

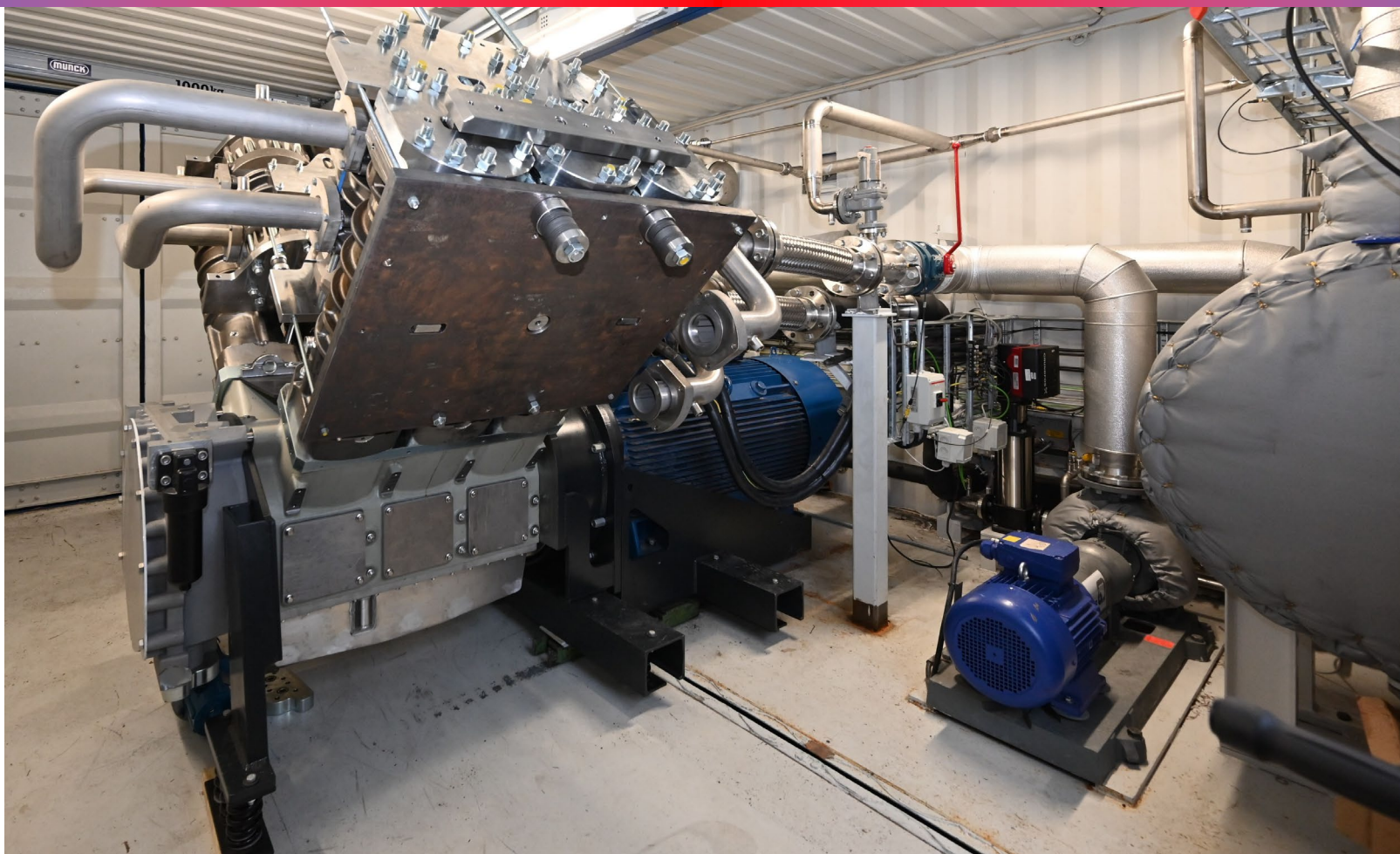
Performance of a new ultra-high temperature industrial heat pump

