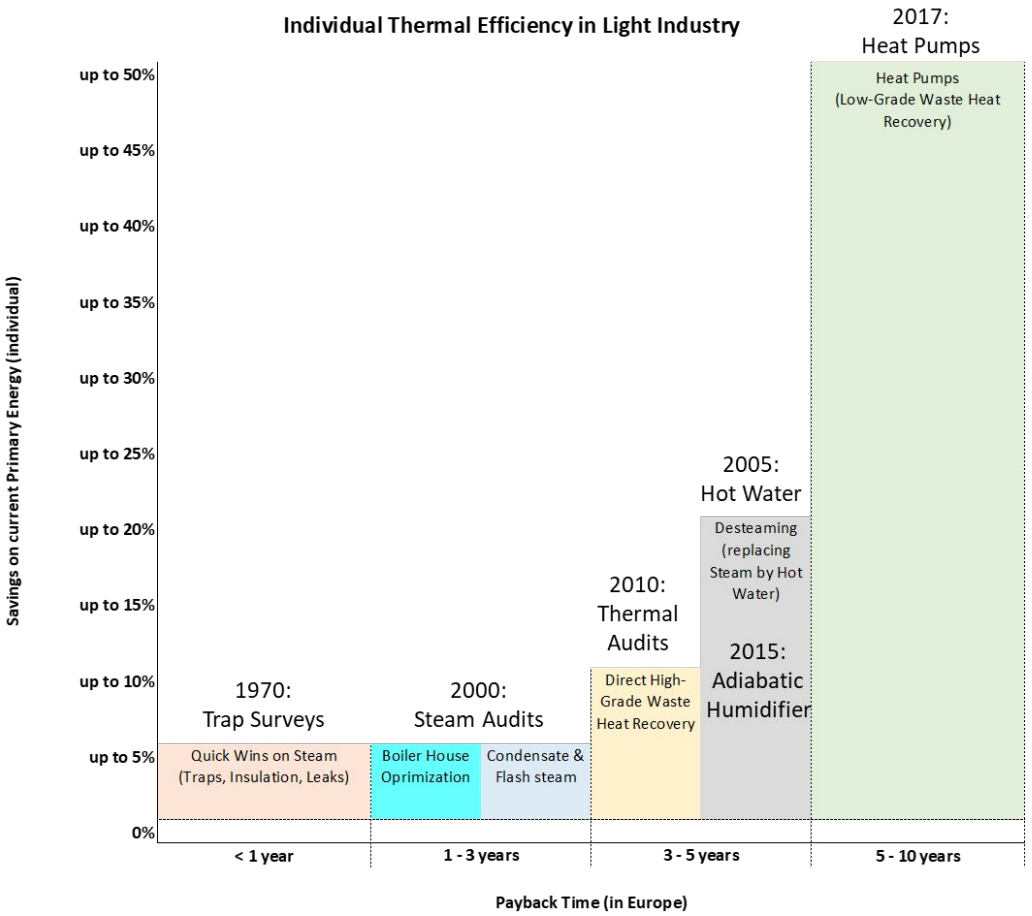
Armstrong®
EXPERIENCE MATTERS℠

CIRCULAR THERMAL℠

How to put Waste Heat back in Industrial Processes

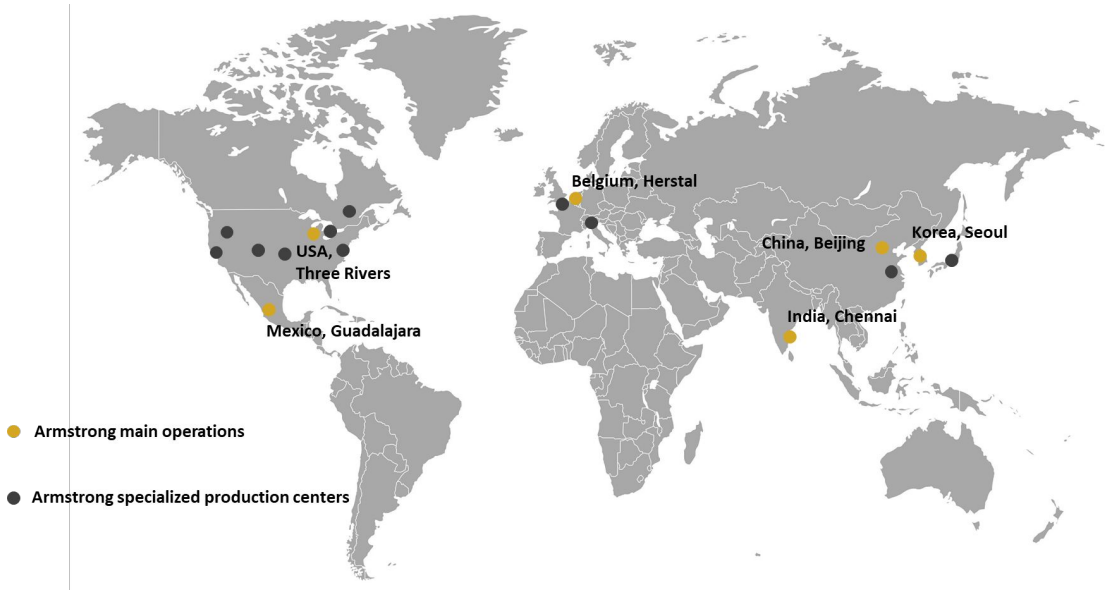
Armstrong International

- Founded in 1900 in Michigan
- 5th generation privately-owned and managed;
- 15 facilities globally, 2000+ employees;
- Steam systems in Refining, Petrochemical, Food, Beverage, Pharma, Paper, etc.
- Thermal Decarbonization to support globally Fortune 500 companies in their Net Zero goals
  - Circular Thermal®: Pinch, Direct Heat Recovery, Desteaming, Low-Grade Heat Upgrade (heat pumps)
- Global JV / license w/Combitherm GmbH (Germany)
  - Manufacturing of heat pumps in since 1972



