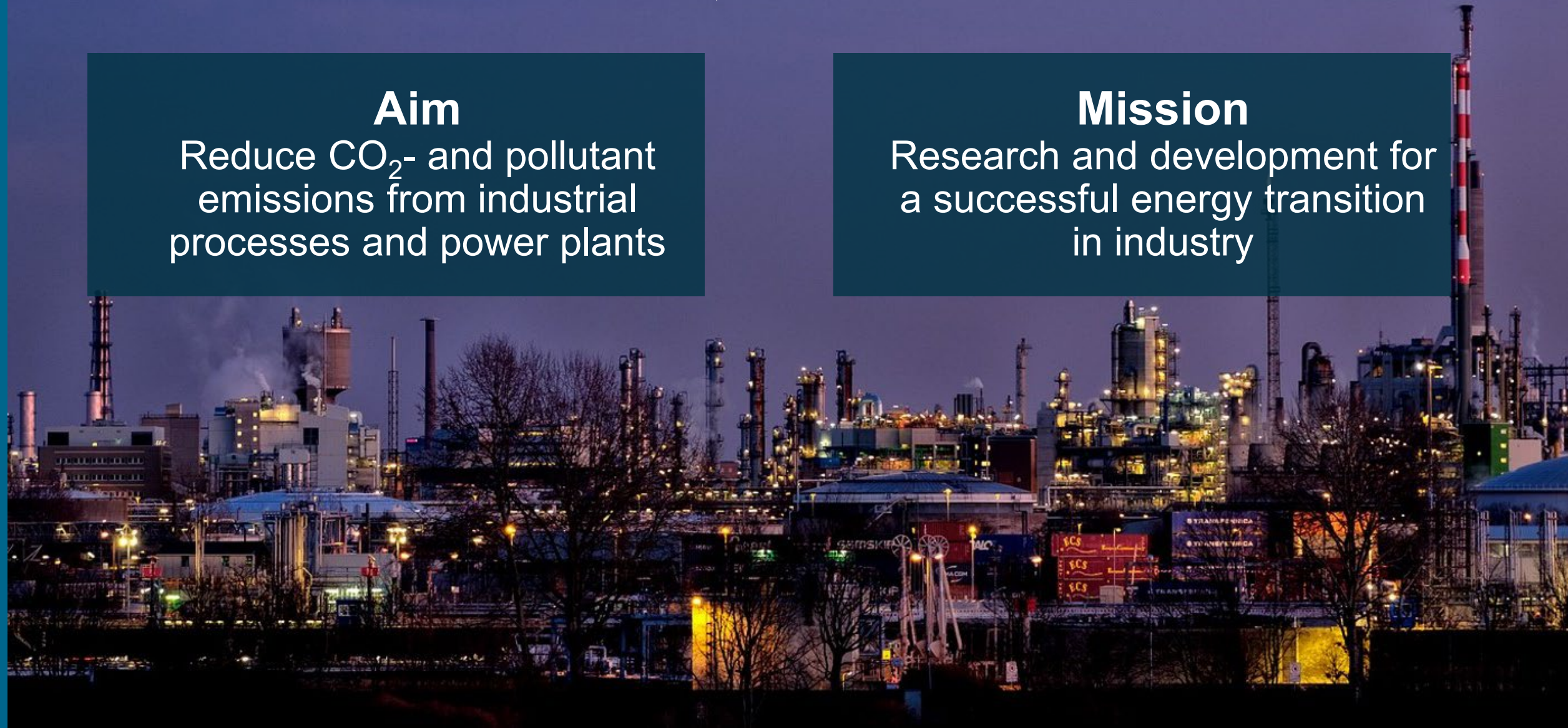
- 10.000 Total number of employees
- 35 Locations nationwide with 55 institutes and facilities
- 4 international offices
- Turnover 2020 Research facilities: approx 1,2 Mrd. €

Aim

Reduce CO_2- and pollutant emissions from industrial processes and power plants

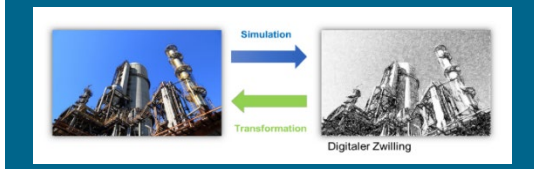
Mission

Research and development for a successful energy transition in industry

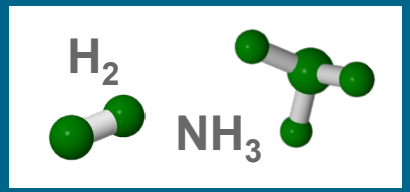


DLR-Institute of Low-Carbon Industrial Processes

High-Temperature Heat Pumps



Simulation and Virtual Design



Low Carbon Reducing Agents

University Library Cottbus

City Center Zittau

From the Pilot to the Demonstration

Pilot Plant CoBra (Cottbus **Bra**yton)

- Working fluid: Air
- Axial (and radial) turbomachines
- Electric Power : ca.120 kW
- Heat: ca. 180kW @ 250-300°C
- Cooling: ca. 60kW @ -40,-70°C

Next generations of HTHPs

- Compact HTWP
- Electric Power : ca.1 MW
- Heat: ca. 1.5-2MW @ 250-300°C
- Waste heat sources between 60-100°C

