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TNO innovation
for life

Demonstration of a full-scale
industrial heat pump producing
steam above 140 °C

Demonstration of a full-scale industrial heat pump producing steam above 140 °C

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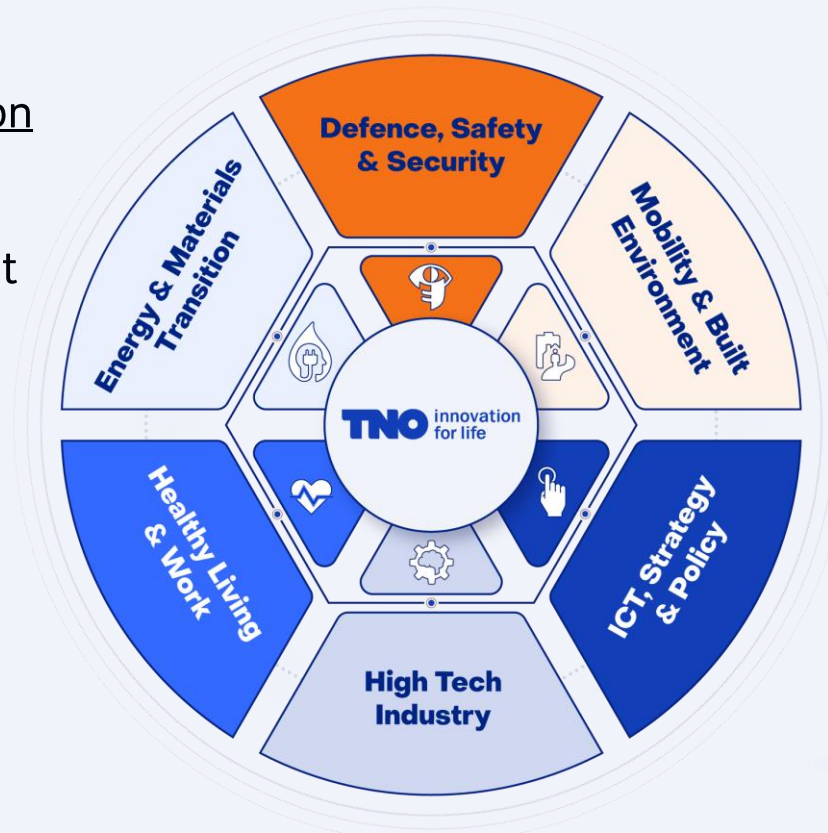
Topics discussed



- About TNO
- Project context & goals
- Experimental setup
- Test results
- Discussion & conclusion
- Follow up project: SPIRIT (Horizon Europe)

About TNO

- Dutch Organization for Applied Scientific Research
- 688 M€ turnover (2023)
- Over 4000 employees
- 13 locations & lab facilities in the Netherlands + some abroad
- Divided into 6 units
 - Energy & Materials Transition
 - Defence, Safety & Security
 - Mobility & Built Environment
 - ICT, Strategy & Policy
 - High Tech Industry
 - Healthy Living & Work