Scaling-up industrial high-temperature heat pumps manufacturing

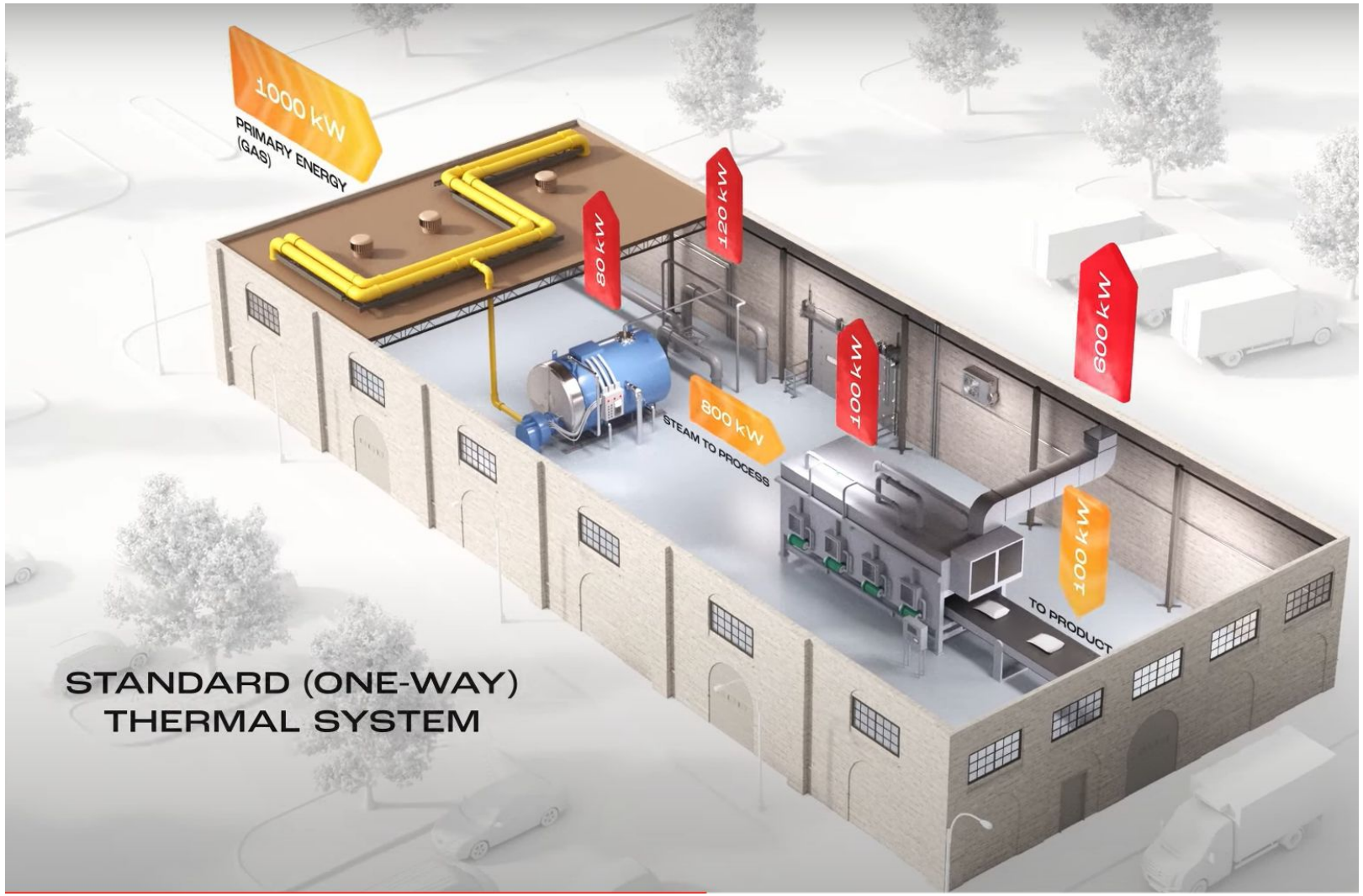
- **Europe:**
  - 50 MW/year from 2027 in Belgium (Herstal)
  - Co-funded by the EU Innovation Fund
  - Possible expansion in Belgium up to 150 MW/year
- **Americas:**
  - 50 MW/year from 2026 in the USA (Three Rivers, Michigan)
  - Co-funded by the Department of Energy (DoE)
  - 10 MW/year currently in operation in Mexico
- **Asia:**
  - 50 MW/year from 2025 in India (Chennai), up from 20 MW/year currently in operation
  - 40 MW/year from 2026 in Beijing (China)
- **Globally:**
  - 200 MW/year from 2027



Circular Thermal® – video

Link:
https://www.youtube.com/watch?v=ScfDrhr9n_4&t=4s

Legacy One-way Thermal Systems



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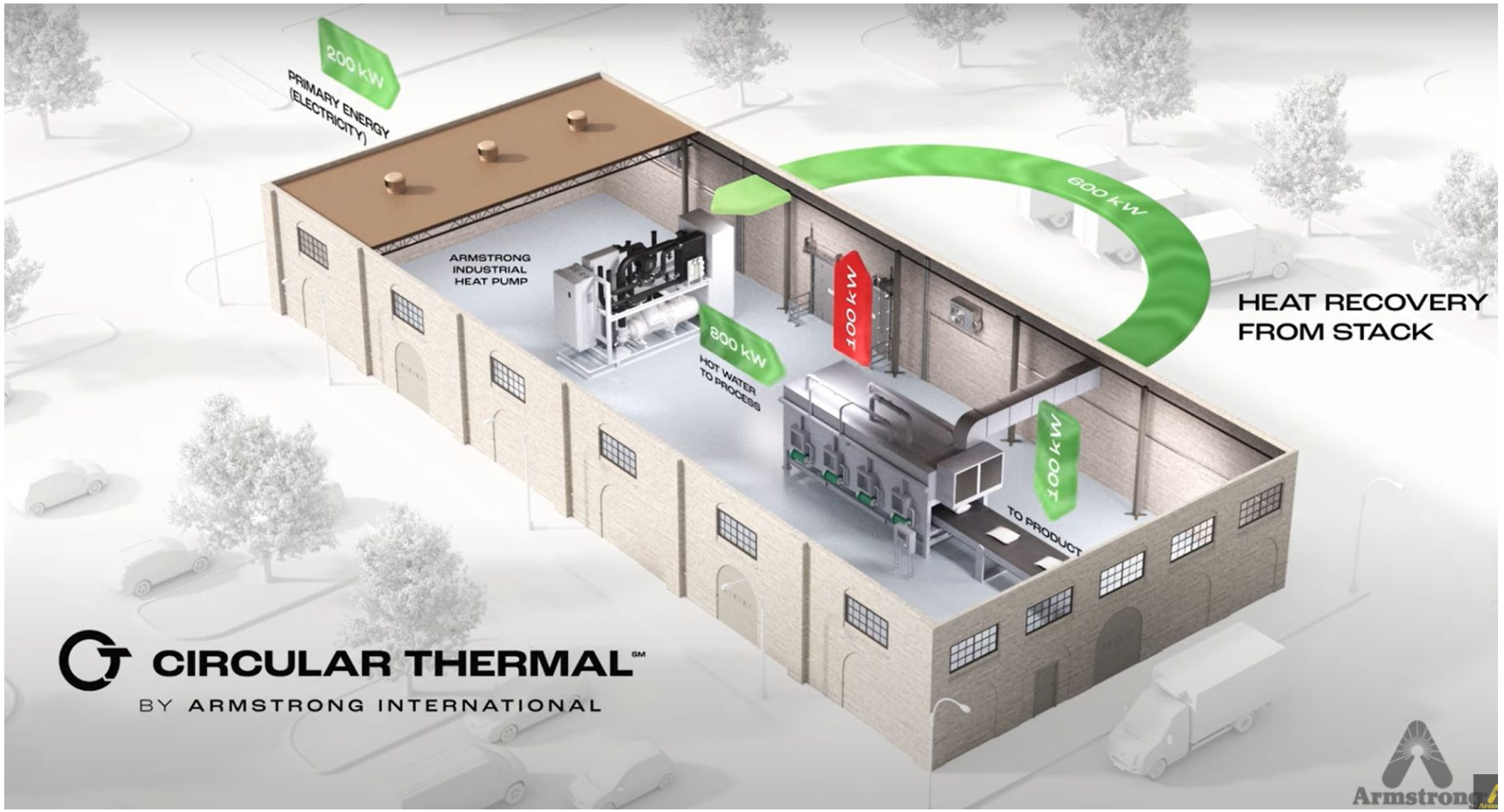
Circular Thermal® System