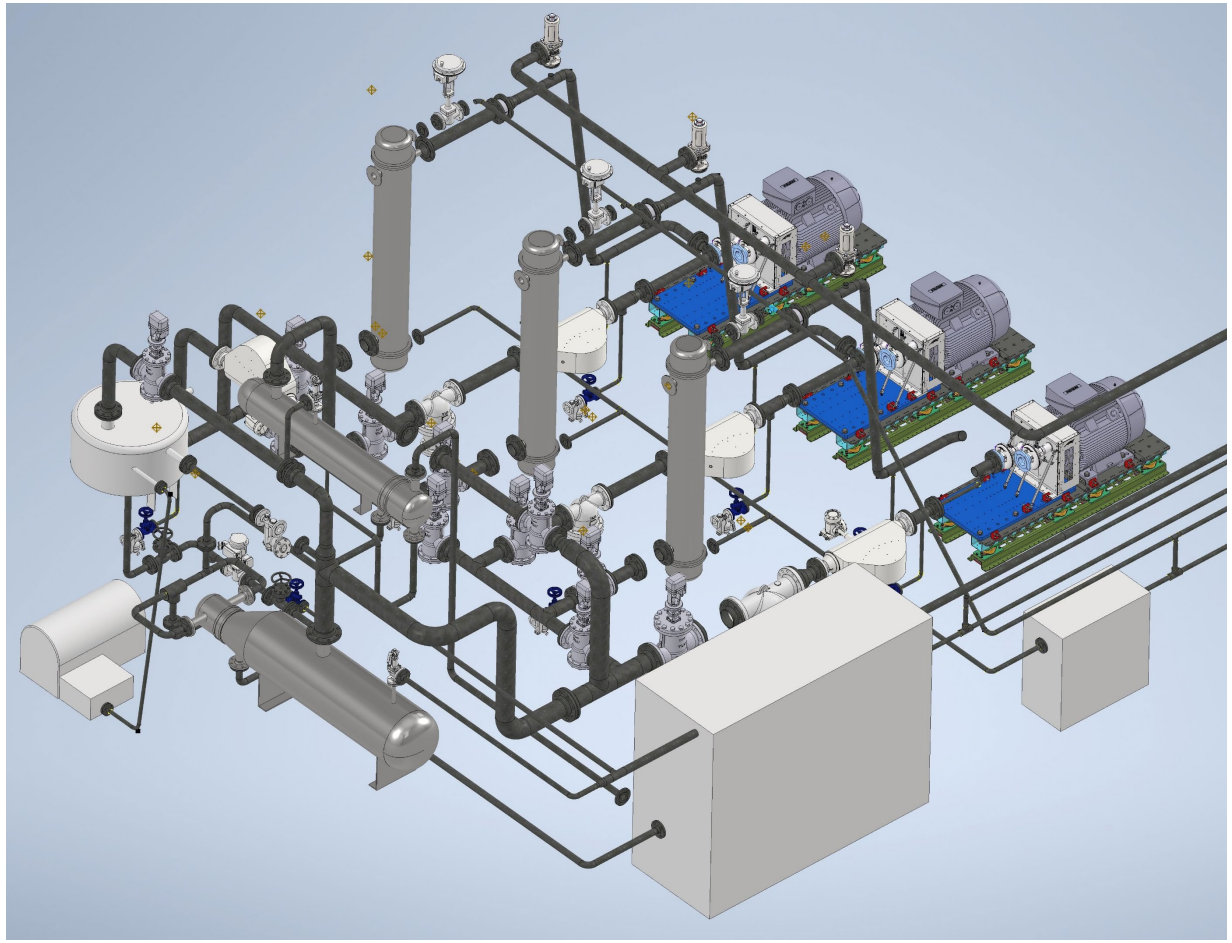
From the Pilot to the Demonstration

Pilot Plant ZiRa (Zittau Rankine)

- Working fluid: Water-Steam
- Radial turbomachines
- Electric Power: ~ 240kW
- Heat: ~750 kW @~ 180-200 °C
- Heat source ~95-120°C

Next steps

- Steam compressor development and scale up (up to 600kW per stage)
- Raise sink Temperature to 250 °C - 40 bar



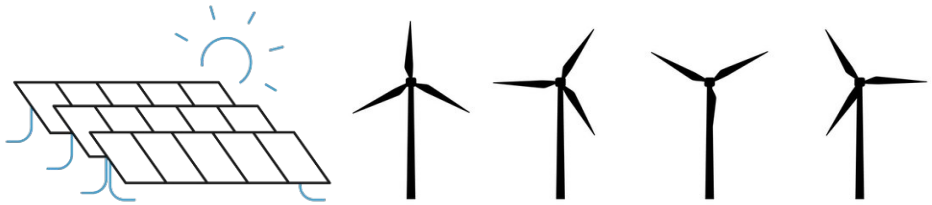
The scale of the challenge in Germany

In year 2020 the energy consumption for industrial heat in DE is estimated at 490TWh

Source:

Approximately 160TWh of this heat is consumed at temperatures below 300°C and can be potentially electrified with heat pumps

Source:

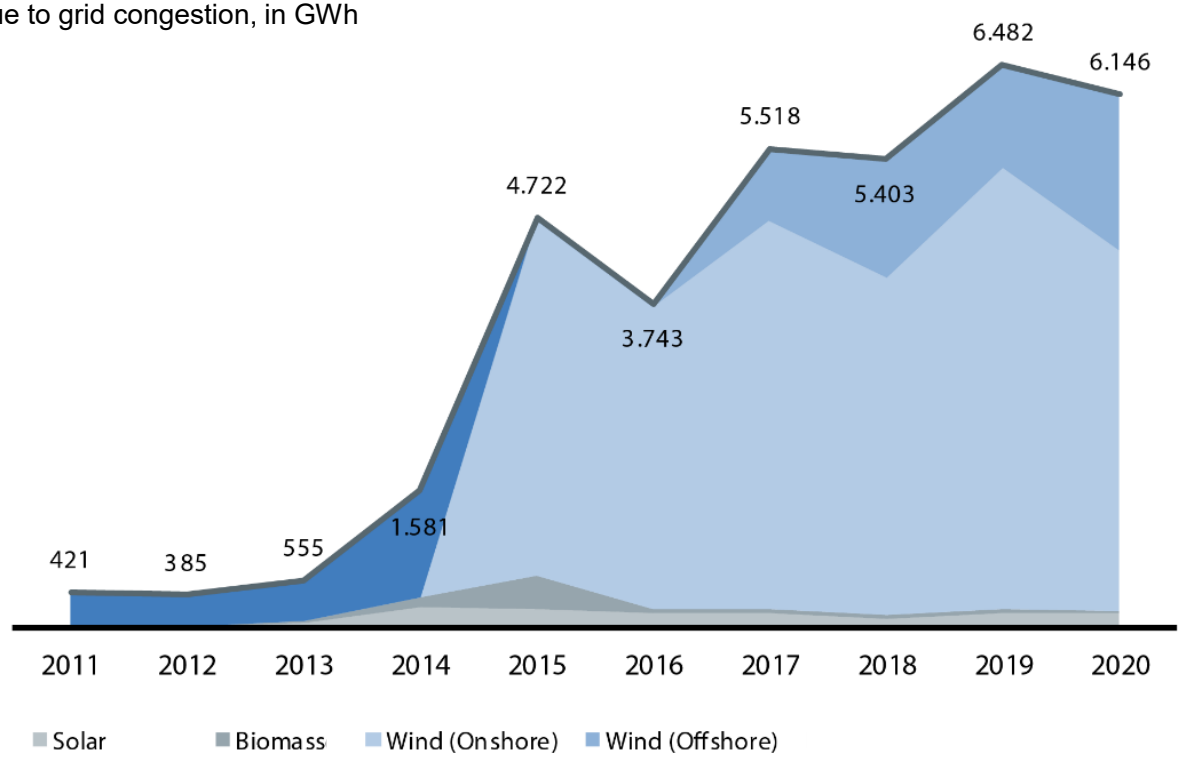


This will result in an additional renewable generation of 80-120 TWh. An increase of ~50% compared to renewable generation in 2020

Source:

What does the grid say about this?

Curtailment of renewable energy in Germany
due to grid congestion, in GWh



Source:

The Grid story

- Germany curtails every year around 6 TWh of renewable electricity
- The cost of this lost energy is around 1 billion € per year
- Industrial sites are often located at crucial grid points

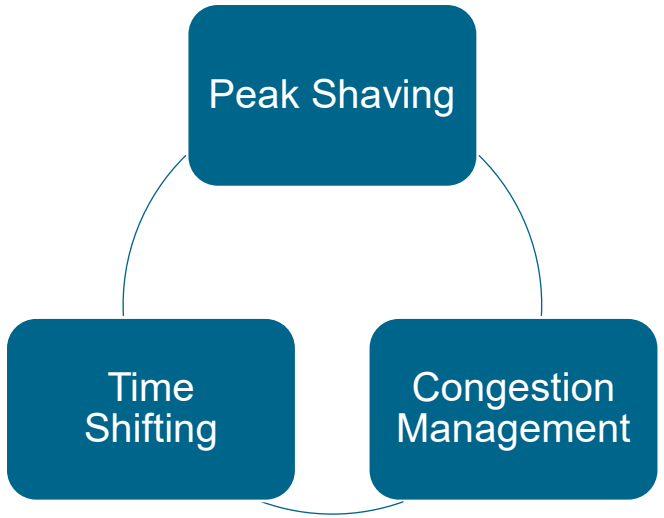
What can flexible industrial heat pumps contribute?

Flex HTHP

Industrial demand side management

Connection to renewable heat sources

Connection to renewable power sources



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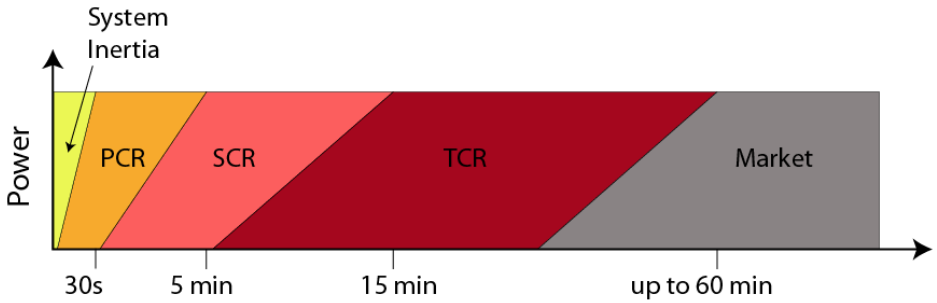

Source.

