WEBINAR ON HIGH TEMPERATURE HEAT PUMPS

7 NOVEMBER 2024

ELSA Dairy case study: Integration concept & status

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Outline

- ELSA : big picture
- ELSA : energy efficiency
- CIP 0 / 3 / 4 : candidate process for HTHP integration
- Cleaning-in-Place (CIP) process
- CIP 0 measurements
- Results
- Pinch Analysis
- HP integration concept
- Comparison of HP concepts
- Conclusions

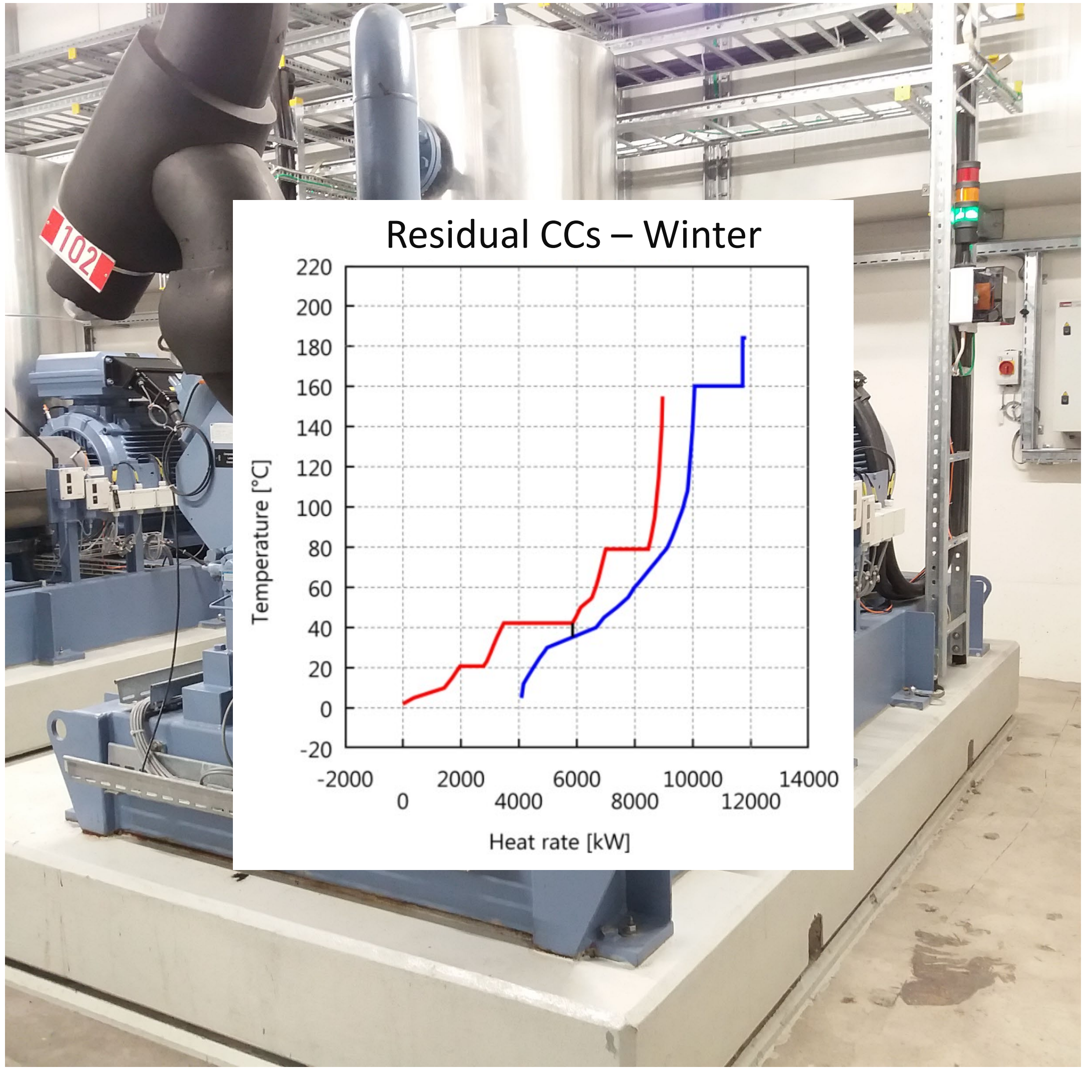
ELSA: Big picture

- Founded 1955 as a canning factory
- Dairy products since 1960
- Step-by-step site expansion
- Key data (2021):
  - 640 employees
  - 72 GWh/y heat (gas, wood ships)
  - 42 GWh/y electricity
  - 1’800’000 m^3/y city water
  - 260’000 t/y milk processed into:
    - 160’000 t/y milk (UP, UHT)
    - 52’000 t/y yogurts
    - 4’000 t/y cottage cheese
    - 6’000 t/y curd
    - 420 t/y cream
    - Desserts
  - Plant based products