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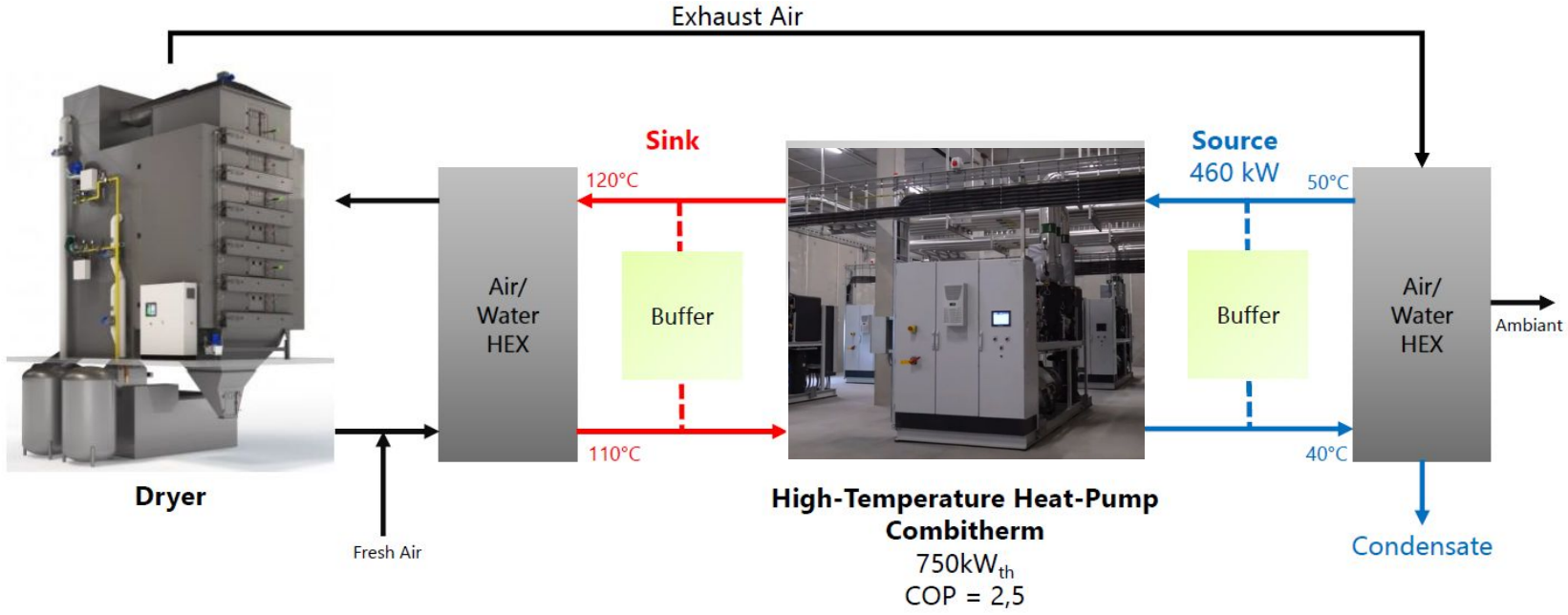
Case study: electrified petfood dryer (Cargill Norway)

- Vertical fluid bed dryer for aquafeed delivered by Geelen Counterflow (Netherlands) with integrated Combitherm GmbH (Germany) heat pumps
  - Operational since April 2022 for a total power of 3.5 MW thermal (0.9 MW electric)
  - Achieved final COP = 4 (thermal integration improved initial estimated COP = 2.5)
  - Decreased primary energy use by 75% (15 000 MWh/year) and CO2 emissions by 3 000 tons/year
- IEA Annex 58 case: https://heatpumpingtechnologies.org/annex58/wp-content/uploads/sites/70/2022/12/combithermhthpannex



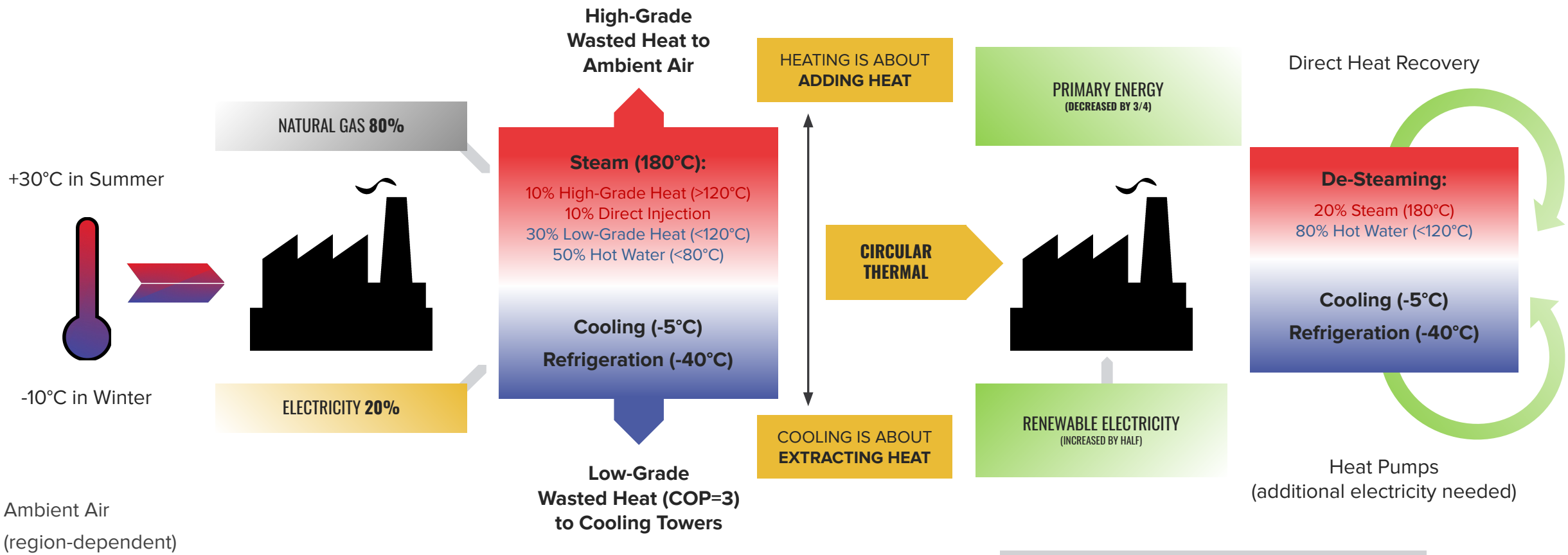
Case study: electrified petfood dryer (Cargill Norway)

- 4 industrial high-temperature heat pumps, total of 3.5 MWth
- Total of 10 compressor circuits

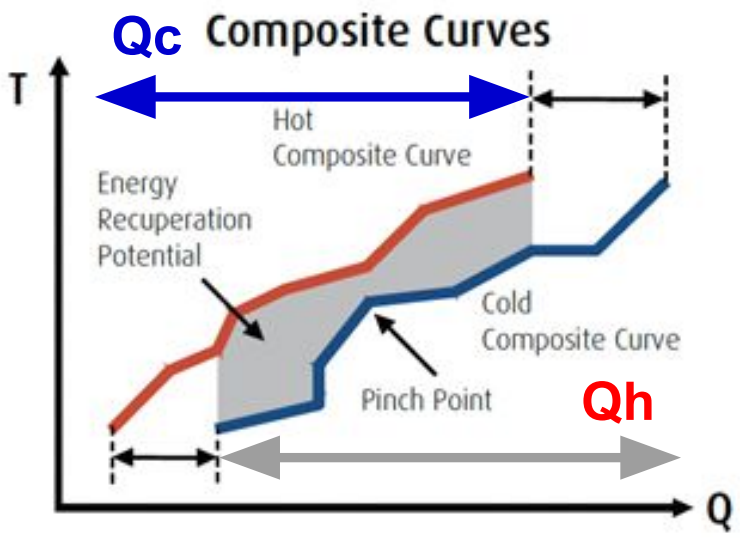
Case study: electrified petfood dryer (Cargill Norway)