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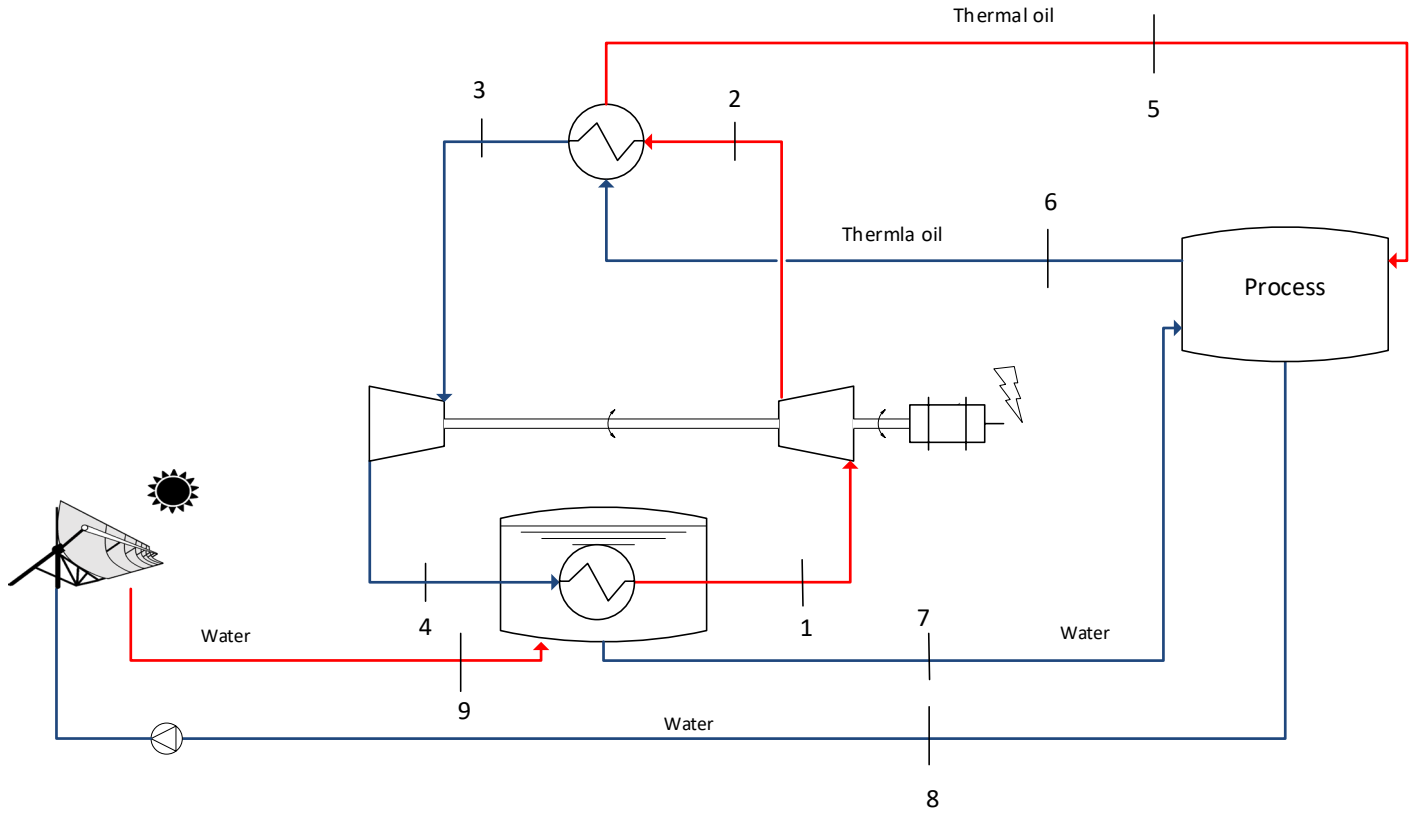
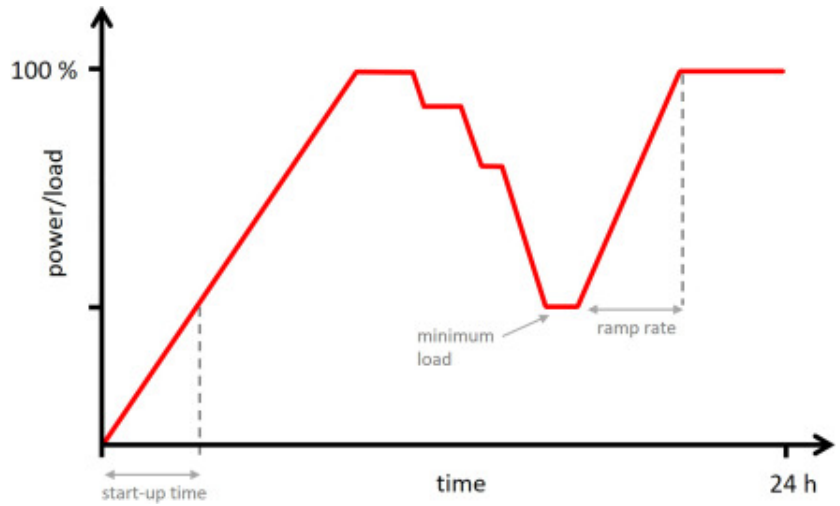


HTHP operational flexibility – two aspects

Part load capability

How can we extend the operational envelope in a simple and cost effective way?



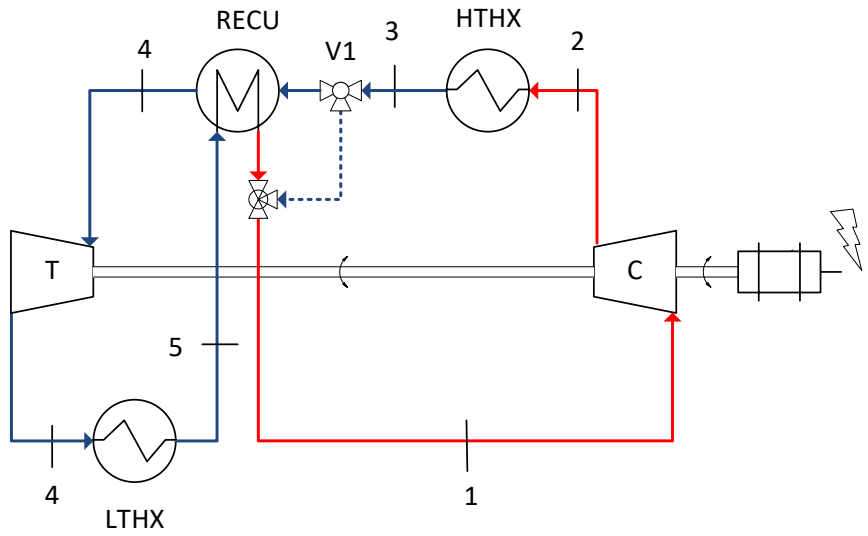
Dynamic operation

Adapt to intraday changes in production processes

Deliver network services like primary and secondary control reserve.

Facilitate direct hybridization with renewable heat and power sources?