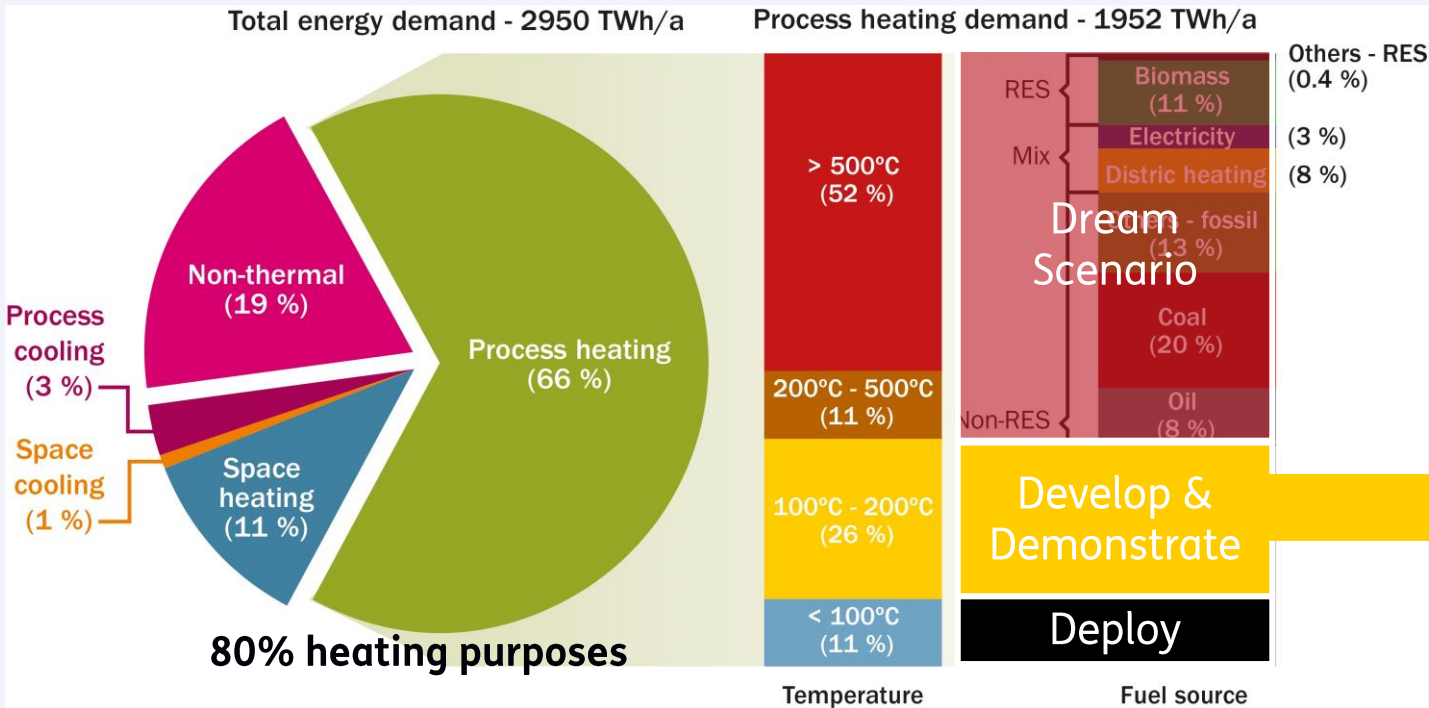


About TNO

- Research group Sustainable Technologies for Industrial Processes
 - Thermal Systems – heat pumps, thermal energy storage, direct electrification
 - Green hydrogen production
 - CO₂ capture and reuse
- Carnot Laboratory in Petten
 - Infrastructure for testing heat pumps from 10 kWth up to 2 MWth
 - 1 MWe grid connection
 - Simulated waste heat as hot water
 - Process heat demand as low pressure steam



Context: Industrial Energy Demand



European process heat demand by temperature level and fuel source

- Applying heat pumps in industry
 - ✓ Uptake/upgrade of waste heat
 - ✓ Electrification of industrial heat demand
 - ✓ Lower energy use and (no) CO₂ emissions
- Key barriers to overcome
 - › End-user confidence
 - › Manufacturers hesitance (market?)
 - › Economic constraints (CAPEX and OPEX)
 - › Technology availability

Project context & goals

- “FUSE (Full Scale Industrial Heat Pump Using Natural Refrigerants)”
- “KickStart market industrial heat pumps”

Objective: To demonstrate a full-scale industrial heat pump

- Steam production above 140 °C
- Approximately 1 MWth

Heat pump details:

- Compressor and supporting skid with heat exchangers and oil management designed and manufactured by Mayekawa
- Custom oil injected screw compressor featuring tailored rotors to cope with the elevated temperatures
- n-Pentane (R601) as working medium