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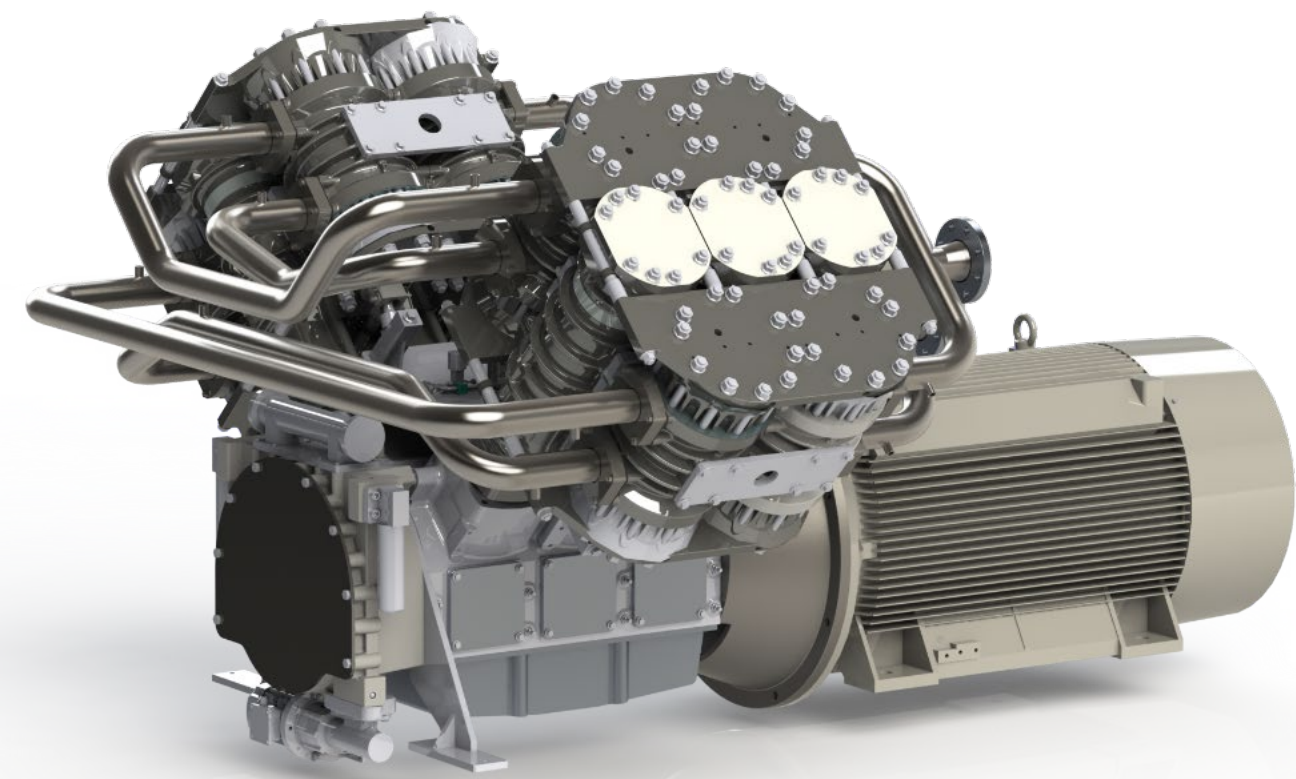
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HoegTemp at IVAR biogas facility