Part load capability – classical approach

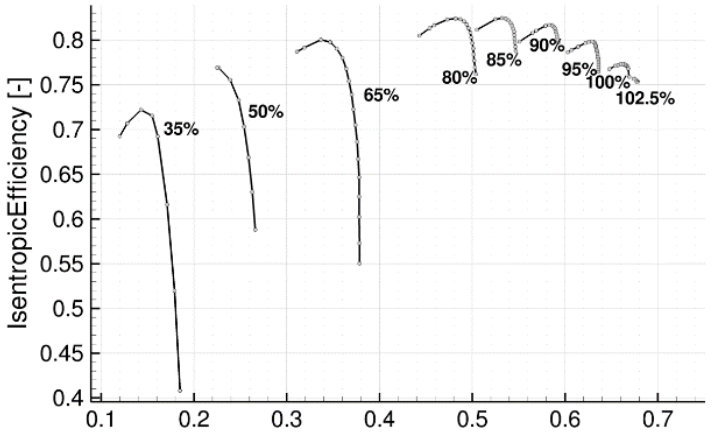


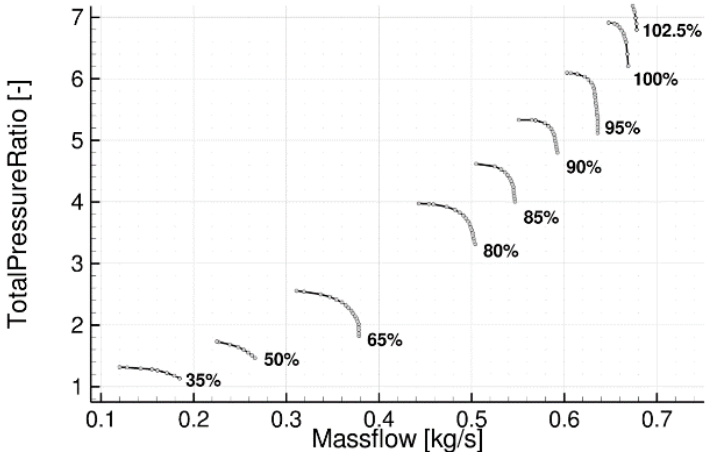
Control options/tools

- Compressor rotational speed
- Degree of recuperation
- Variable vanes in turbomachines

Constraints

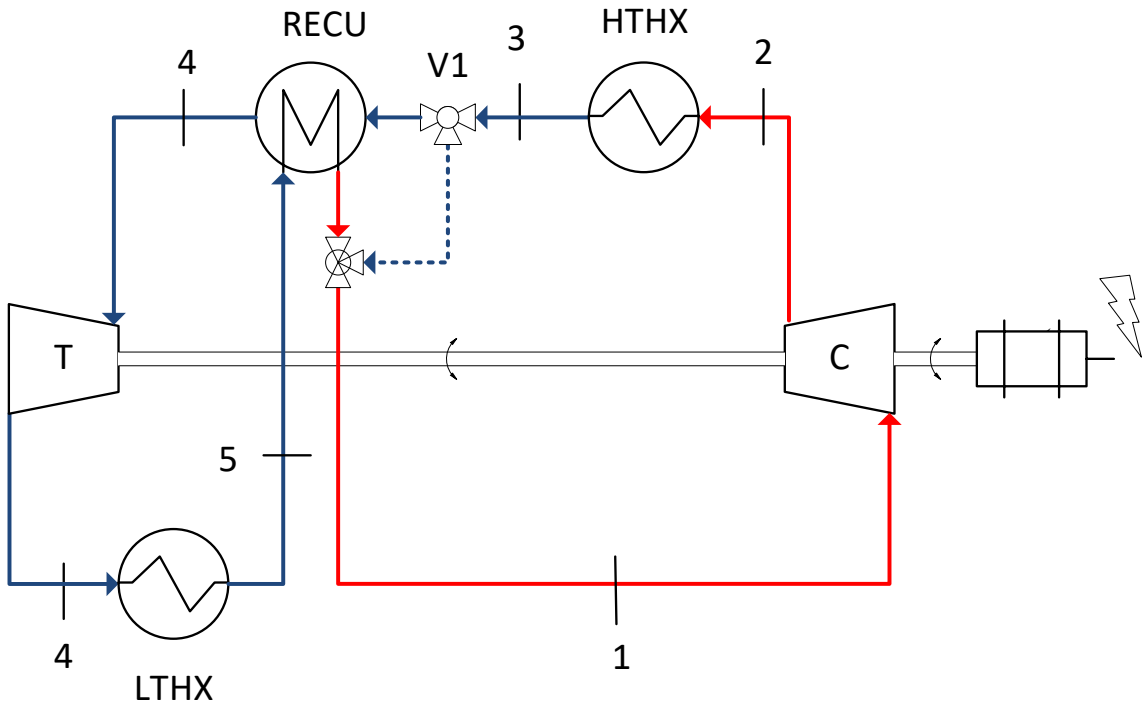
- Compressor stability limits
- Maximum compressor speed
- Maximum compressor T_{in}
- Load limits – secondary circuit