ELSA : energy efficiency measures

- Various «local» opportunities implemented
- Measures mainly on utilities:
  - Ice water production
  - Ice water distribution
  - Waste heat recovery loop (UP, flash steam, NH_3, …) for hot water preheating / heating, HVAC
  - …
- Pinch Analysis (PA) in 2013 → proposed measures (% savings)
  - Improved process internal heat recovery & optimisation of production logistics (-3%)
  - Process optimisation (-8%)
  - Site level HP integration (28/40 & 60/75°C HR loops & storage tank) (-20%)

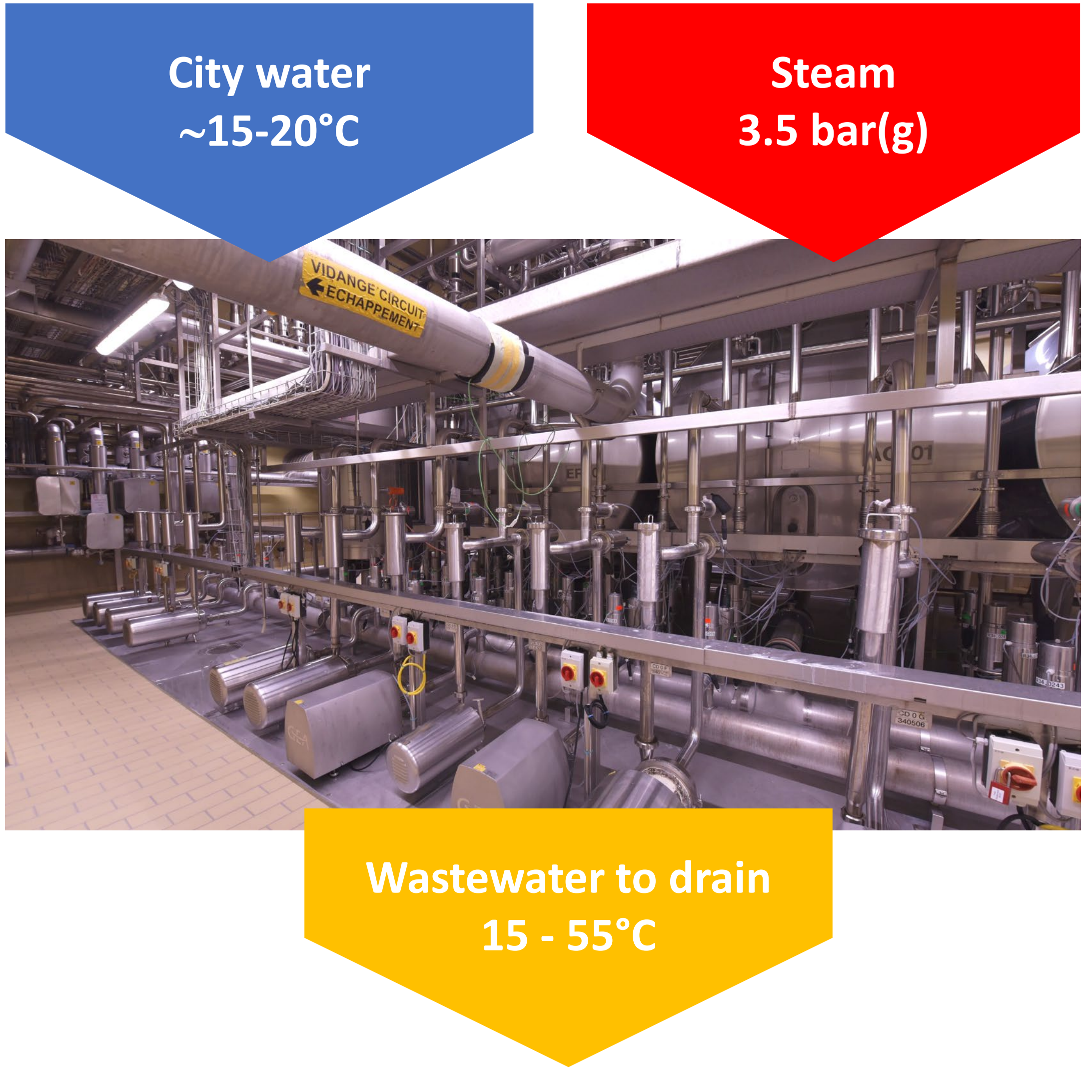
  Measures partially implemented, but not site-wide HP
- 2016: 12 t/h wood ships steam boiler → 80% of the steam consumed on site
- Further measures, road map 2030, …
- Hard constraints: densely-packed production facilities, no free space for HP, piping, storage