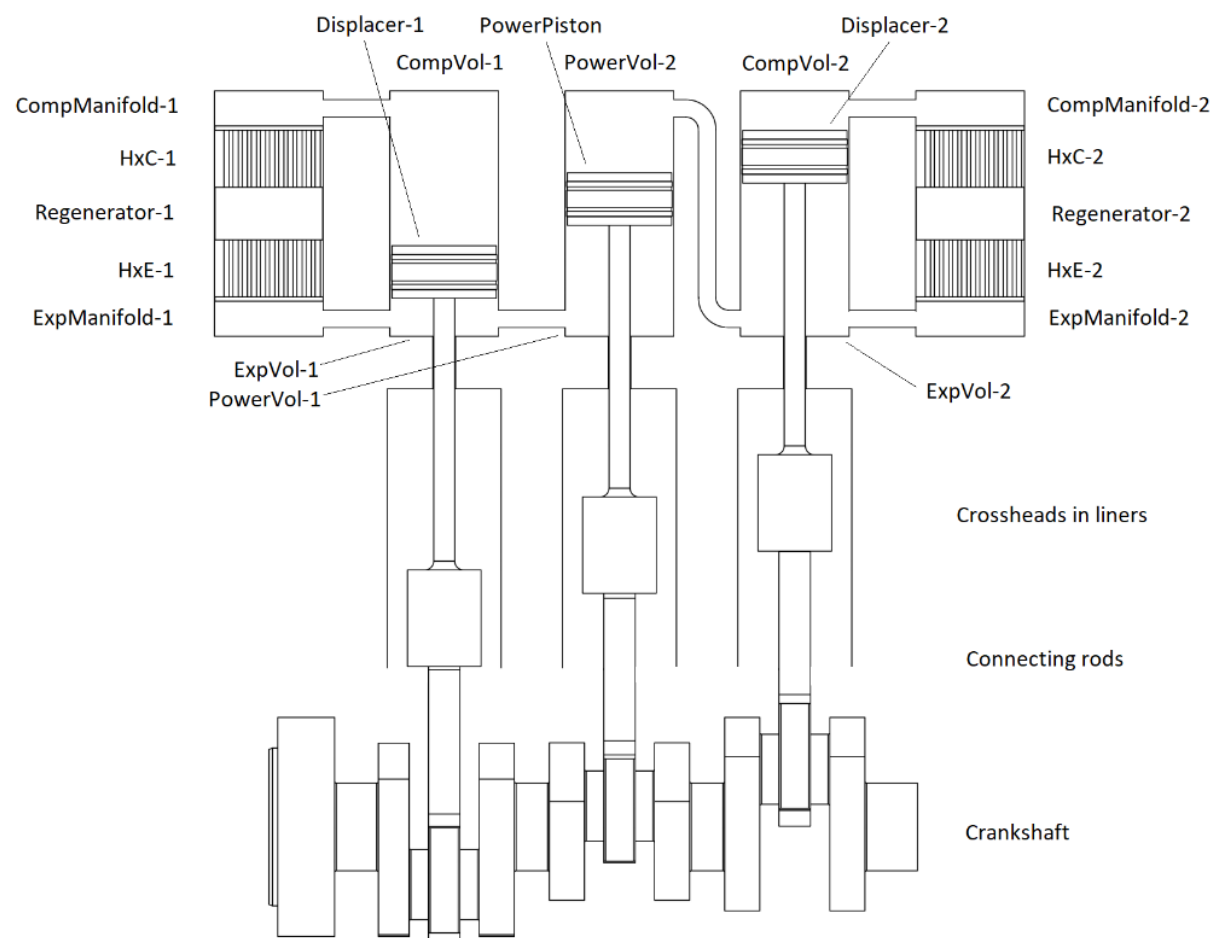




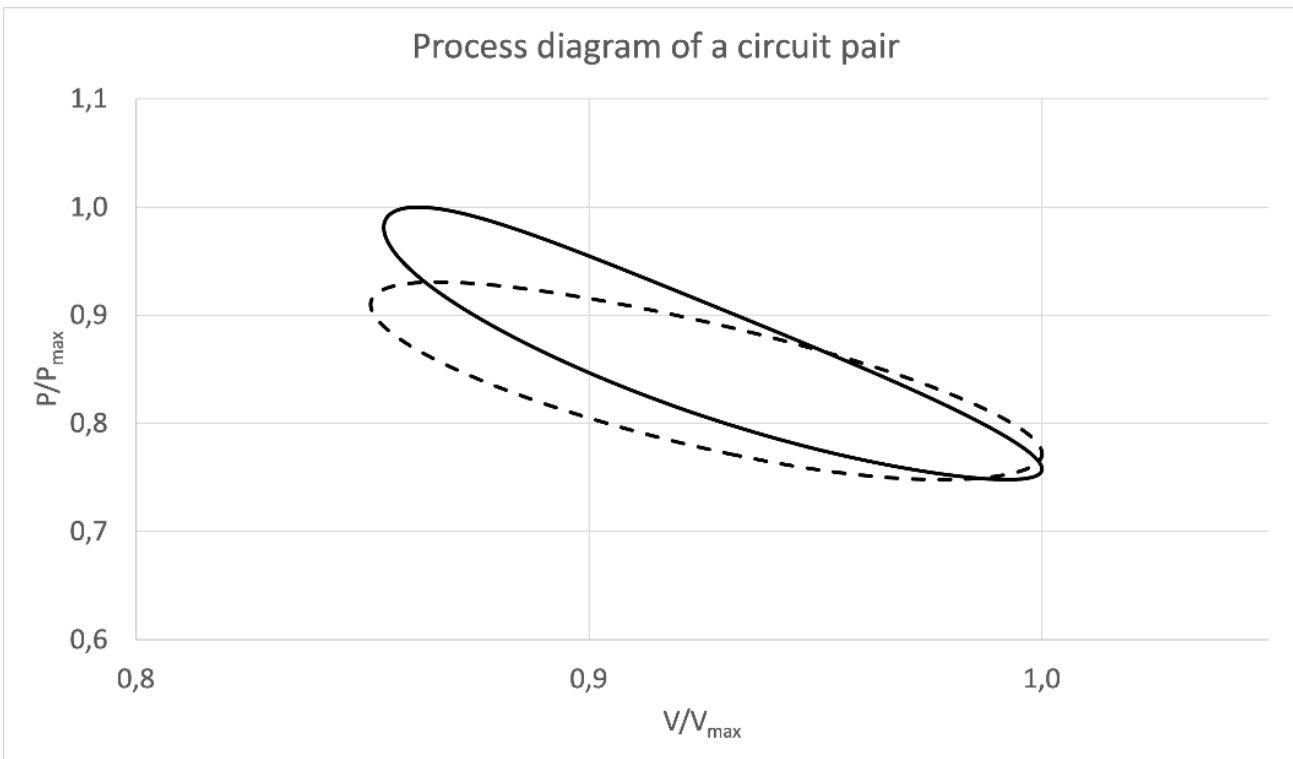
HoegTemp UHT heat pump



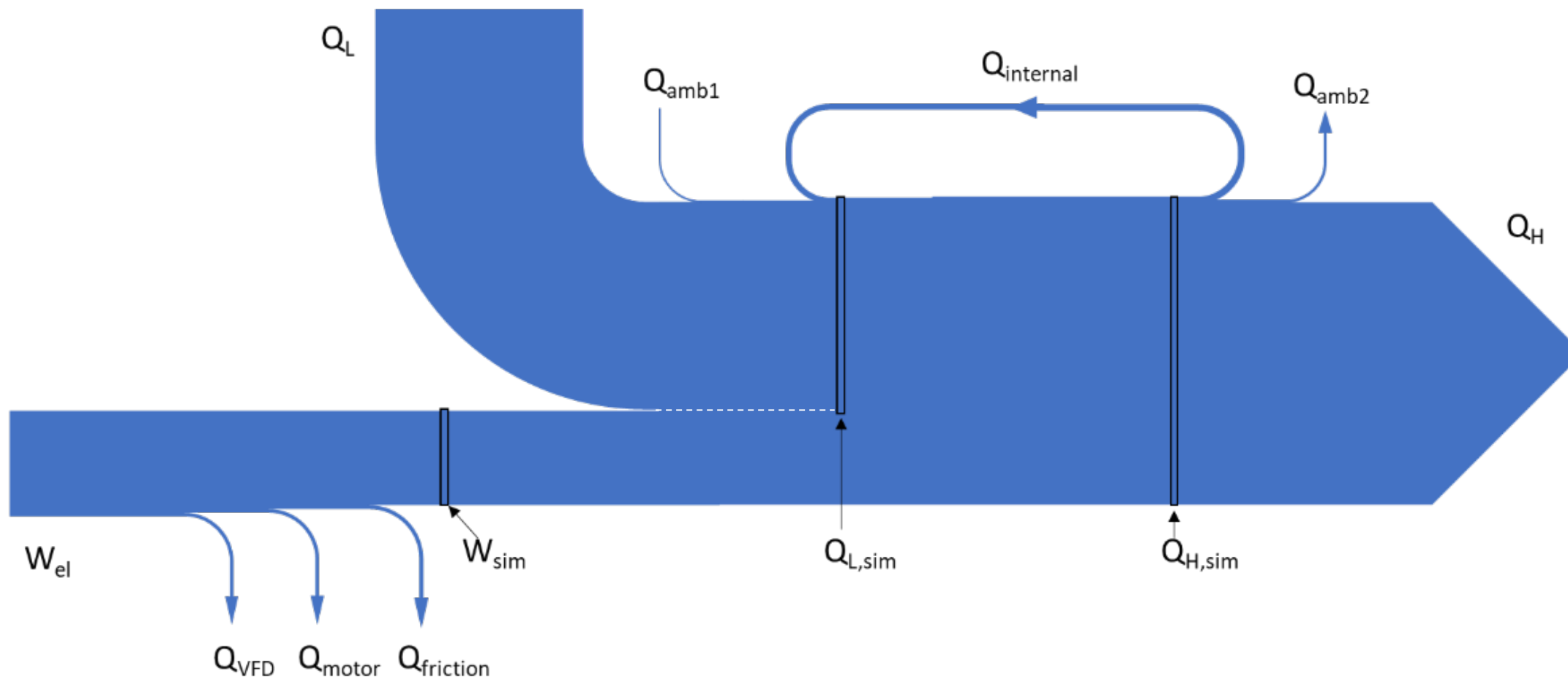
- Stirling-cycle
 - Heat pump or refrigeration cycle
 - External source and sink circuits
 - No temperature limits related to boiling points or condensing
 - Operating range -10°C to 200°C
 - Characterized by temperature ratio (K/K)
 - Fast control response
- R-704 helium
 - Inert, non-toxic, 0 ODP, 0 GWP
 - Alternative refrigerants: nitrogen and hydrogen
- Clean-sheet design based on more than 30 000 hours of operating experience