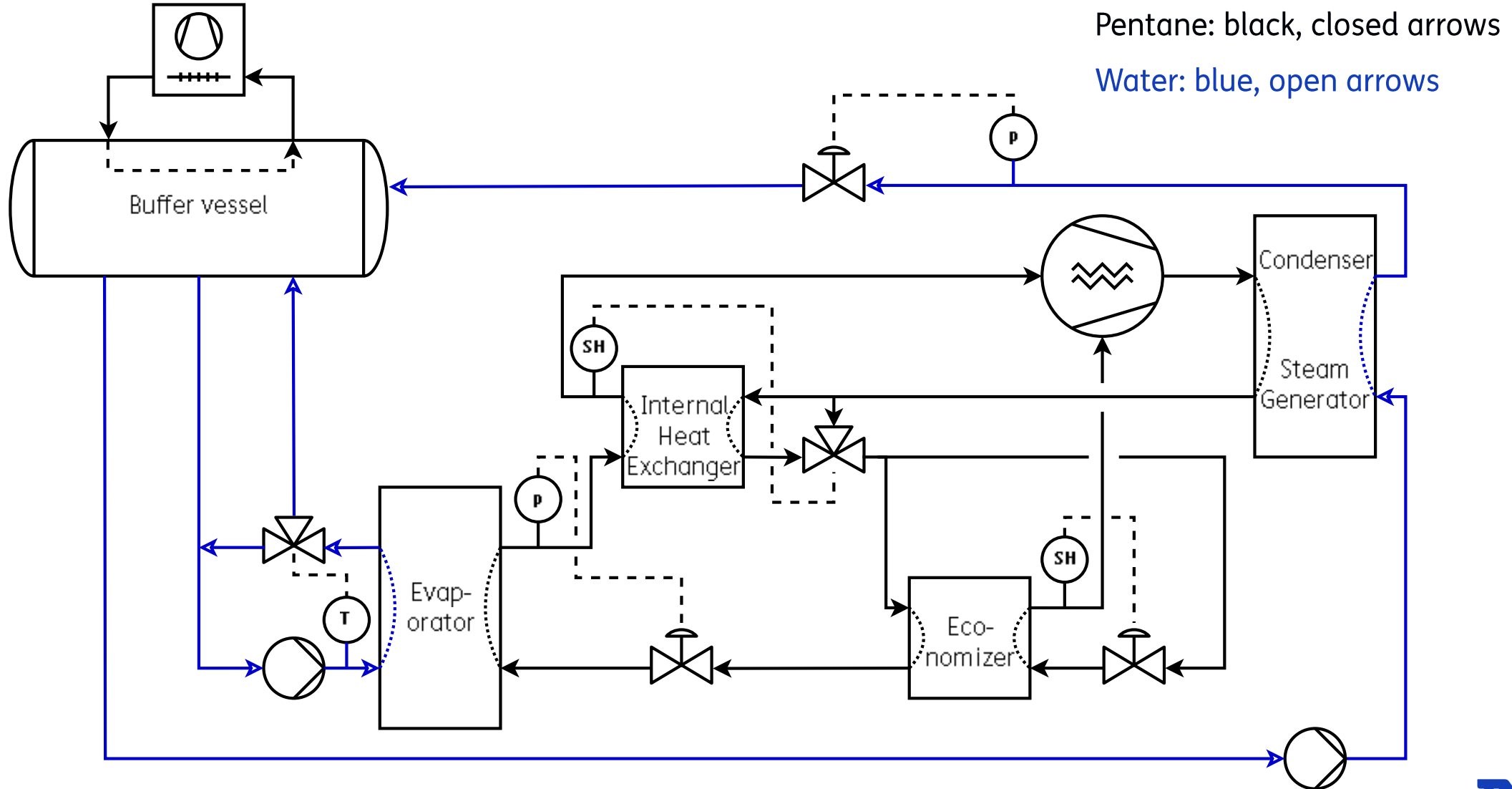
The FUSE & KickStart projects are carried out with Topsector Energy funding from the Ministry of Economic Affairs and Climate Policy

FUSE: [Topsector Energie project number TEEI118008](#)

KickStart: [MOOI Industrie project number MOOI42002](#)



Experimental setup



Experimental setup



- 19 tons
- 5.5 x 4.5 x 3.0 m
- Transported as 2 separate skids

Test results

$$\text{COP}_h = \frac{\text{Heat sink duty}}{\text{Absorbed electrical power}}$$

$$\eta_{\text{carnot}} = \frac{\text{COP}_h}{(T_{\text{sink}} + 273.15)/(T_{\text{sink}} - T_{\text{source}})} \times 100\%$$