CIP: candidate process for (HT)HP

- CIP stations 0 / 3 / 4 at the same place
- 515’000 m^3/y city water (28% of site)
- ~ 15 GWh/y steam at 3.5 bar(g) (21%)
- Large waste heat source available in immediate vicinity of CIP 0 / 3 / 4 :
  - CIP wastewater (~ 35 °C on average)
  - NH_3 from ice water production (~ 20 °C), preferred source to reduce cooling tower load and save electricity
- Production processes unchanged !
- Two HP integration concepts:
  1. 4.5 bar(a) steam generating HP (SGHP)
  2. NH_3 HP to supply CIP with 60 °C hot water

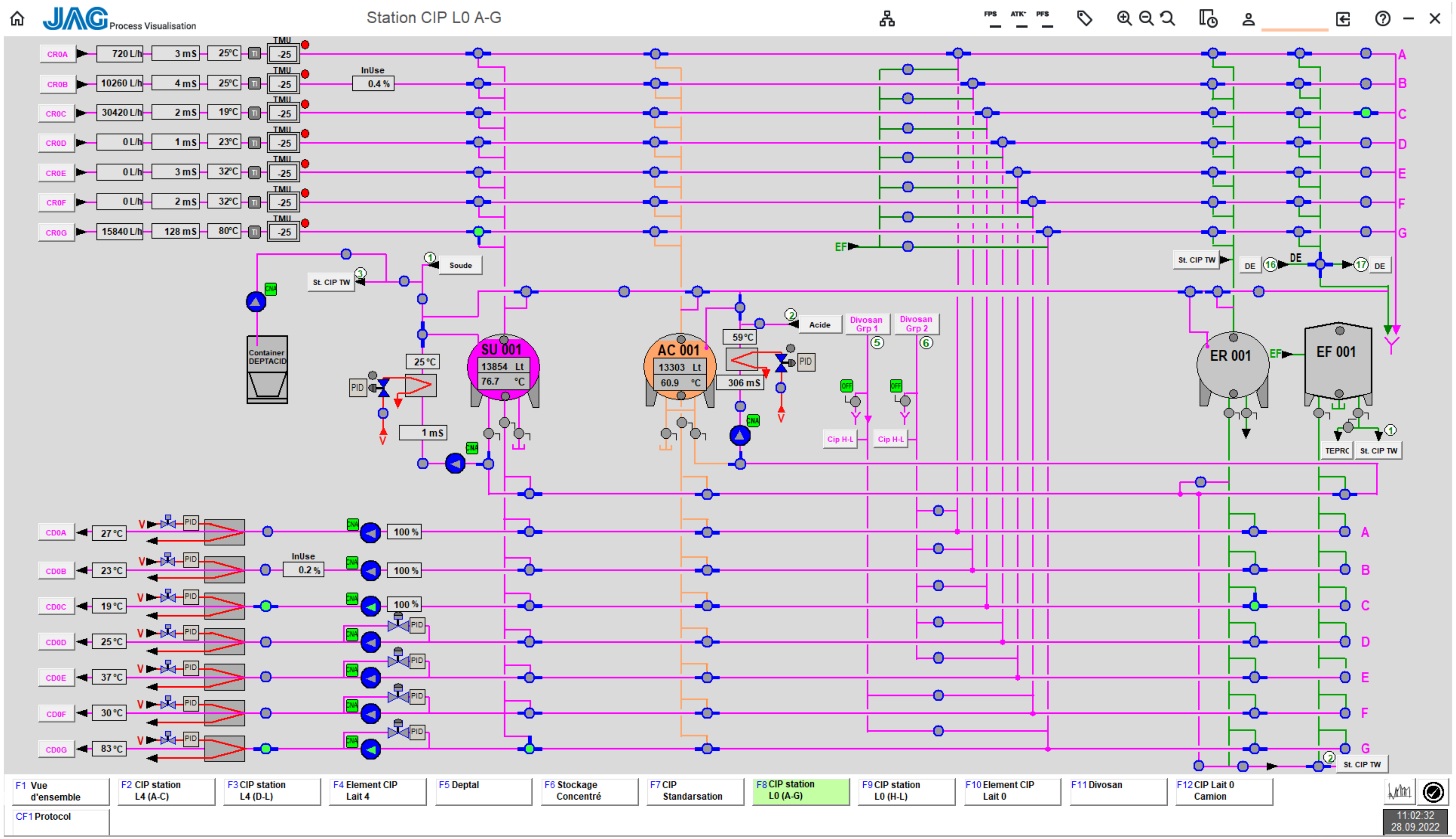
  both with NH_3 from chillers as a heat source



Cleaning-In-Place (CIP)

CIP procedure includes typically 5 steps:

1. **Pre-rinse:**
   A. Fresh water => product recovery
   B. Recycle water at 40-60 °C to remove sugar and melt fats
2. **Caustic circul. (~ 85 °C):**
   Remove proteins and fats
3. **Rinse (~ 45 °C):**
   Recycled water to purge dissolved soil and remove any detergent residues
4. **Acid circul. (~ 65 °C):**
   Dissolve mineral salts and deposits left by hard water
5. **Final Rinse:**
   A. Lukewarm fresh water
   B. Cold fresh water
   to remove any residues
   → recycled water tank



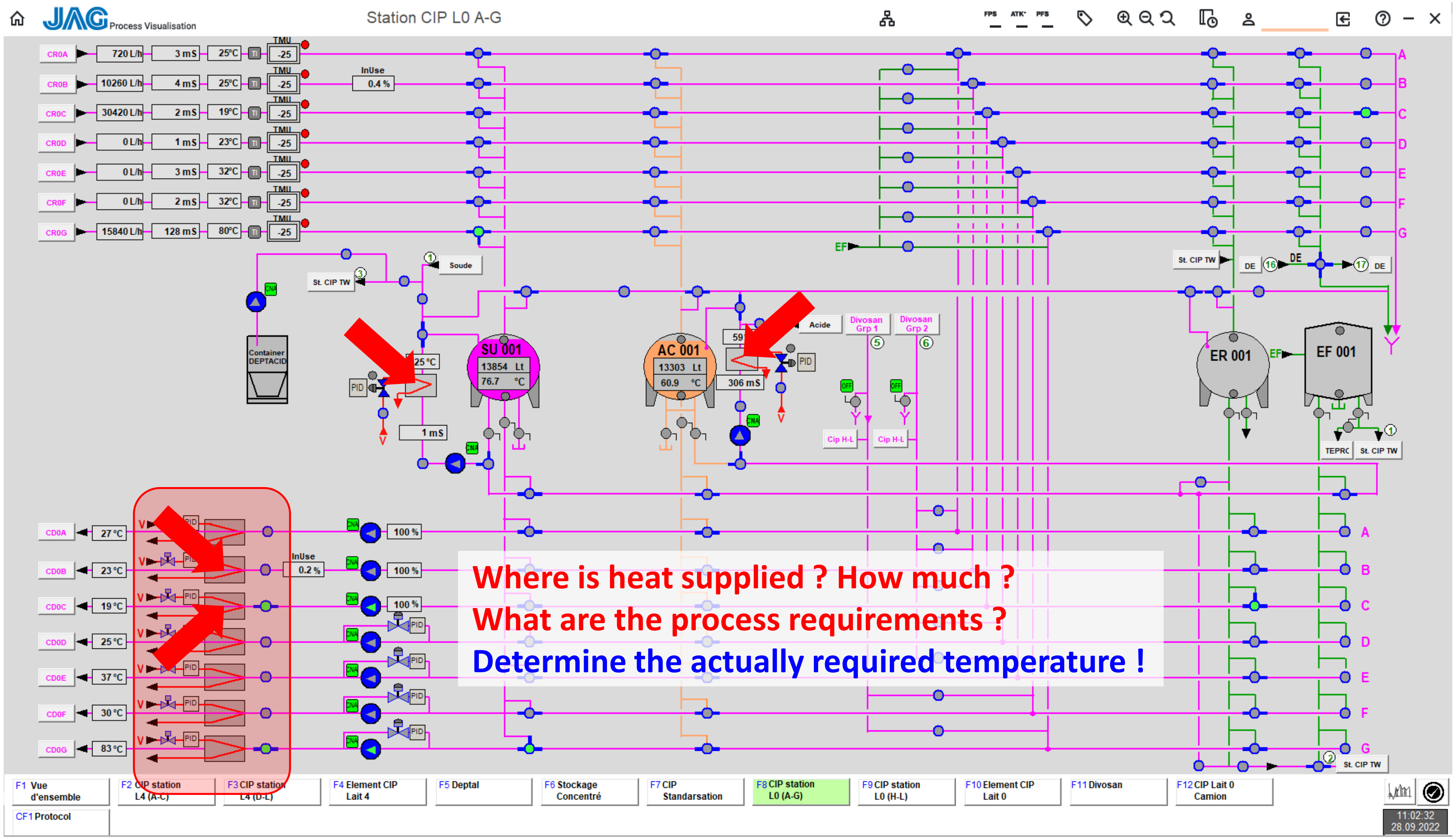
CIP 0 heat & water measurements

1. **Soda (SU) tank:**
   - Heated by steam injection in circul. loop
   - Intermittent make-up with fresh water (not preheated)
2. **Acid (AC) tank:**
   - Heated by steam injection in circul. loop
   - Intermittent make-up with fresh water (not preheated)
3. **Recycled water (ER):**
   No heating (variable T)
4. **In-line HEXs:**
   - Steam heated
   - Ensure heating of CIP media to circuit specific set-point tmperature