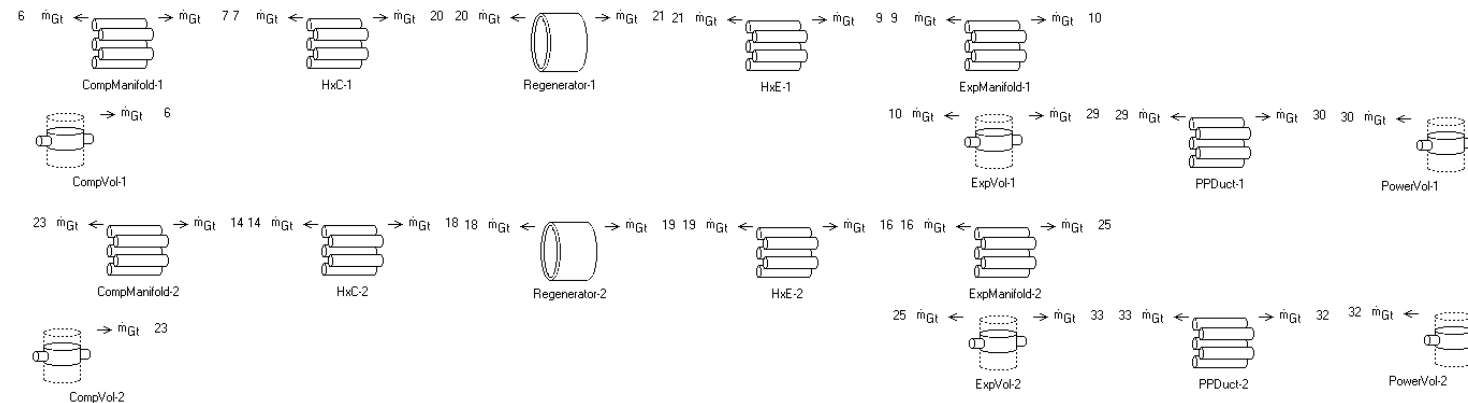
- 2 circuit pairs per cylinder bank
- Each circuit consists of:
 - Hot heat exchanger (sink)
 - Cold heat exchanger (source)
 - Regenerator (stratified storage)
 - Displacer (moves refrigerant)
 - Power piston (compression and expansion)
- Conventional double-acting lay-out
- Lubricated mechanicals
- Patented piston rod seal



- Does not look like the ideal stirling cycle:
 - Process overlap due to sinusoidal piston motion
 - No particle in the stirling machine undergo a stirling cycle
- Ideal gas – similar process at all temperatures
- Slightly different process in the circuits of each pair
- Low compression