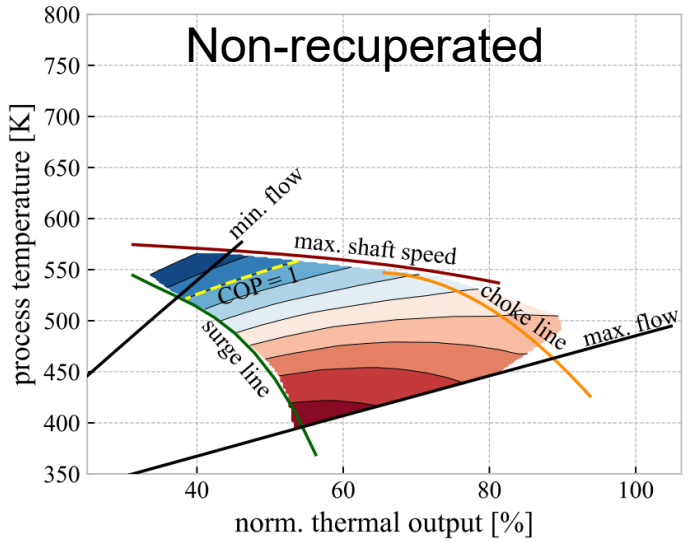


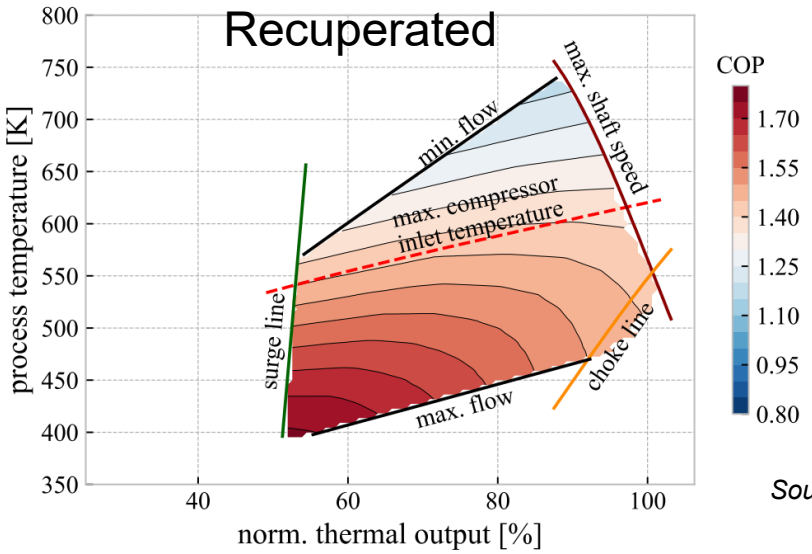


Source: Compressor manufacturer – AeroDesignWorks

Part load capability – classical approach







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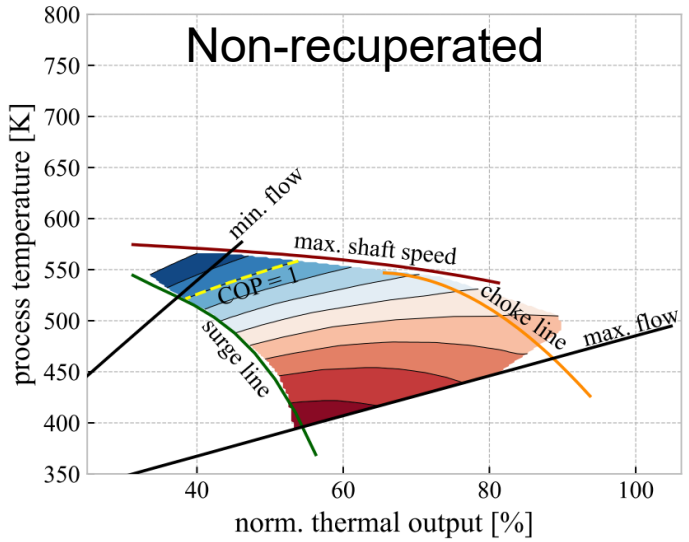
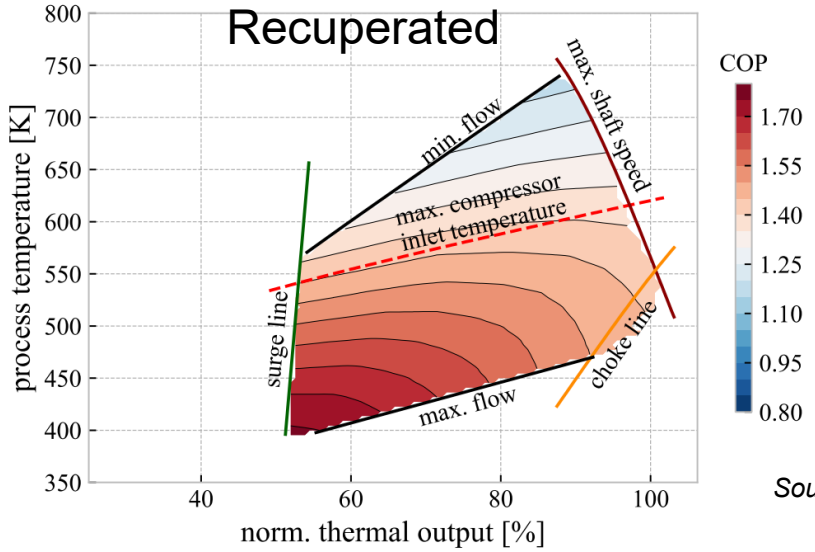


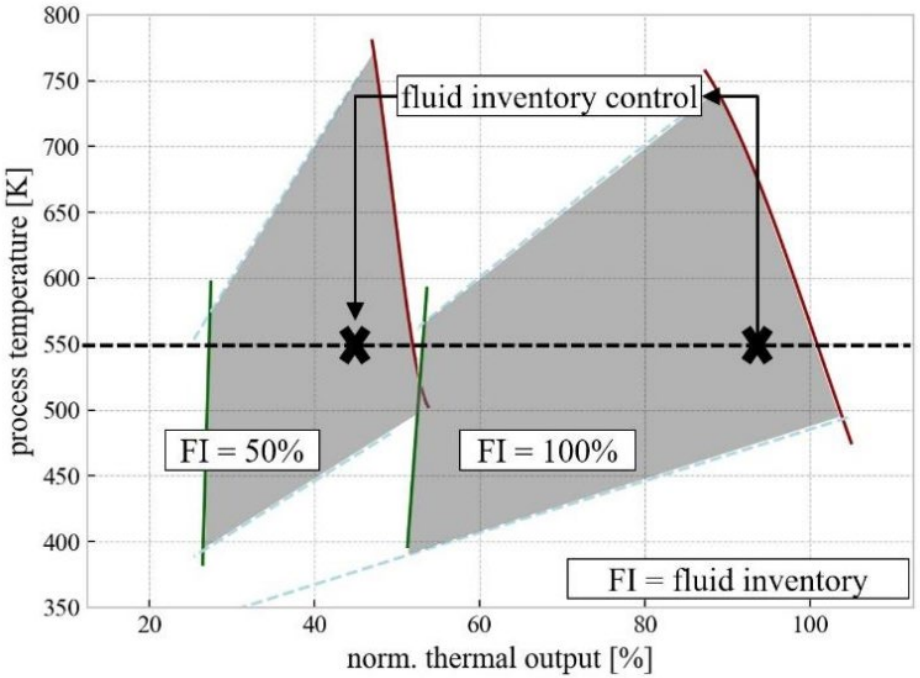
Shortcomings

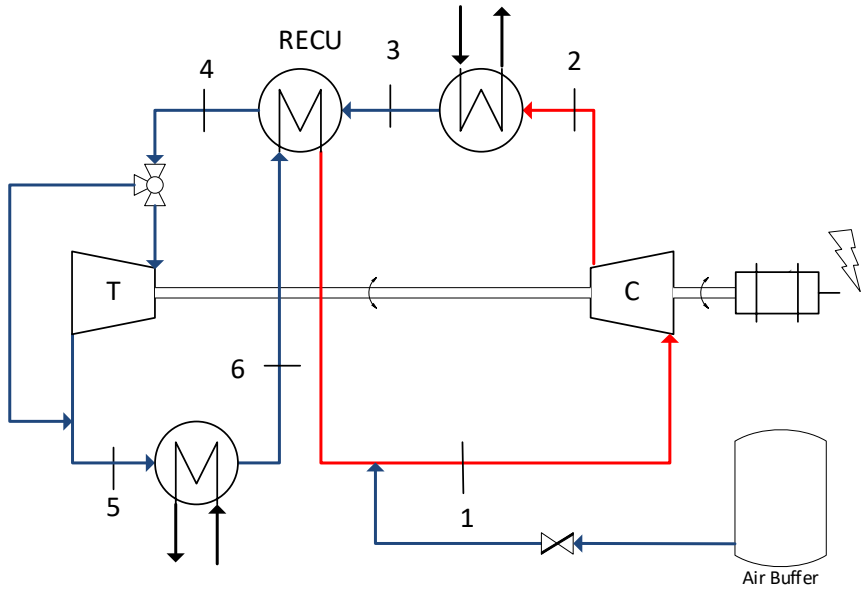
- **Limited Part load capability – 50-55%**
  Strong variation of demand will require the installation of more than one unit to cover it
- **Heating capacity, COP and delivery temperature are interconnected**



Source:

Part load capability – fluid inventory control





Control Variables

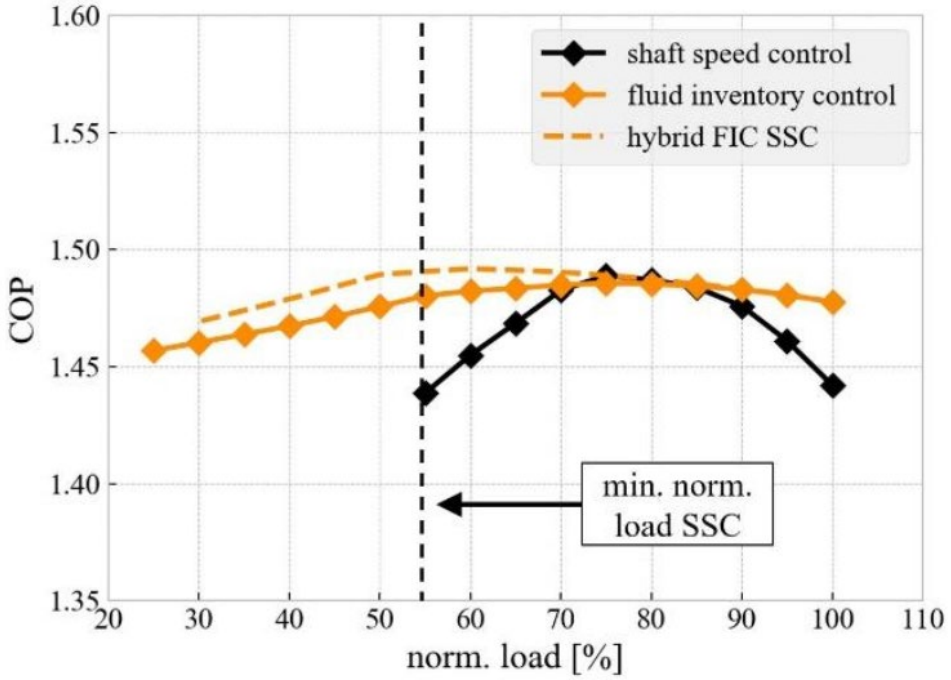
- Mass of fluid in the closed cycle – Fluid inventory