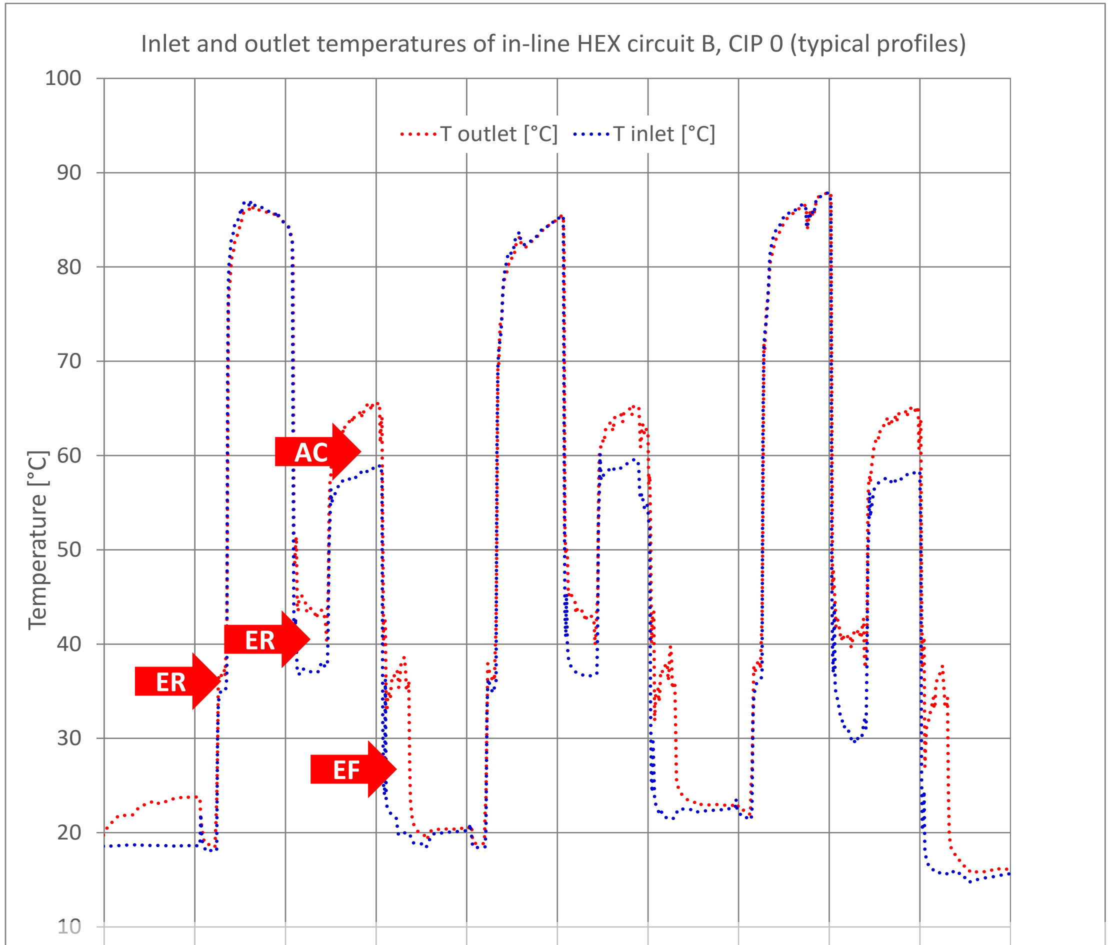
Measurements

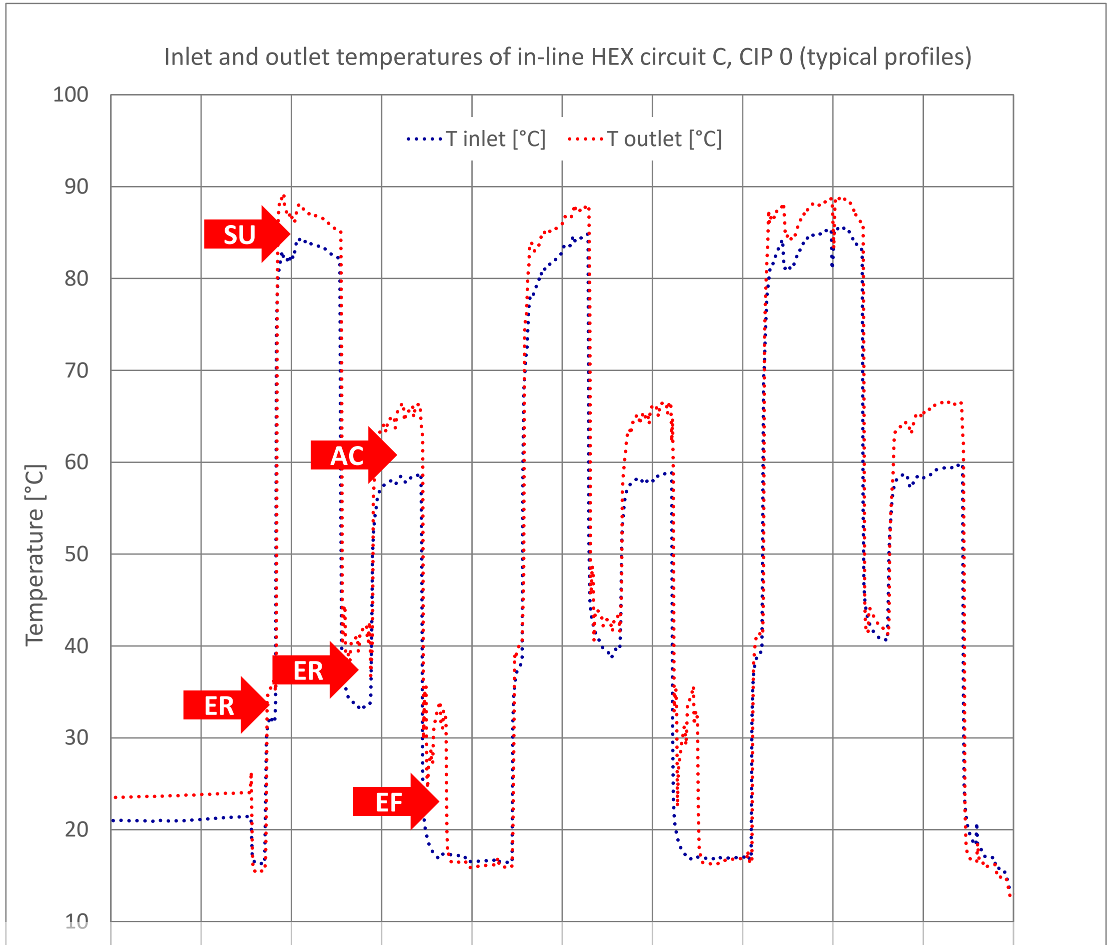
Temperature & mass flow for:

- SU & AC tanks T holding
- In-line HEXs circuits B & C



Results: Heating by in-line HEXs





→ Shift ~75% of SU, AC, ER media heating by in-line