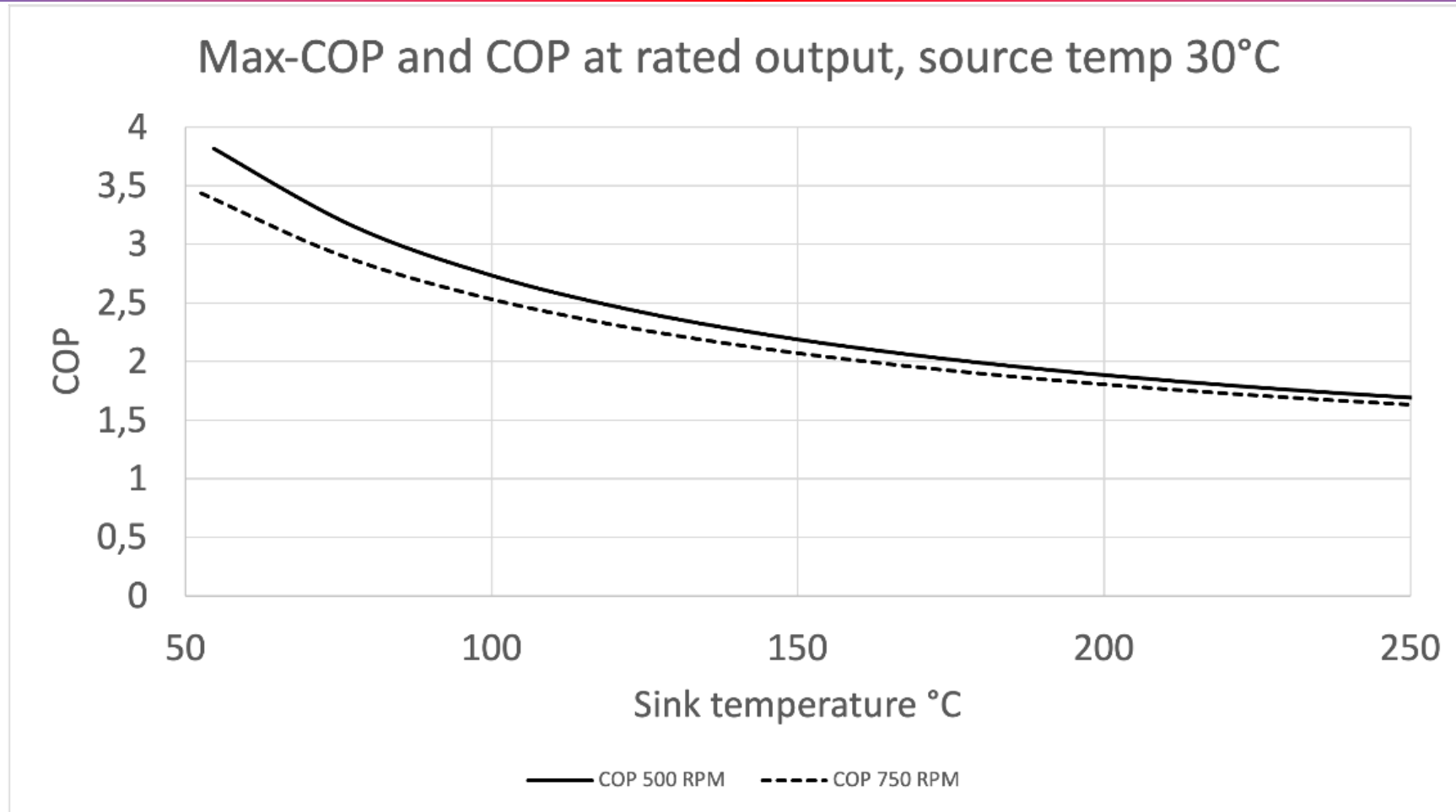


- 1-dimensional FE model
- Cyclic time dimension
- Decoupled losses:
 - Conduction through pressure walls
 - Radiation and convection to environment
 - Friction and drive efficiency
- SAGE of Athens