Link: https://www.youtube.com/watch?v=keeBW6Y8OeQ&t=19s

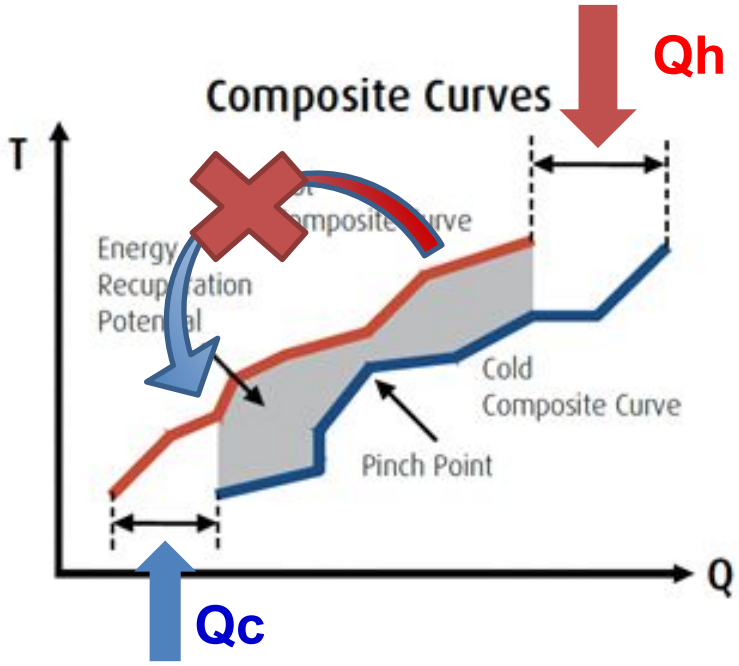
Circular Thermal® by Armstrong



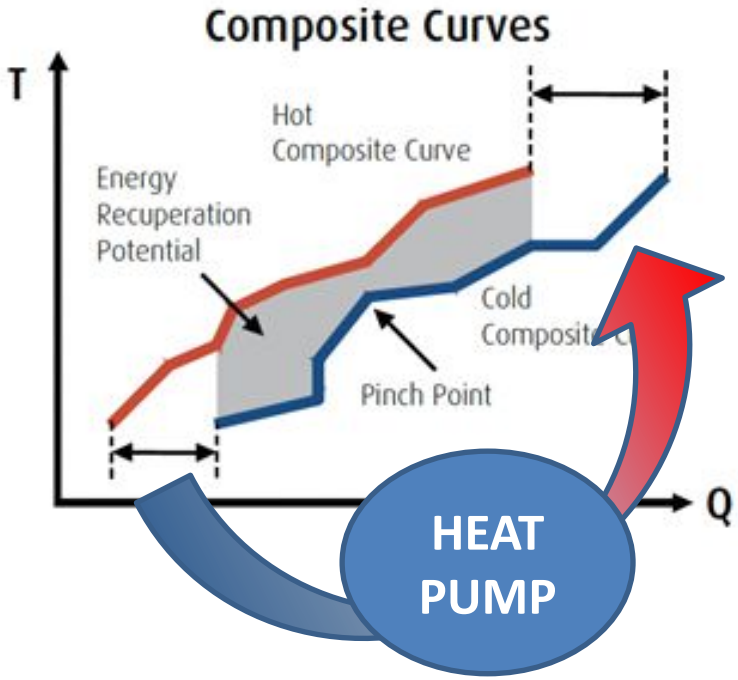
Pinch Methodology



No Heat Recovery



100% Heat Recovery

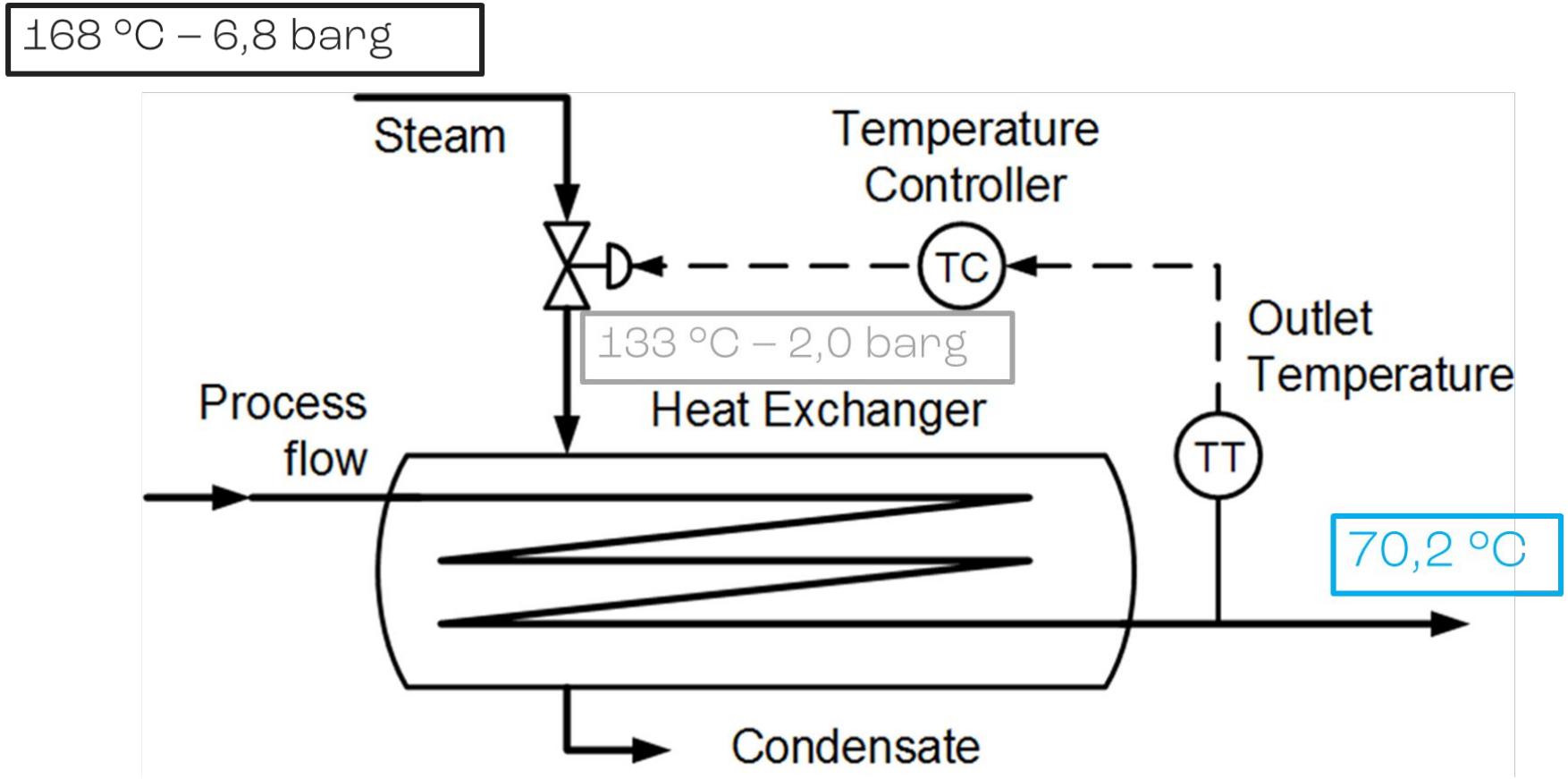


Heat pump can be used to upgrade low grade heat above the Pinch point to further reduce heat demand (Qh)

- **Qc**: Energy to be removed from the system through cooling
- **Qh**: Energy to be added to the system through heating