HEXs to tanks by increasing their set-point temperature !

SU: Soda
AC: Acid
ER: Recycled water

Results: Heat & water balance CIP

Make-up water CIP 0+3+4

SU tanks (90 °C)

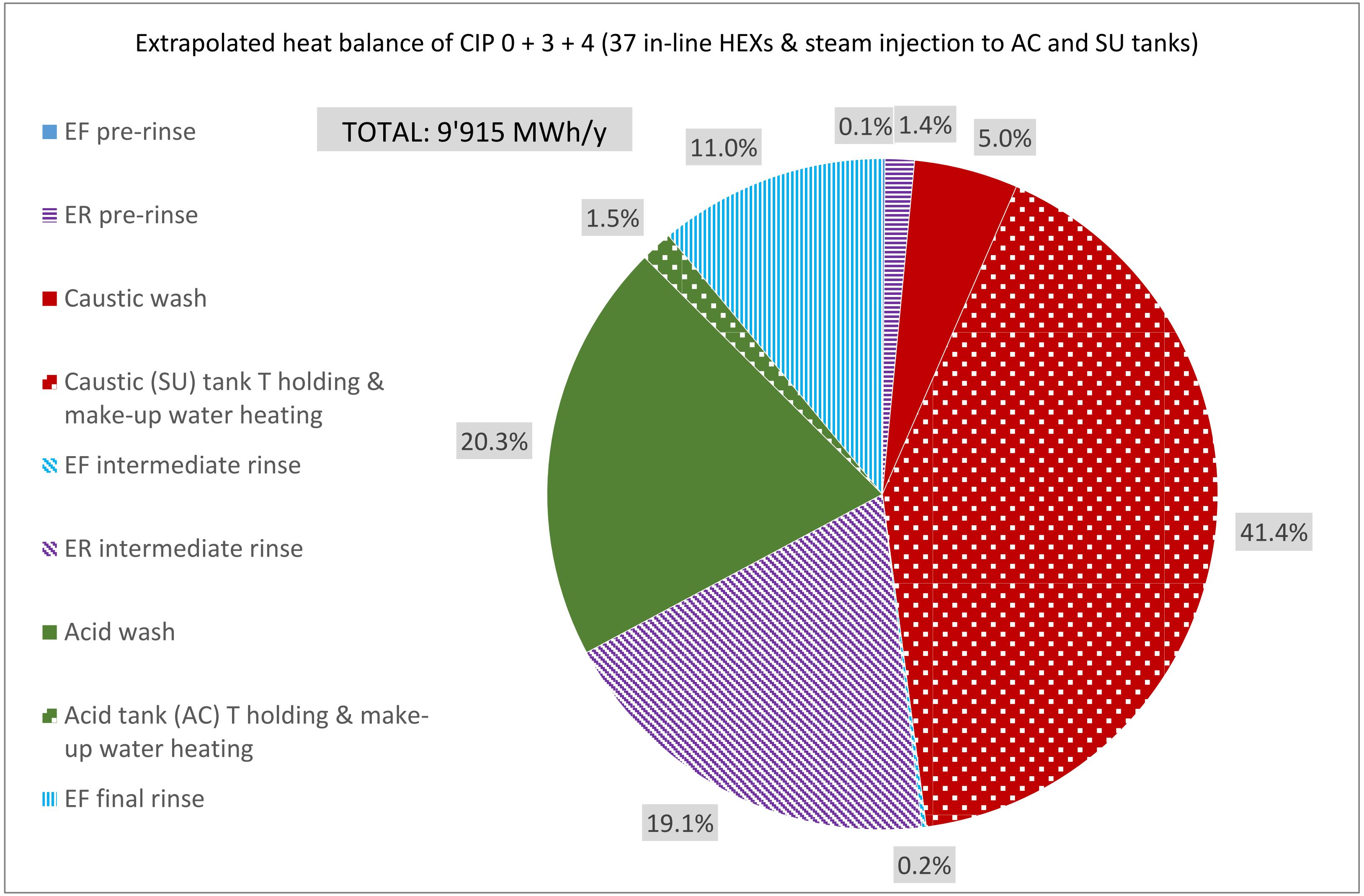
- 9’820 m^3/y as fresh water
- 5’553 m^3/y as injected steam