Test #	Source temperature	Sink temperature	Compressor speed	Heat sink duty	Coefficient of performance	Fraction of Carnot COP
	°C	°C	RPM	kW	-	%
1	91	142	1500	435	2.3	28
2	63	144	2700	420	1.3	24
3	97	140	2700	905	2.7	28
4	91	140	2700	823	2.4	29
5	91	135	2700	840	2.7	29
6	91	130	2700	836	2.9	28
7	96	135	2700	900	2.8	27
8	64	105	2700	584	3.2	34
9	65	123	2700	522	2.1	31
10	77	140	3000	642	1.7	26
11*	77	140	3000	788	1.9	29

* Economizer enabled

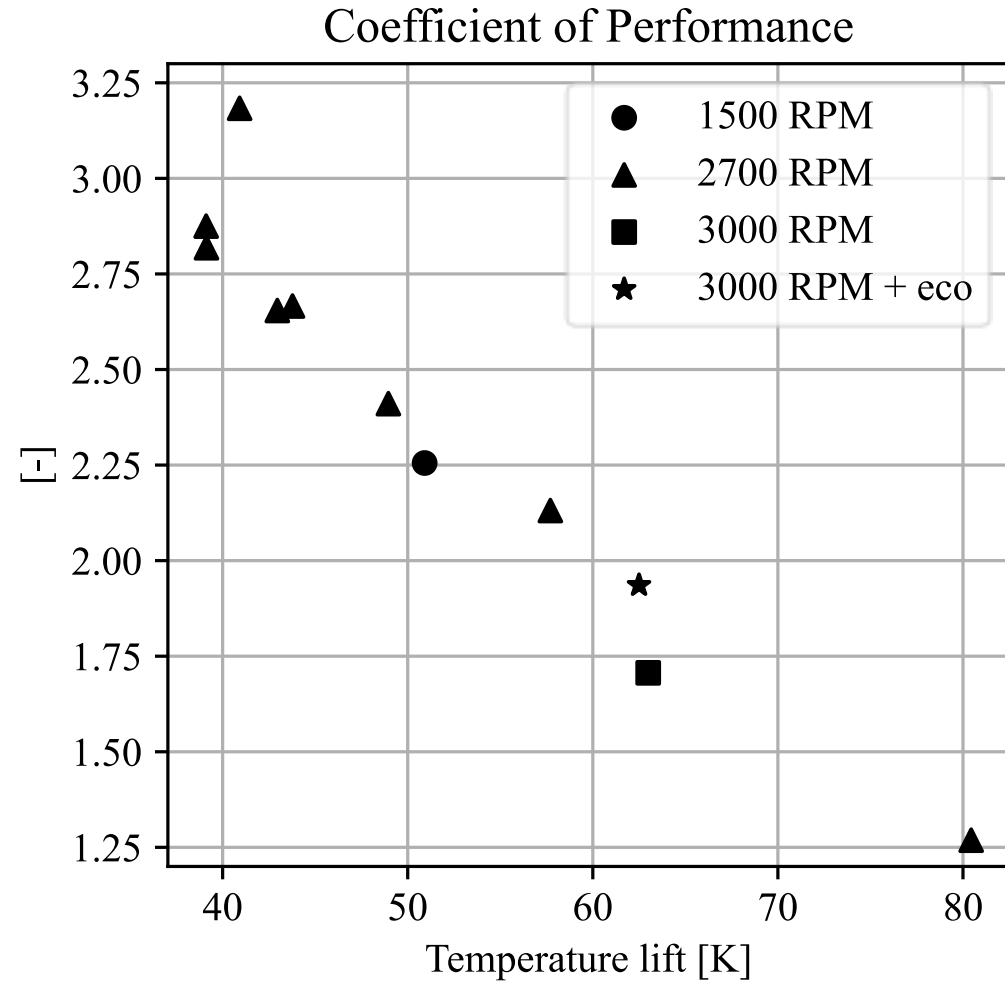
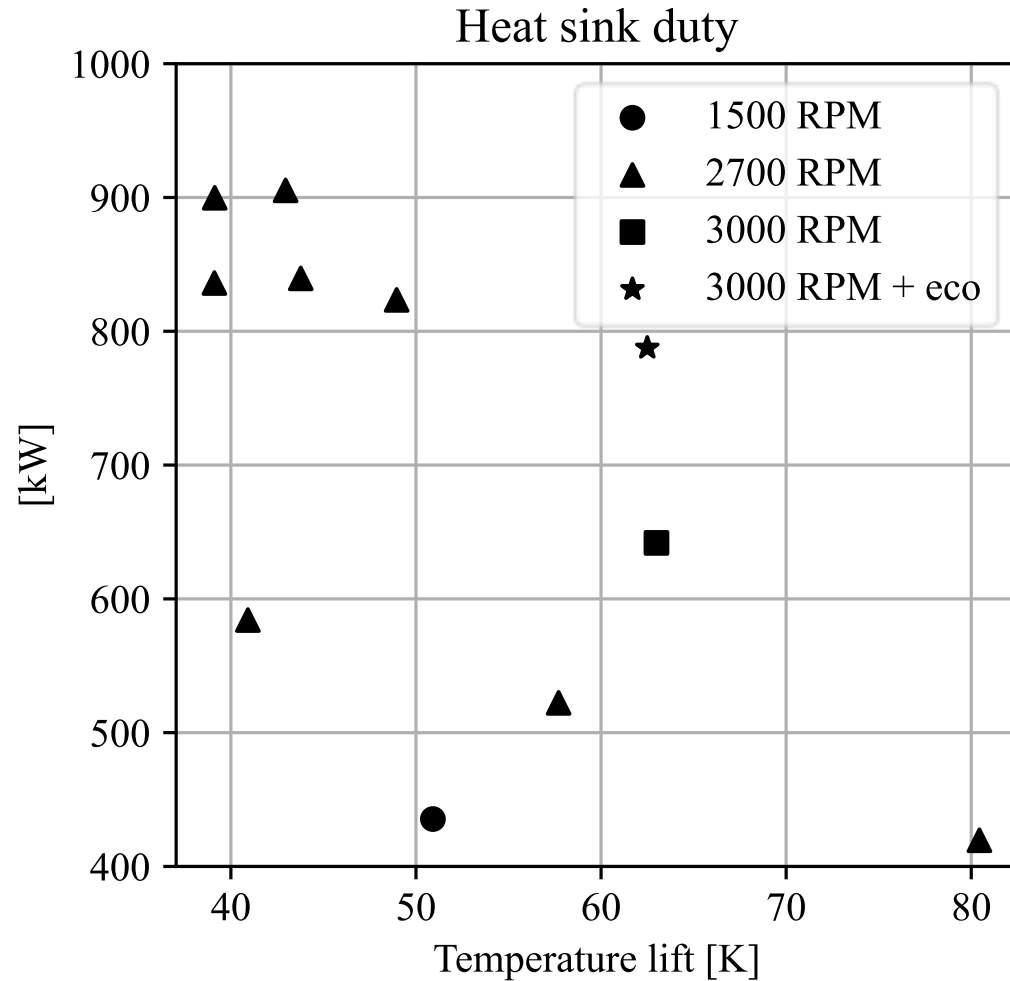
Hot water supply temperature to evaporator