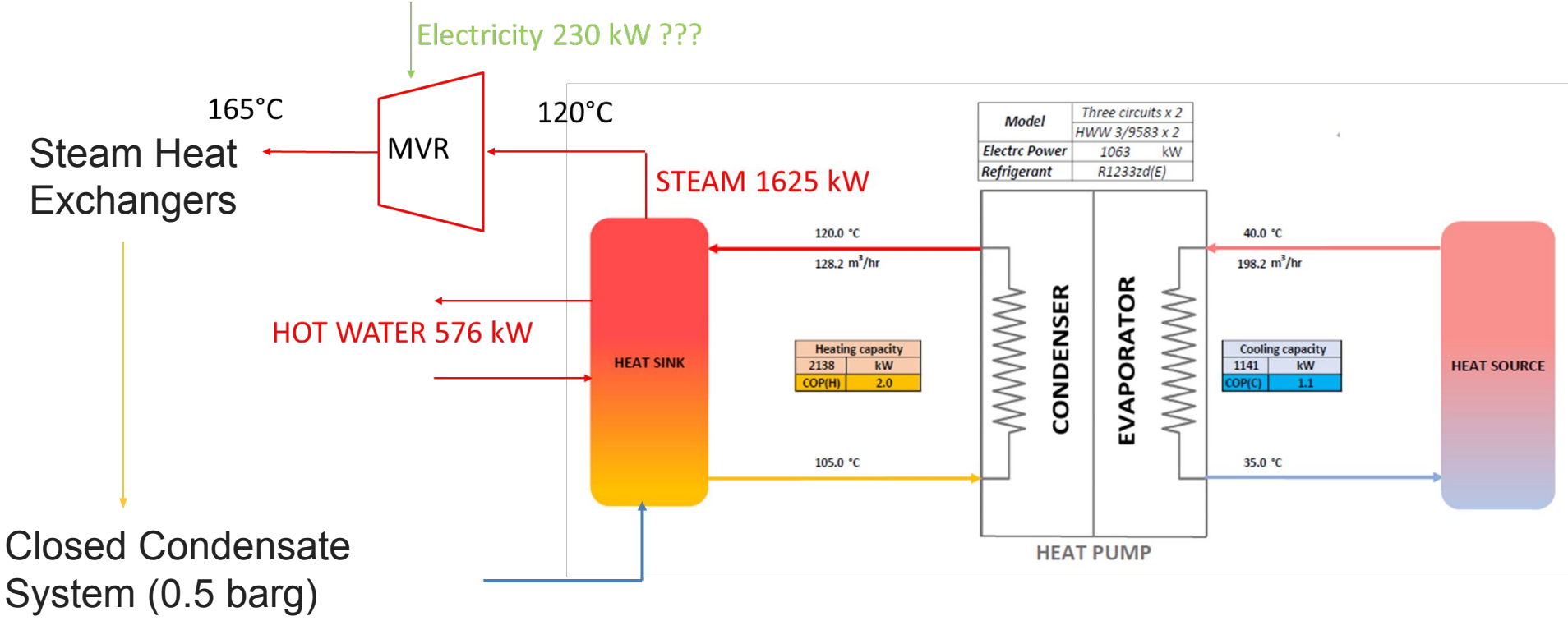
Source: “Pinch Analysis: For the Efficient Use of Energy, Water & Hydrogen”, CanmetENERGY, Canada (2003)

“Black / Grey / White” box in Pinch



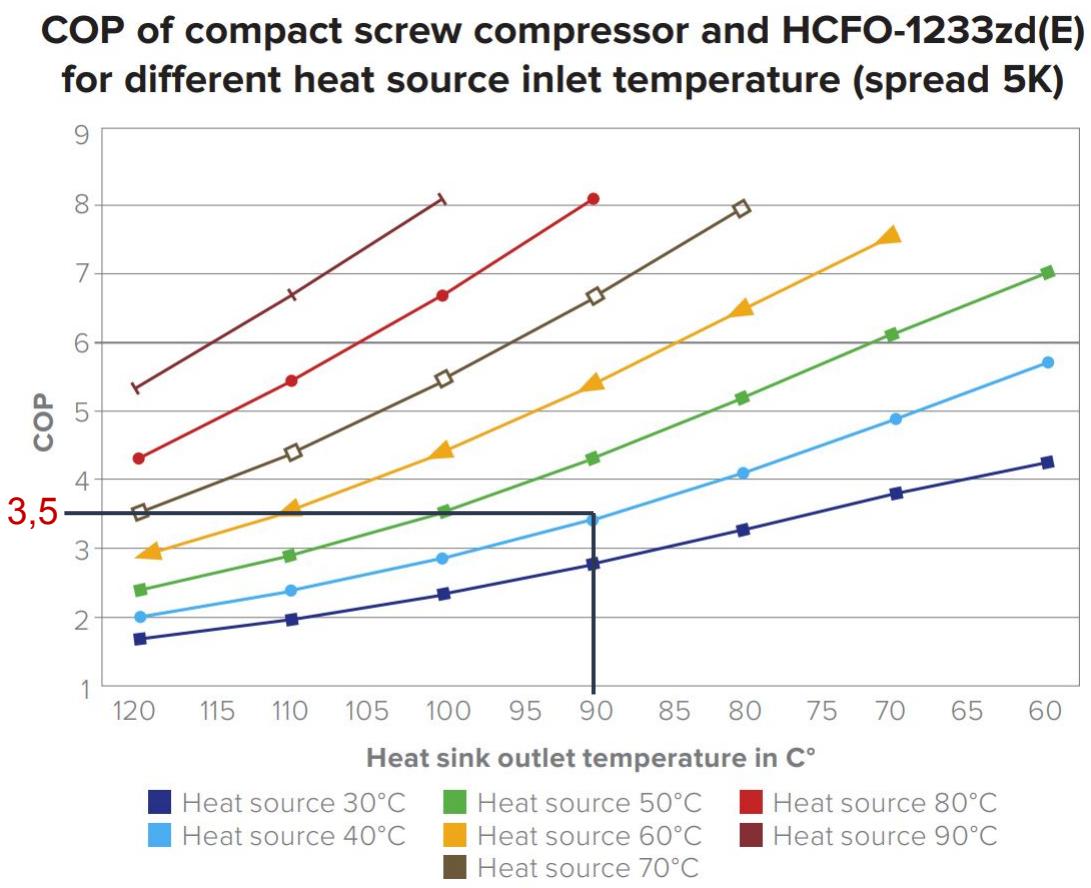
Heat pump generating low pressure steam

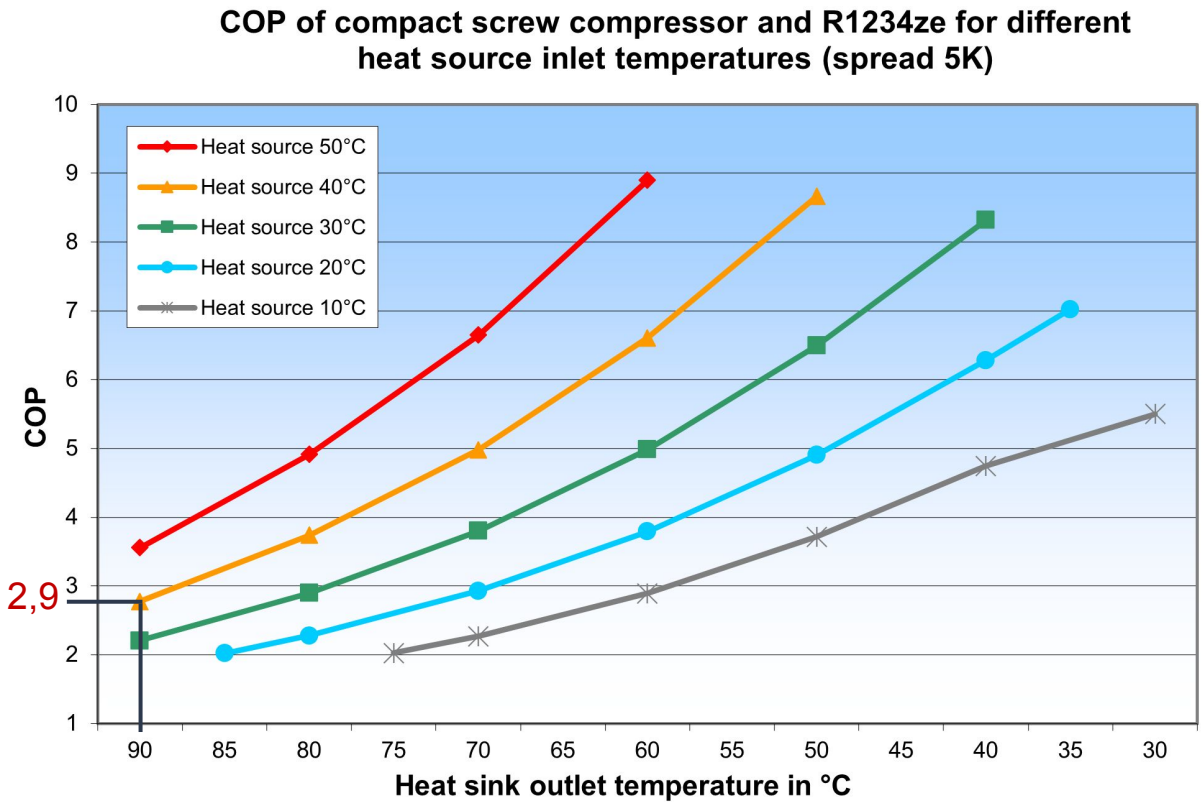
- Heat pump can generate low-pressure steam up to 120°C (1 barg);
- Steam compressors can increase pressure & temperature > 200°C (2 stages);
- 10% water injection in compressor, increasing total steam load;
- Steam and condensate system should be closed (no live steam, flash steam or condensate losses)