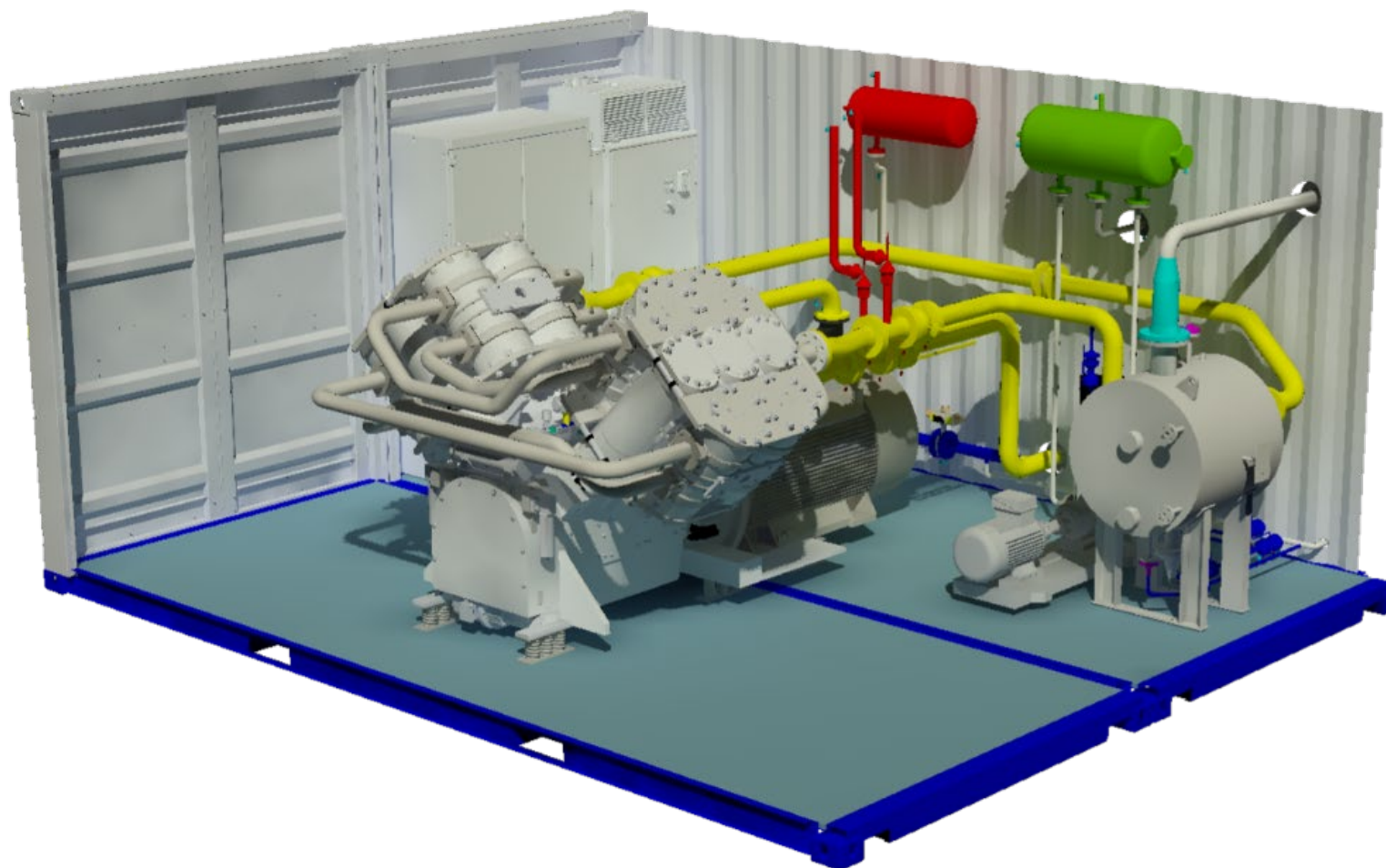




Simulated performance

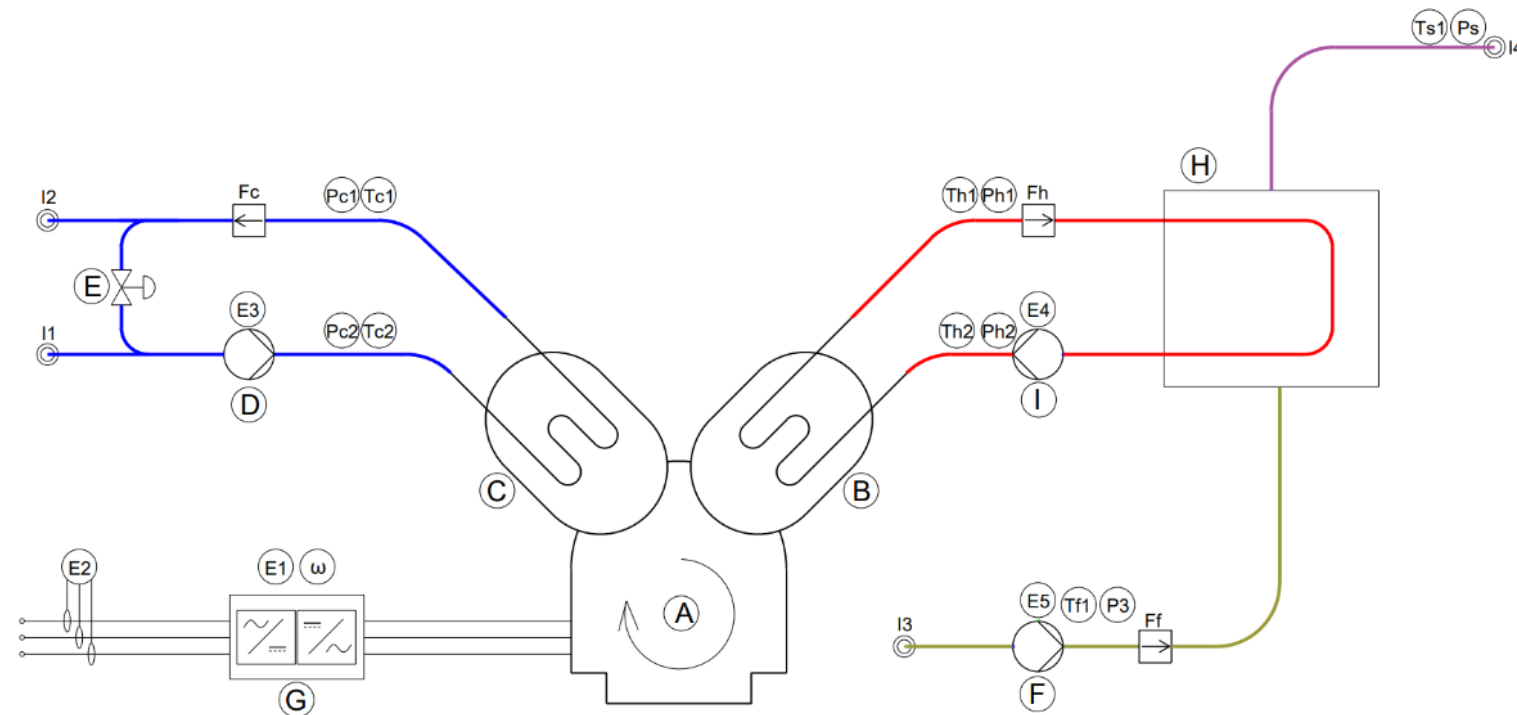


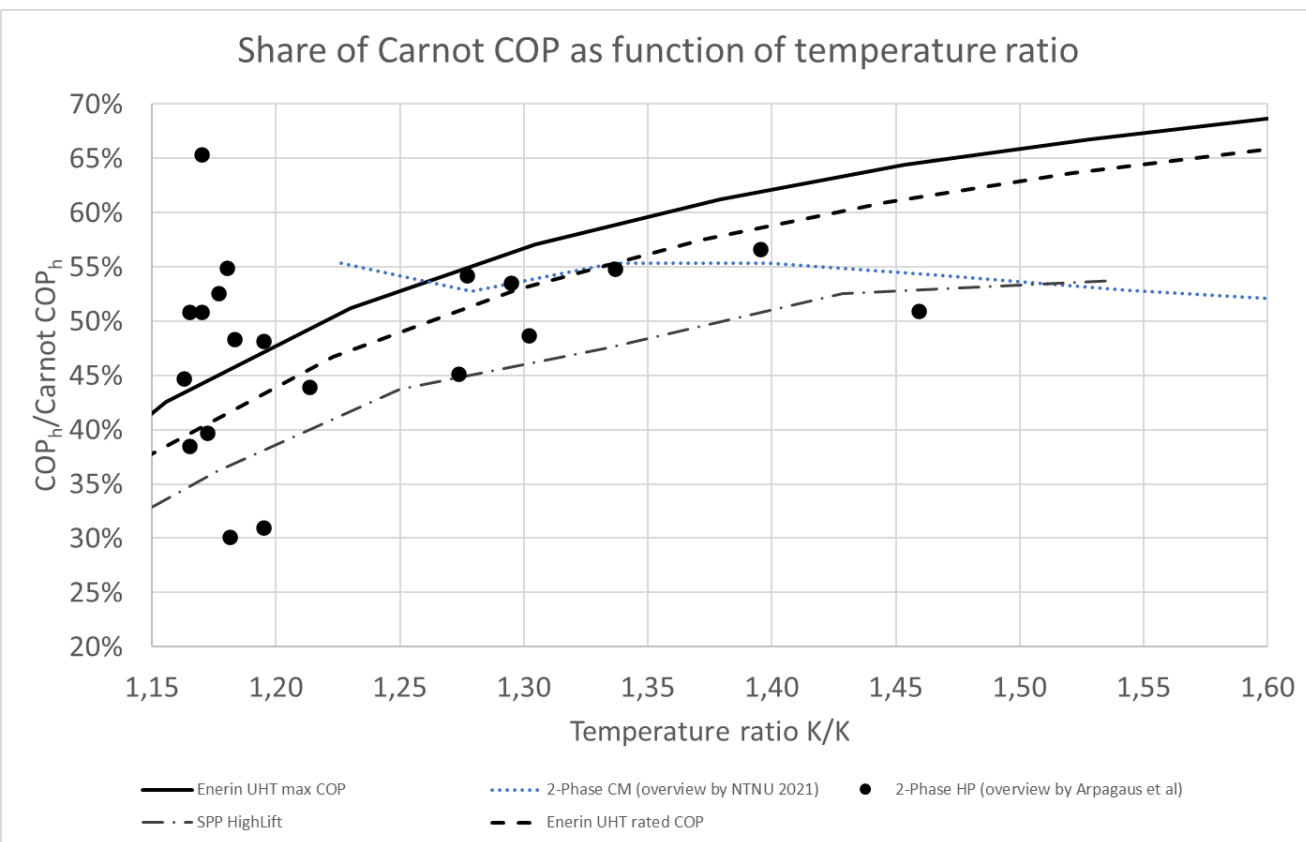
HoegTemp at IVAR biogas facility





- Performance mapping
 - Source temperature controlled by shunt E between 5°C and 45°C
 - Sink temperature controlled by steam pressure regulator between 140°C and 190°C
- Long-term testing
 - 24/7 plant operation





- Expected COP higher than vapor compression cycles for temperature ratios above 1.3 K/K (30°C to 120°C or 70°C to 170°C)
- Expected performance increase versus previous generation stirling-cycle heat pump designed by author and presented at IEA HPC 2014



Plan forward



- Pilot installation at GE Healthcare (pharmaceutical plant in Norway)
- Pilot installation at Pelagia (fishmeal plant in Norway)
- Commercial scaling in Europe and later worldwide

- R&D installation at KTH Sweden for performance mapping at higher temperatures
- Lab testing at cryo temperatures at Western Norway University of Applied Sciences