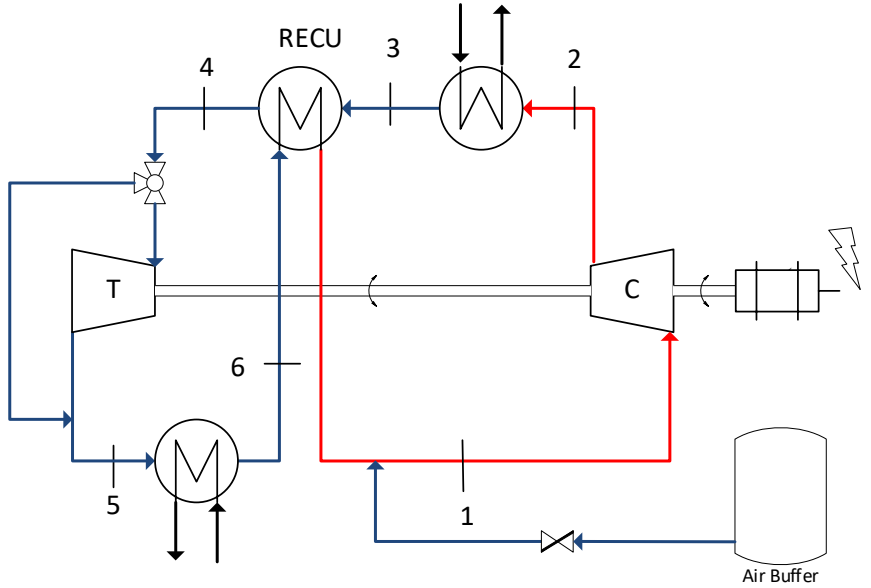
Constraints

- Lower bound of compressor operation – inlet density and pressure

Source:

Part load capability – fluid inventory control





Challenges

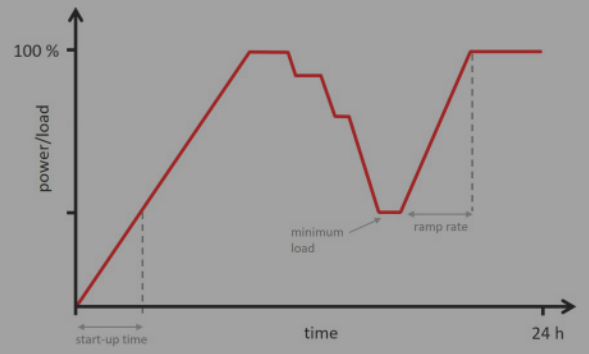
- Optimal fluid injection and extraction points
- Transient requirements and stability issues
- Combine part load methods for optimum operation

Source:

HTHP operational flexibility – two aspects

Part load capability

How can we extend the operational envelope in a simple and cost effective way?



Dynamic operation

Adapt to intraday changes in production processes

Deliver network services like primary and secondary control reserve

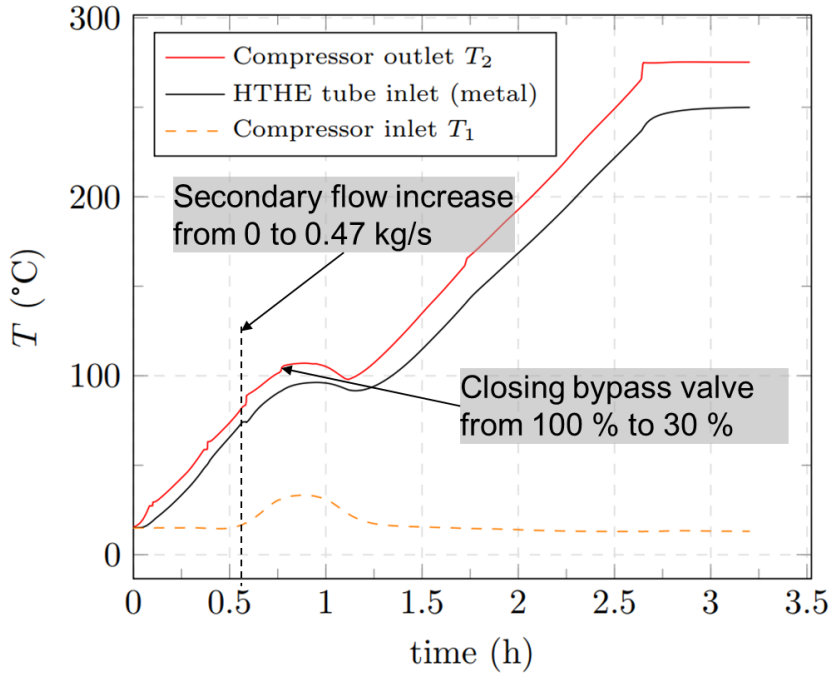
Facilitate direct hybridization with renewable heat and power sources

Dynamic operation – Physical constraints

Constraints

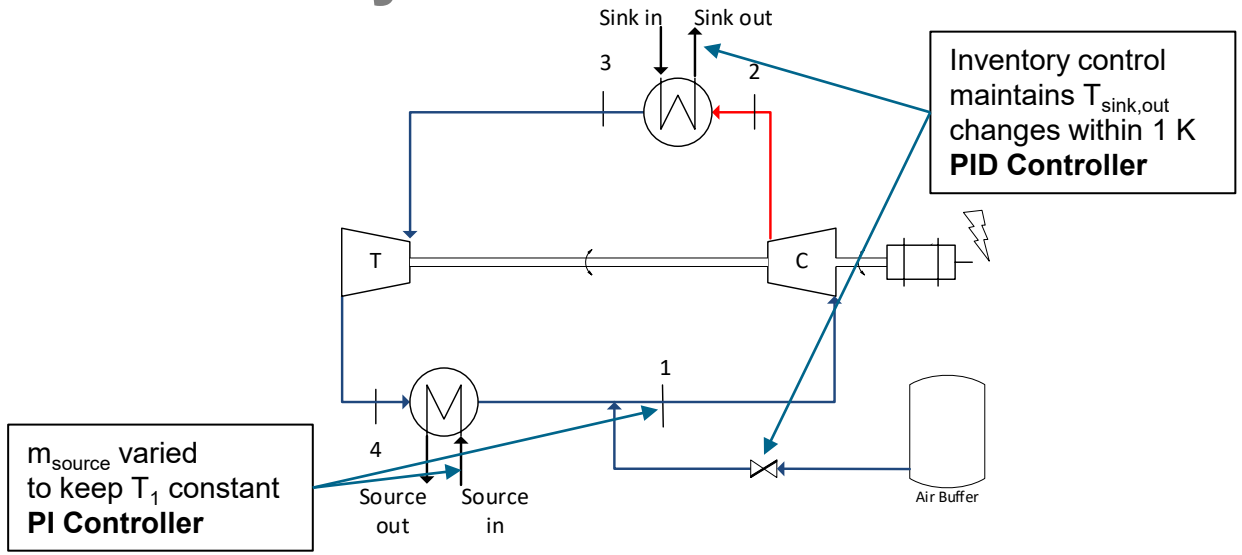
- Physical limitations and dimensions
- Eigenmodes to be crossed as fast as possible
- Temperature gradient limitations
- Limit step changes in temperature and pressure
- Compressor stability – Maintain surge margin