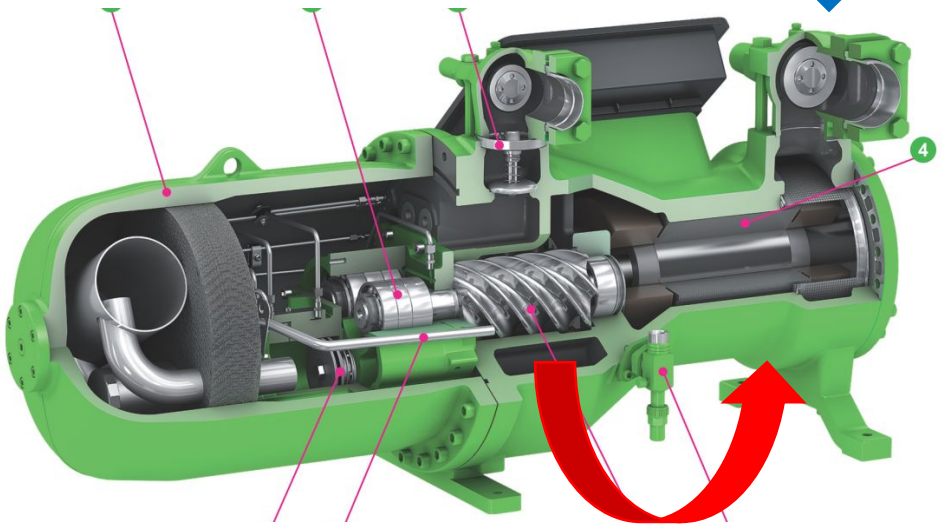
High-Temperature Heat Pump with Steam Evaporator

COP Curves – R-1233zd(E) and 1234ze(E)





Semi-hermetic compressors



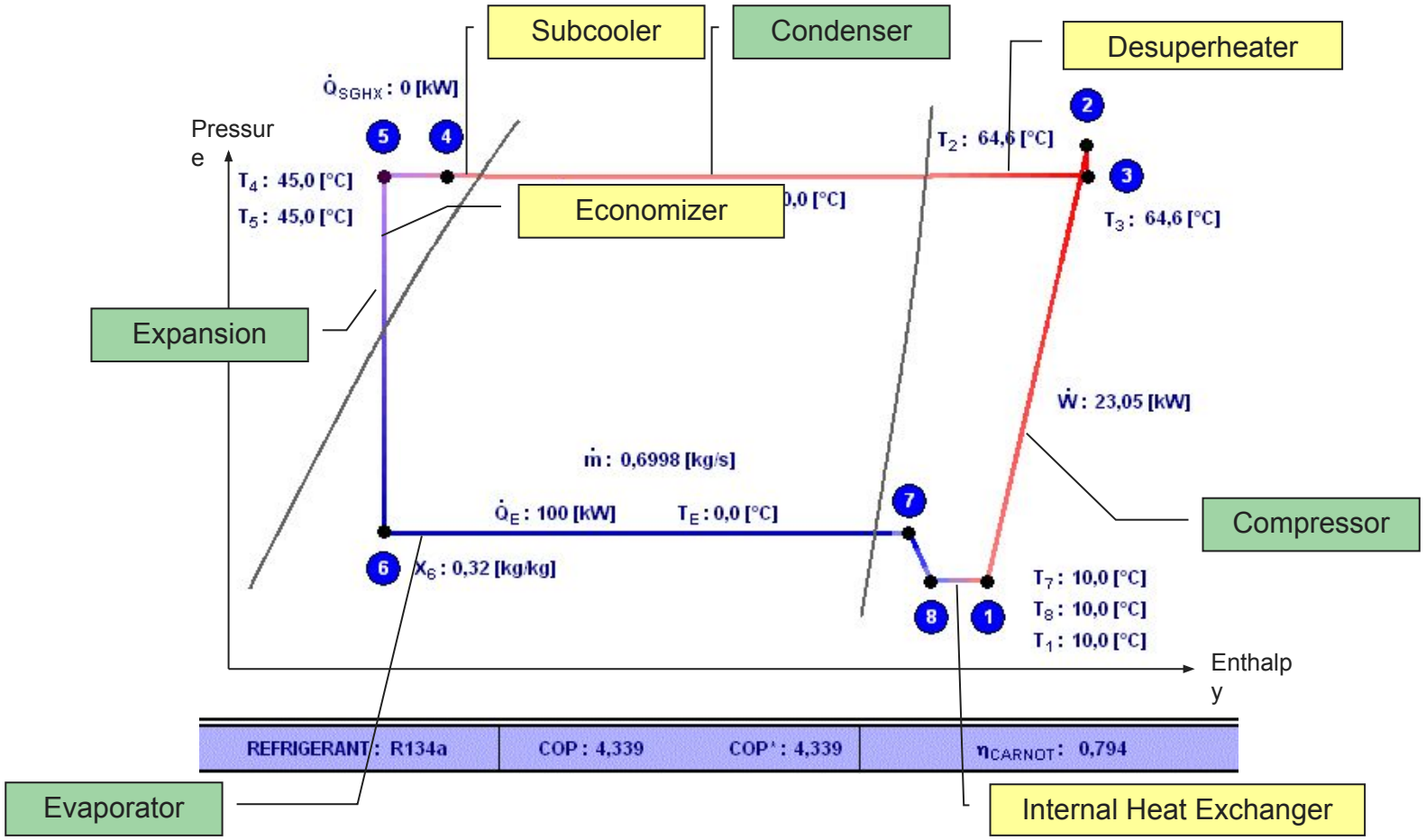
Heat in high-pressure refrigerant

Heat in low-pressure refrigerant

Electrical input (“Compressor COP”)