Steam saturation temperature
0.2 – 3.0 barg

Steam production + sensible duty of feedwater

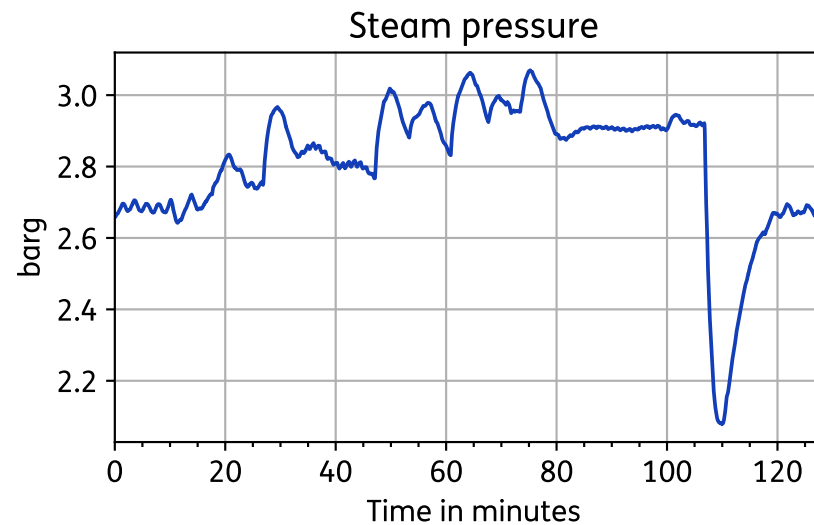
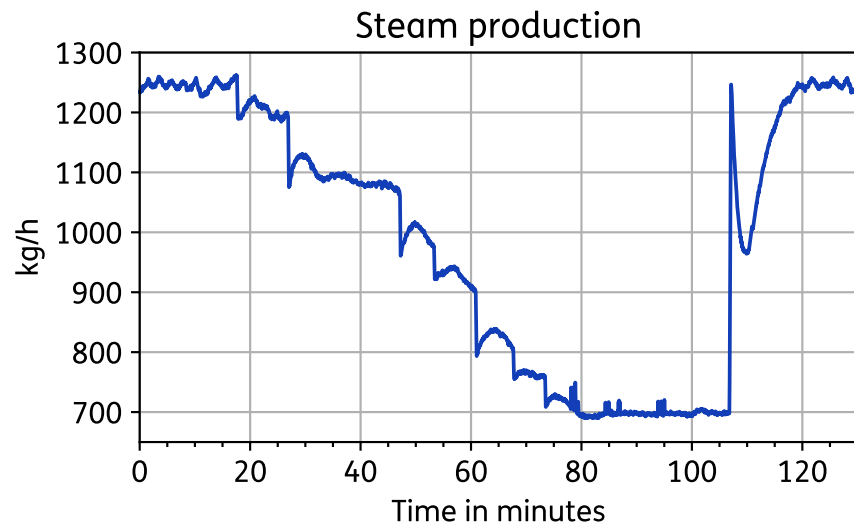
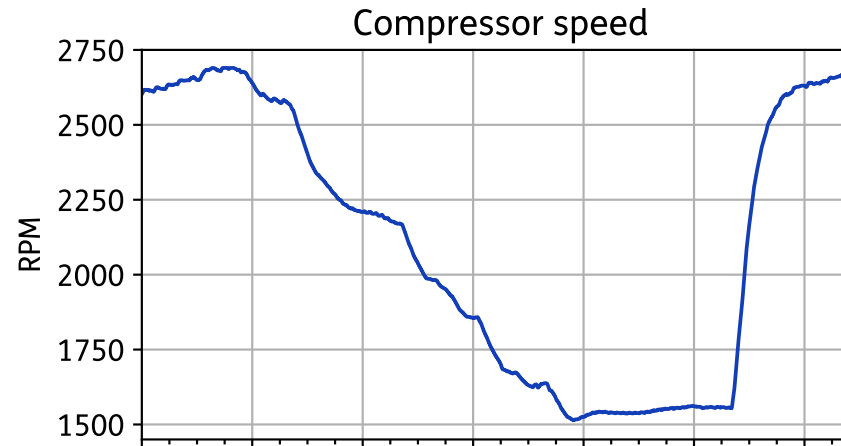
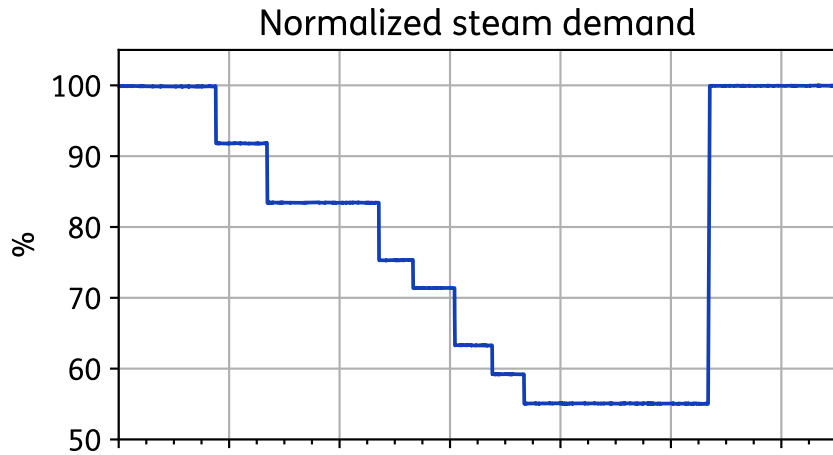
External temperatures