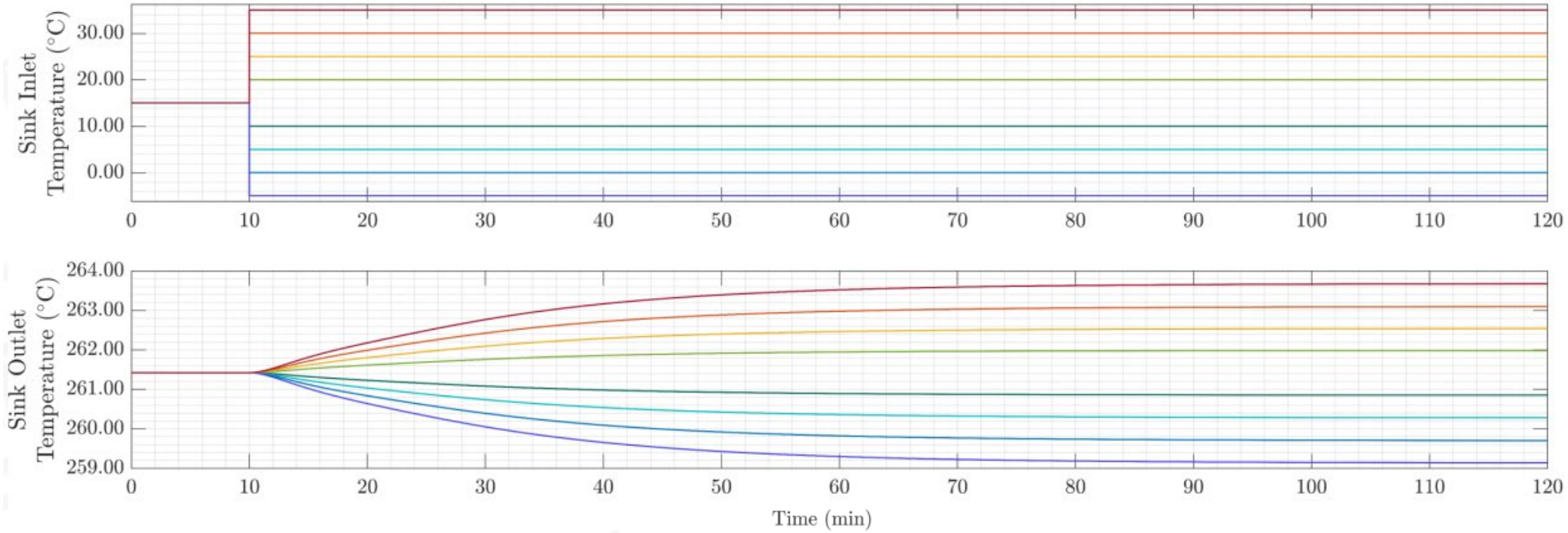
Source:



Dynamic operation – Fluid inventory control reloaded

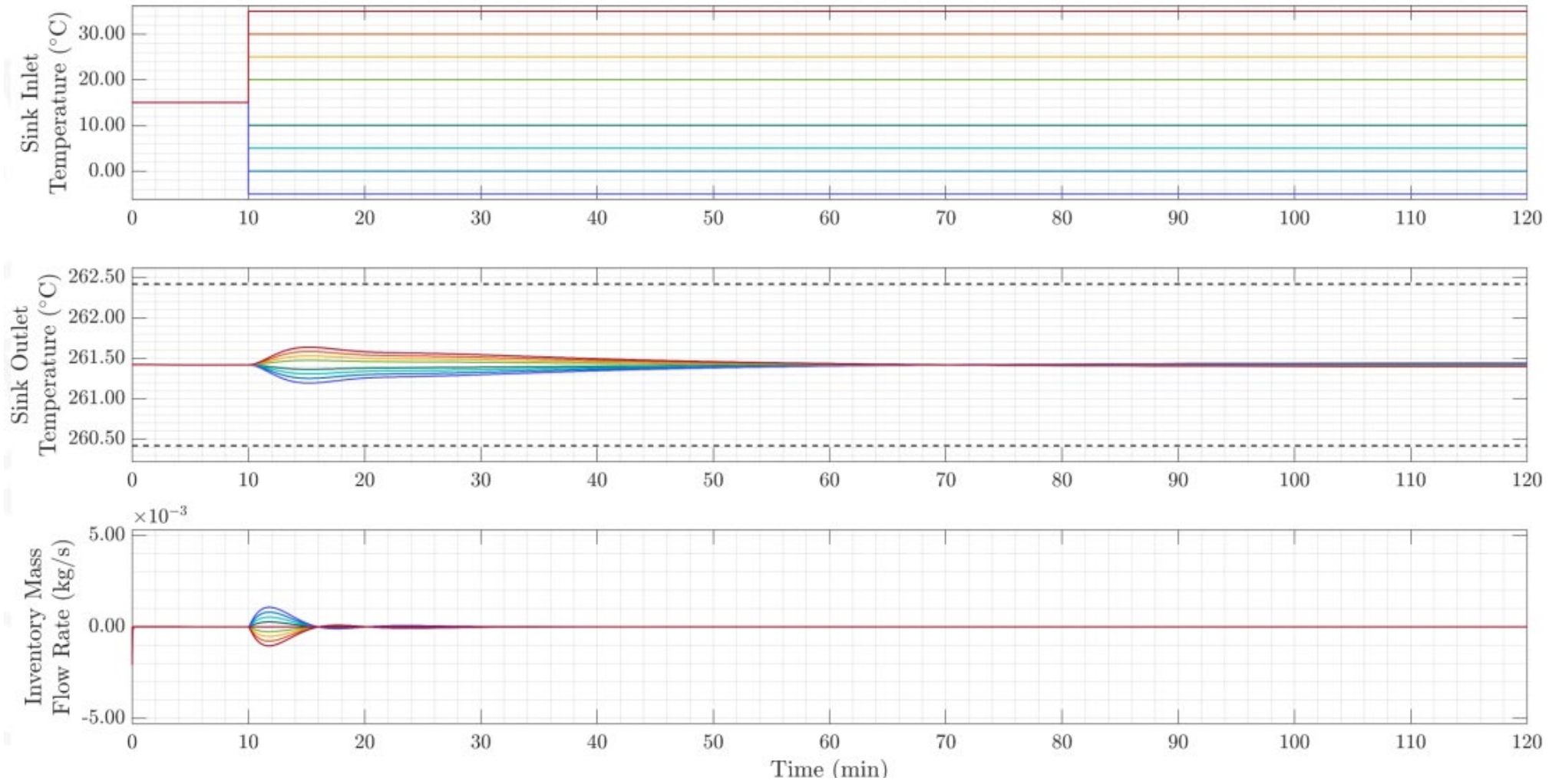
- Step change in sink inlet temperature/mass flow rate
- Natural response of system
- Is it possible to make this faster, despite the specified dimensions?