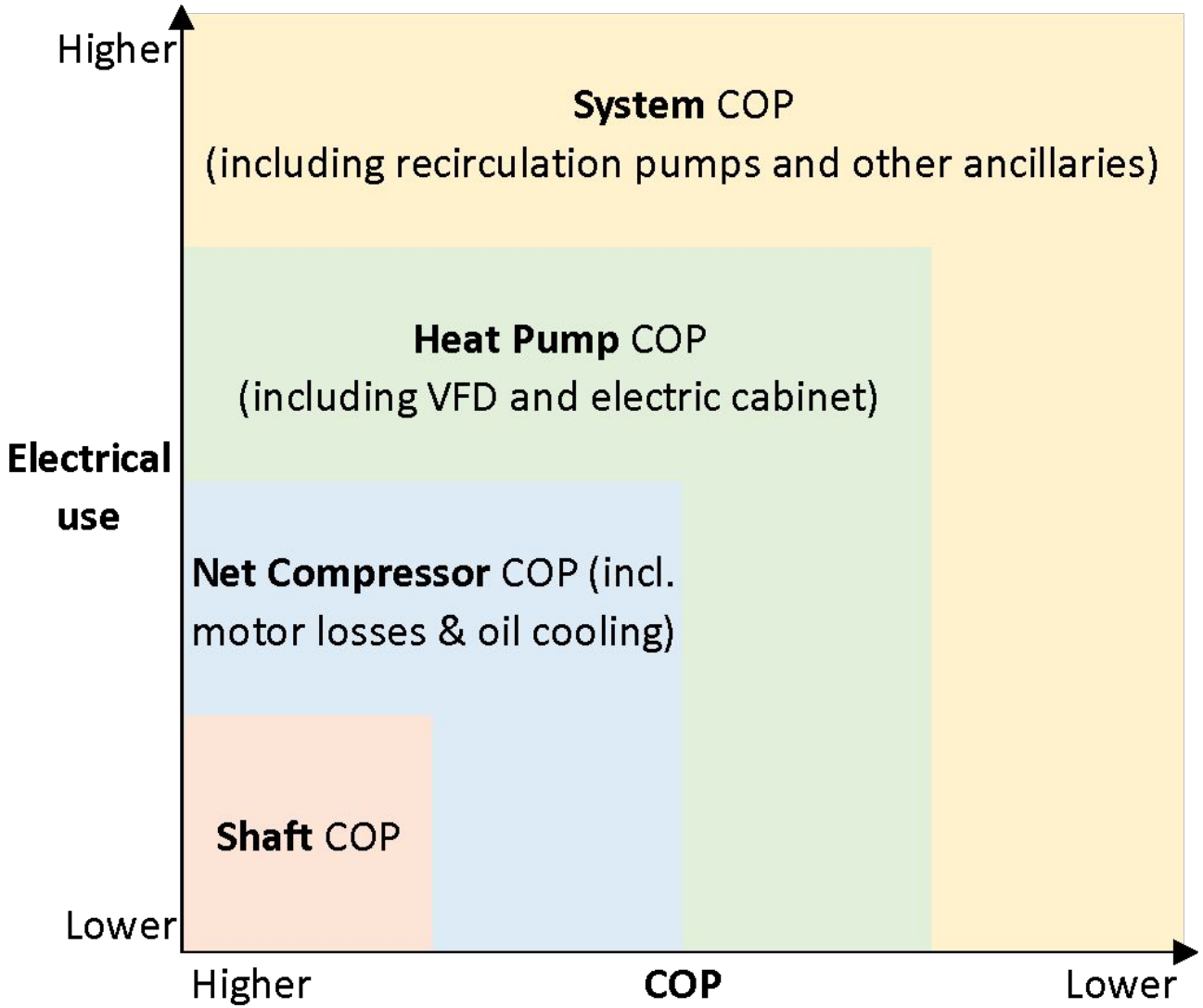
Heat recovered internally through refrigerant-cooled motor and oil