Test results - static



$$\text{Temperature lift} = T_{\text{sink}} - T_{\text{source}}$$

Test results - dynamic



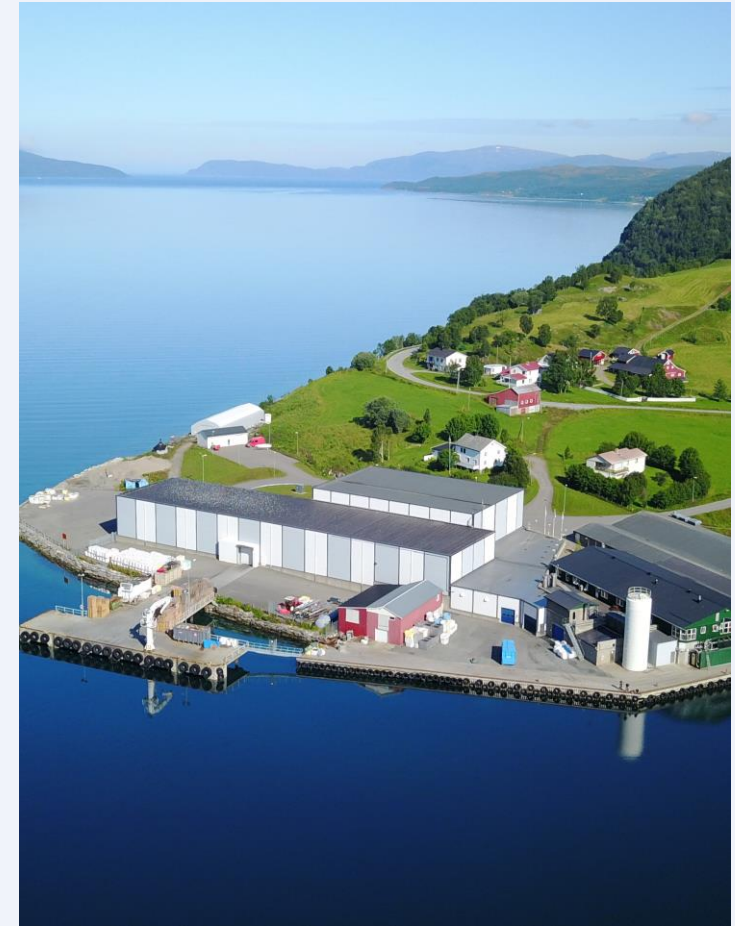
Discussion & conclusion

High temperature heat pump manufactured by Mayekawa has been successfully integrated and tested at the Carnot Laboratory of TNO

- Performance values have been determined for the full operating range of the heat pump
 - Heat sink duty shows a strong dependence on source temperature and the temperature lift
 - For lower source temperatures, butane might be considered as an alternative working medium
 - For extreme temperature lifts, a two stage system with suitable working media could be considered
- Areas of improvement have been identified
 - Reduced volumetric efficiency due to the tailored compressor rotors
 - Relatively high approach temperatures in the heat exchangers, resulting in an external Carnot COP of 24% to 34%. The Carnot COP based on the internal temperatures (pentane side) is significantly higher at > 40%.
- Next steps
 - Testing within the TNO laboratory has been finalized. The heat pump will be transported back to Mayekawa to be retrofitted in preparation for installation at an end user.
 - A heat pump of similar design is under construction in the European SPIRIT project

SPIRIT – HEU project


- Current situation
 - Annual production of 5000 mt prawns
 - Steam at 145°C used for cooking, produced by propane boiler
 - 9000 MWh/year
 - 2600 ton CO₂/year
- Demonstration
 - Cascade heat pump (NH₃, pentane)
 - Waste heat from refrigeration plant at 21°C
 - Process heat 700 kW at 145°C



**Thank you for
your attention**

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