Dynamic operation – Fluid Inventory control reloaded

- Change in the sink inlet temperature
- Use fluid inventory control to keep the sink outlet temperature within ± 1°C



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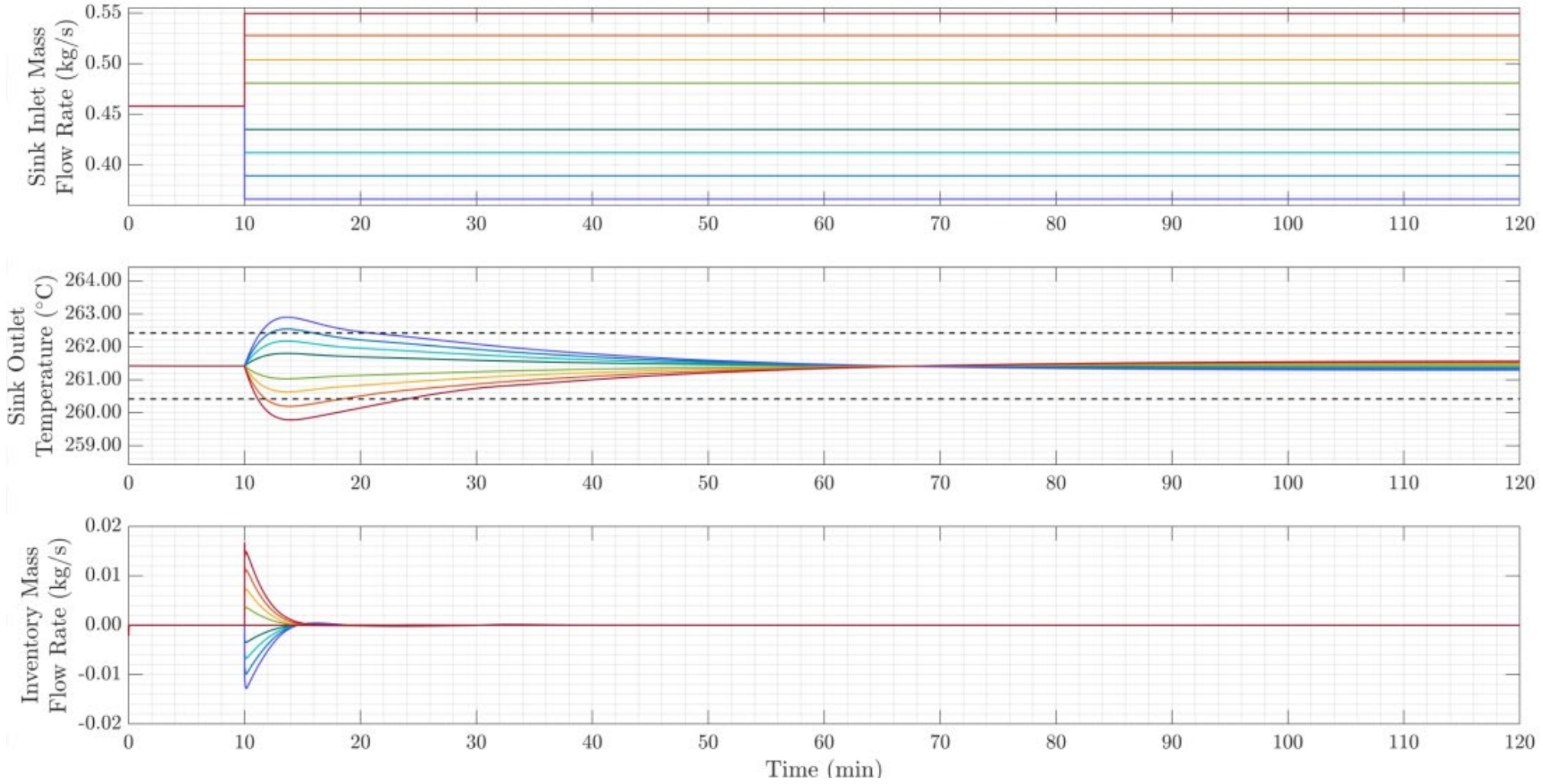
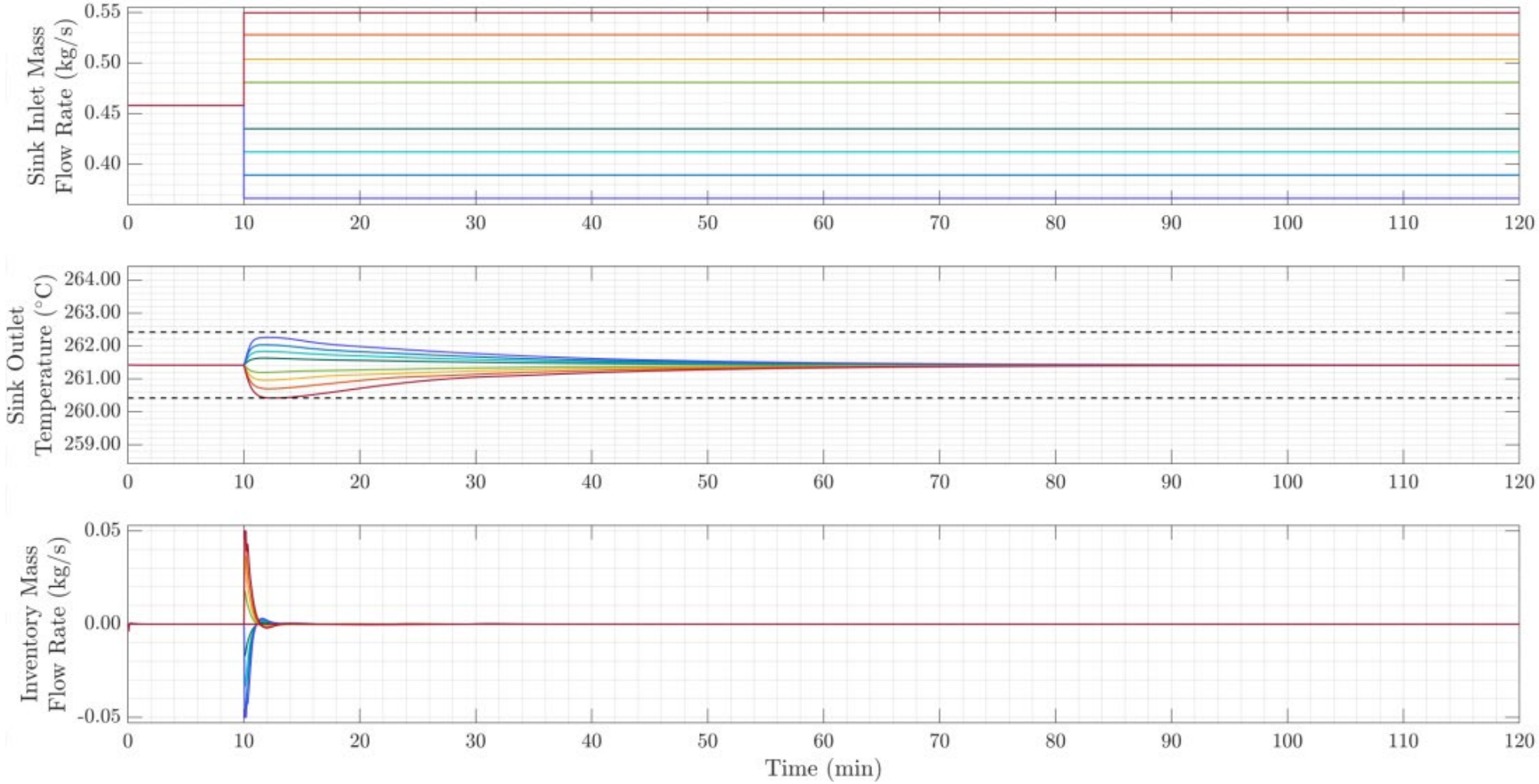


Dynamic operation – Fluid Inventory control reloaded

- Change in the sink flow rate
- Internal model controller for fluid inventory control



A flexible outlook…

…up next

Experimental demonstration of fluid inventory control

Hybrid industrial heat supply systems

Control optimization with machine learning (models and experiments)