Optimizing Heat Pump efficiency



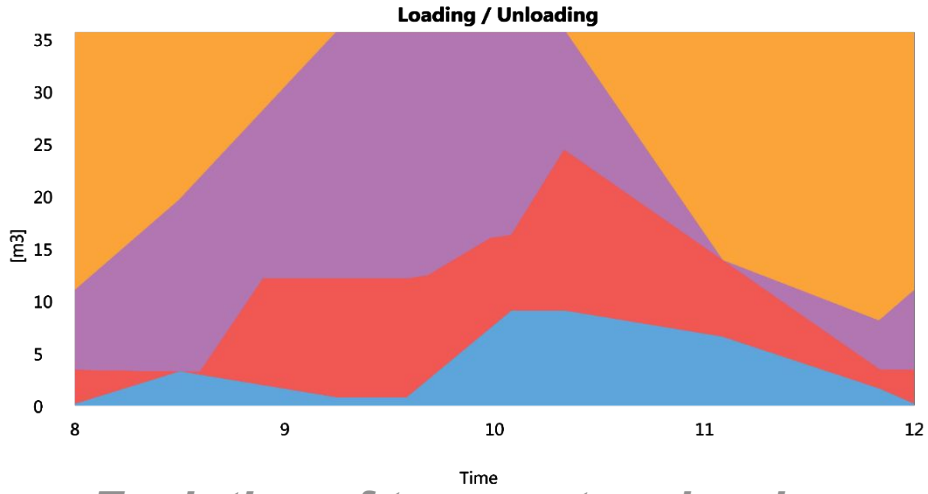
Source: CoolPack / EES

Different levels of COP calculation

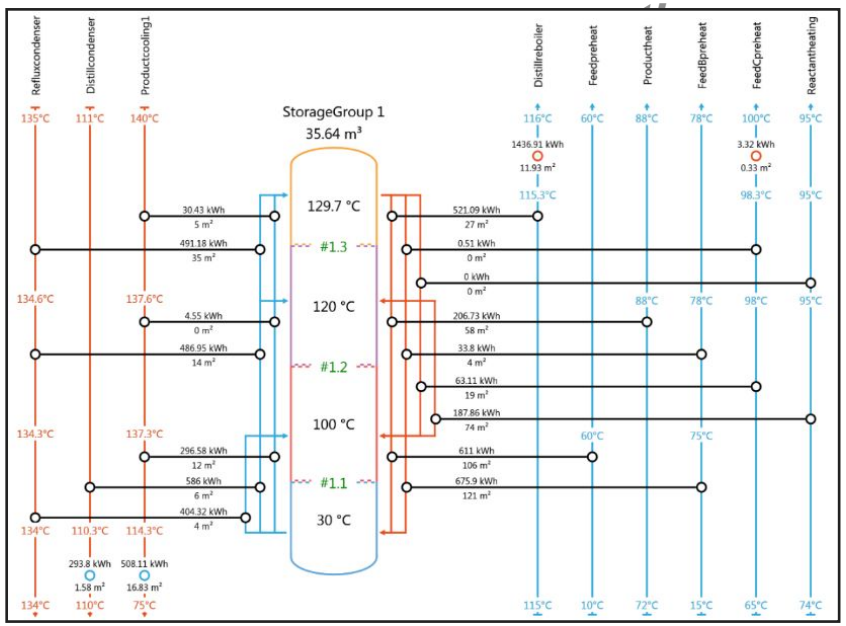


Stratified Storage Tank

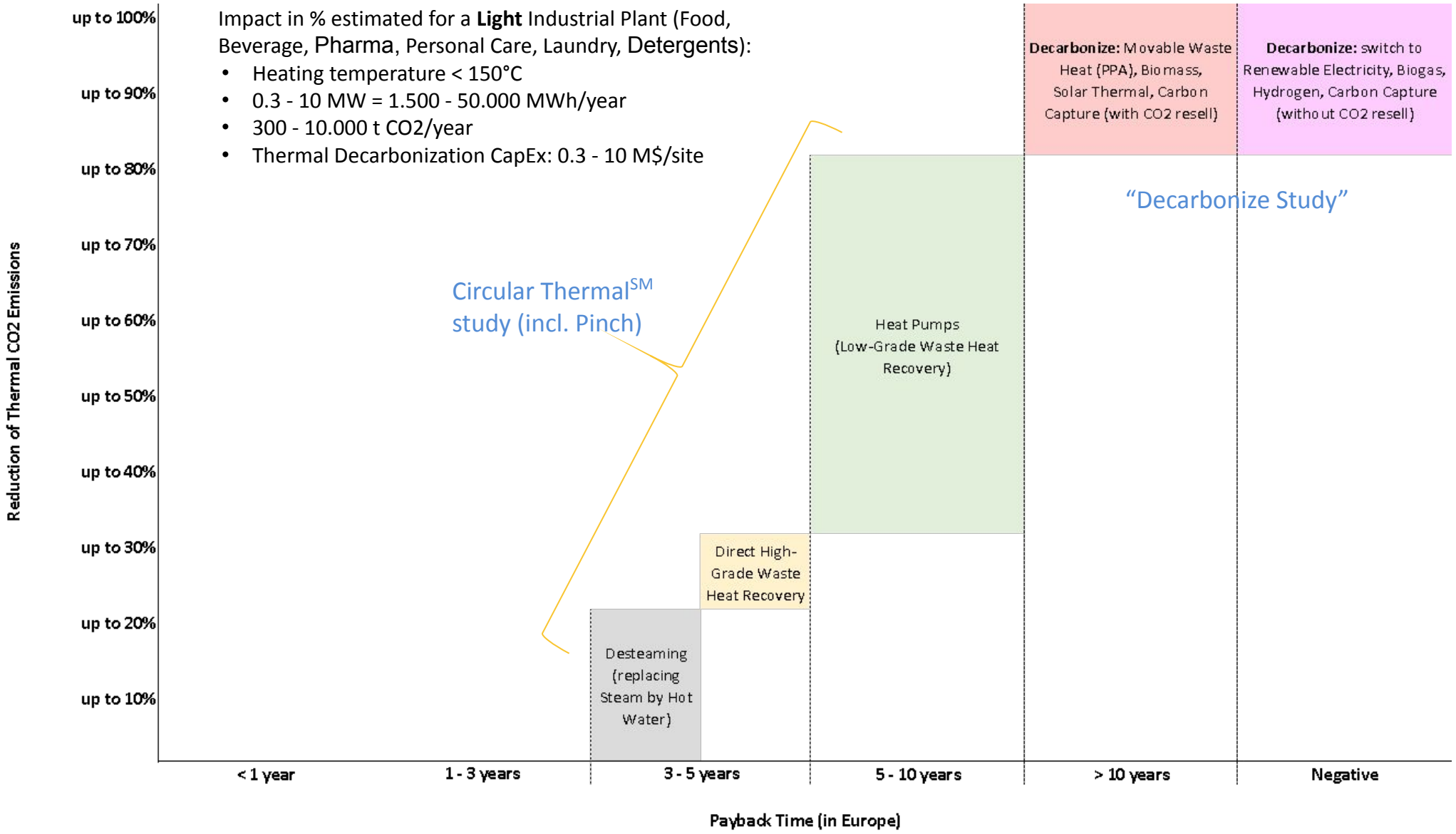
- Advantages
  - Reduces the required storage load
    - Vertical tank: hight exceeding width
  - Allows to deliver the expected sink temperature even at part load, if stratification is maintained
    - The higher the temperature difference, the more stratification will be maintained
    - An increased number of different temperature level is more challenging to maintain
  - Modelling of stratification evolution over a period of time using PinCH software



Evolution of temperature levels over



Typical Thermal Decarbonization Journey in Light Industry



Armstrong Methodology

CURRENT STATE

FEASIBILITY STUDIES

- Thermal Mapping (Pinch)
- Optimize Thermal Efficiency
- Decarbonize Thermal Generation

DETAILED ENGINEERING

- Equipment Sizing & Selection
- Piping Isometrics
- Controls Running Strategy

PROJECT IMPLEMENTATION

- Equipment Sourcing
- Supervision of Site Contractor
- Turnkeys

SUSTAIN OPTIMAL EFFICIENCY

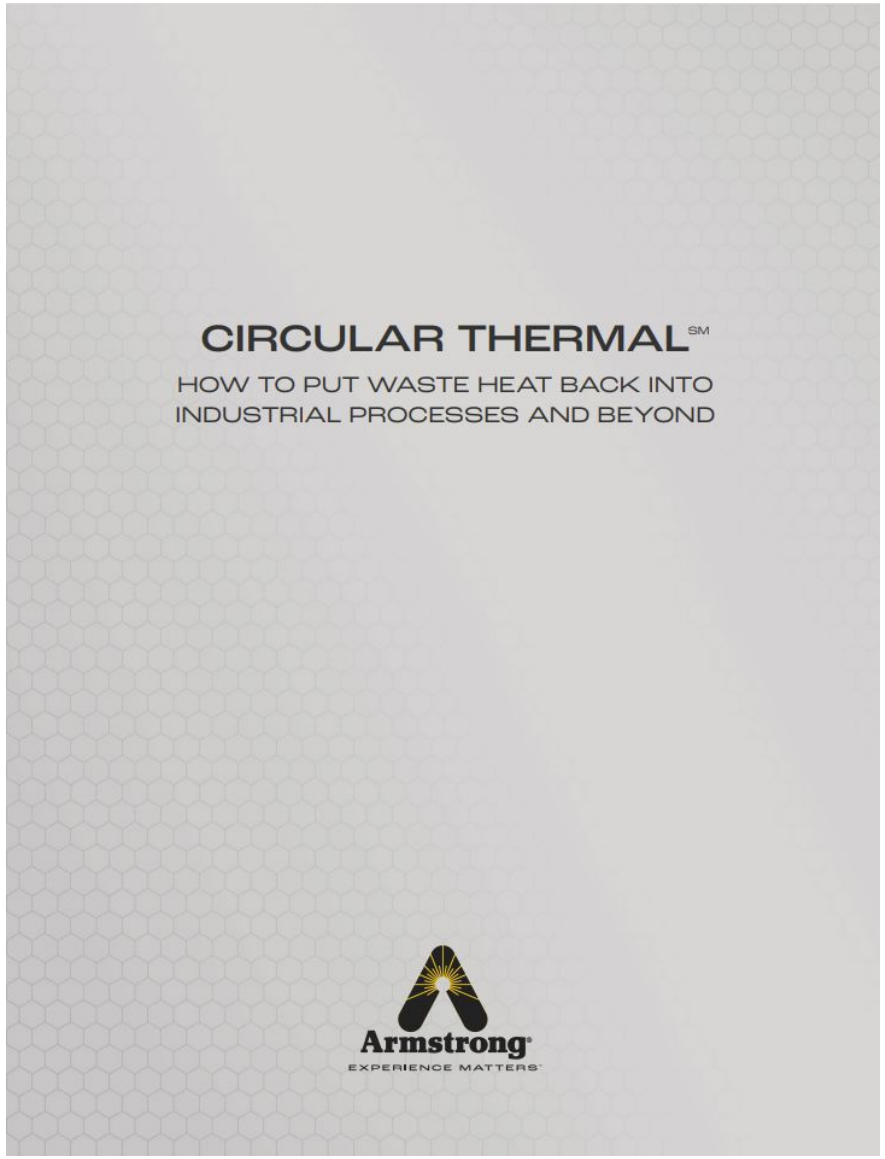
- Internet of Things (IoT)
- Preventive Maintenance Contracts
- Operation & Maintenance (O&M)
- Performance Guarantees
- Decarbonized Thermal as a Service

SINGLE POINT OF RESPONSIBILITY

BUSINESS RISKS AND "CAPEX-TO-OPEX"

GLOBAL COVERAGE

Circular Thermal® White Paper



Link:
https://armstronginternational.com/wp-content/uploads/WP_CircularThermal_1530_EN_20230626.pdf

New European Process Electrifications Subsidies

- EU Innovation Fund Call – 1 Bn€ for “Decarbonization of Industrial Process Heat” through a reversed auction in December 2025:
  - “Reversed auction” for subsidies in “€/ton of CO_2 abated” – companies will express the amount of subsidies they require to trigger an investment in a project. The lowest “subsidies / ton of CO_2” will win – project selected on price until budget is spent. Public spending to trigger private investment.
  - The design favors energy-efficient projects, eliminating the most inefficient current systems, long payback tolerance, rapidity of implementation, etc.
  - No need for a detailed file and in-deep review. Auction would last until February 2026 and winners will be declared in April 2026.
  - First year considered as a trial, before scaling up an improved methodology. Winning offers in “€/ton of CO_2” will become benchmarks for future auctions (“Decarbonization Bank” of 100 Bn€).
  - Focus on scaling-up the electrification of process heat (incl. also solar thermal) – excluding biogas, biomass, hydrogen, carbon capture, etc.
  - Excluding building heating and cooling – minimum temperature to be determined, but would be around 70°C to 100°C. Temperature level is the main “innovation” criteria.
  - Budget of 1 Bn€ split in 2 buckets, most probably based on temperature (200°C?)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Armstrong provides intelligent system solutions that improve utility performance, lower energy consumption, and reduce environmental emissions while providing an enjoyable experience.
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