AC tanks (65 °C)

- 10’765 m^3/y as fresh water
- 180 m^3/y as injected steam

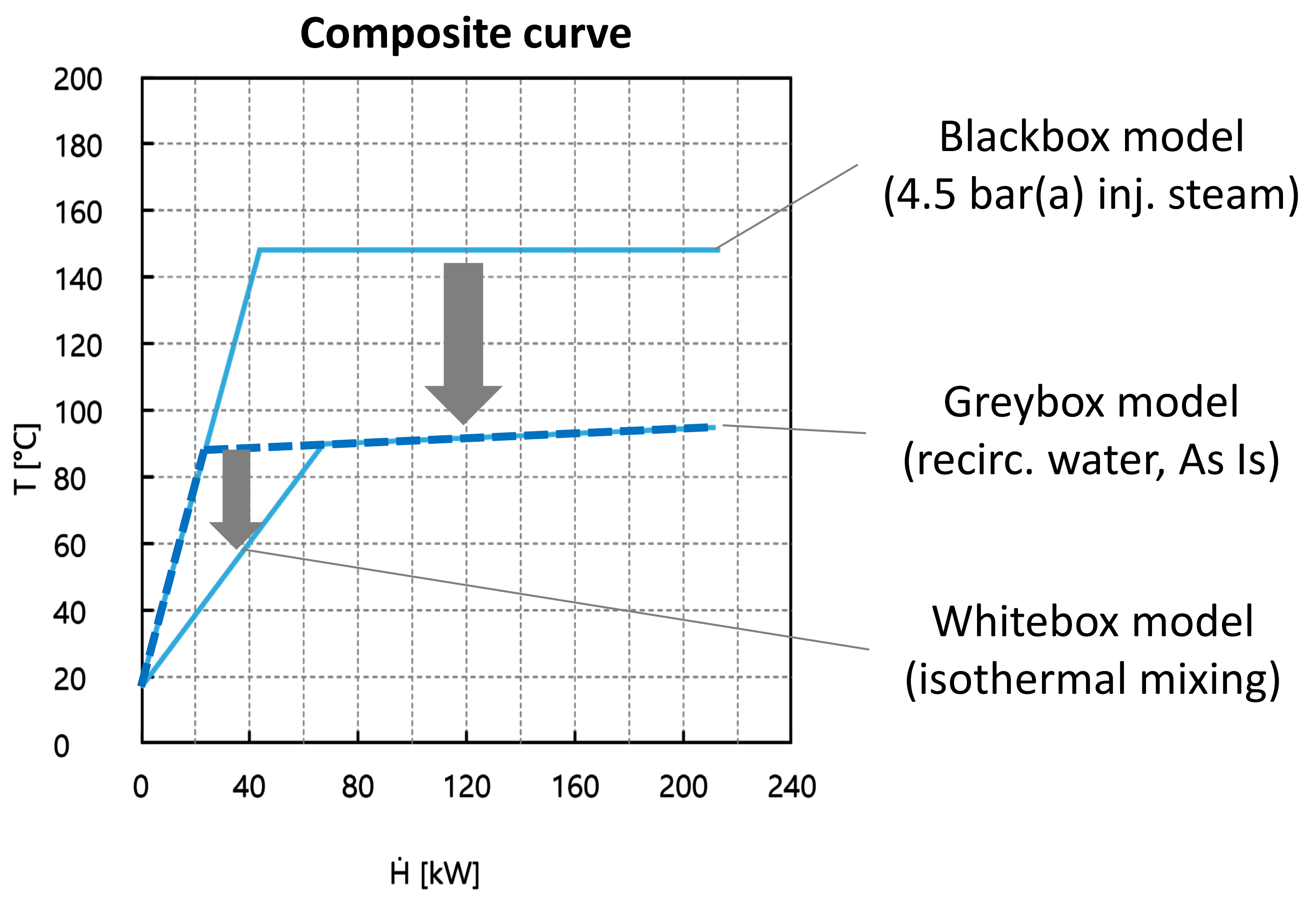
Note:

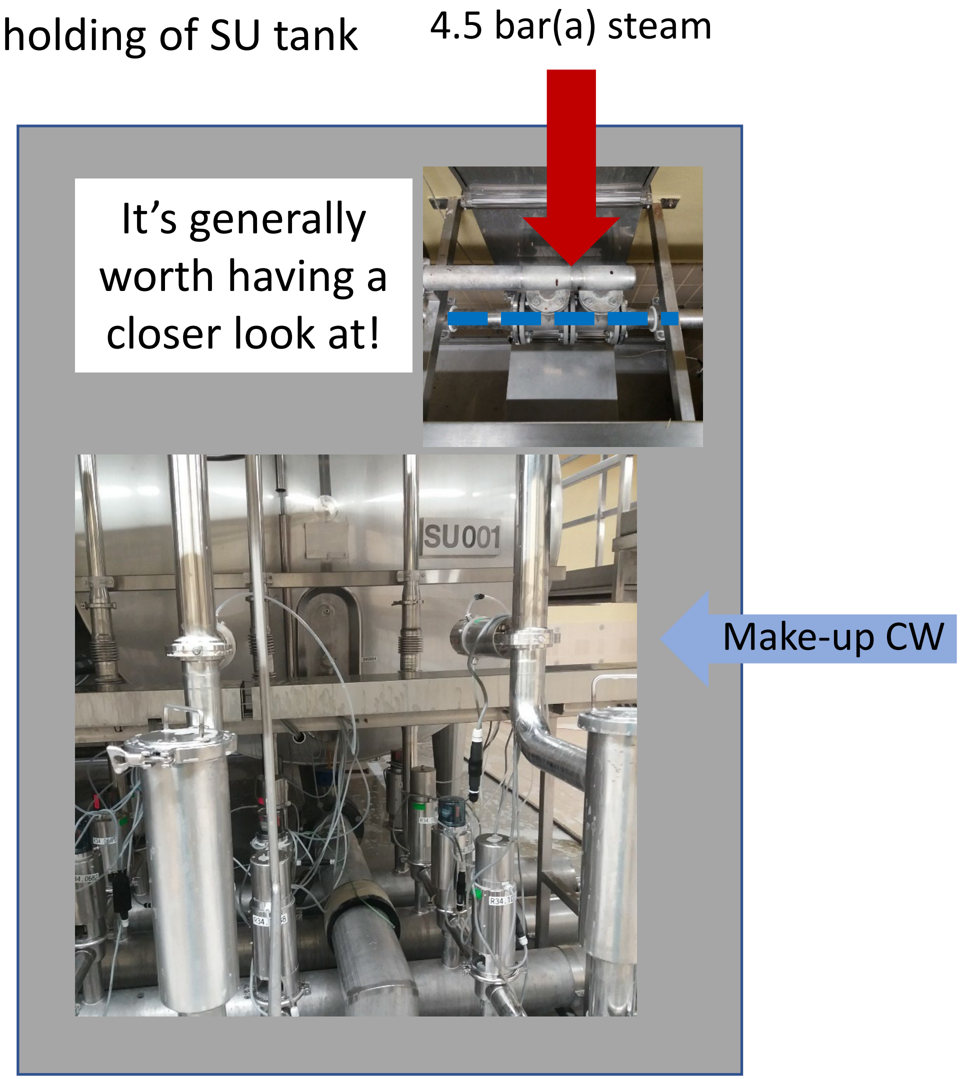
The heat supplied to AC tanks as injected steam is much lower than that needed for make-up water heating ⇔ the return temperature is higher than the flow temperature → “external” heating of AC tanks



Benefits of PA process analysis …

Case of heating requirements for make-up water heating and temperature holding of SU tank



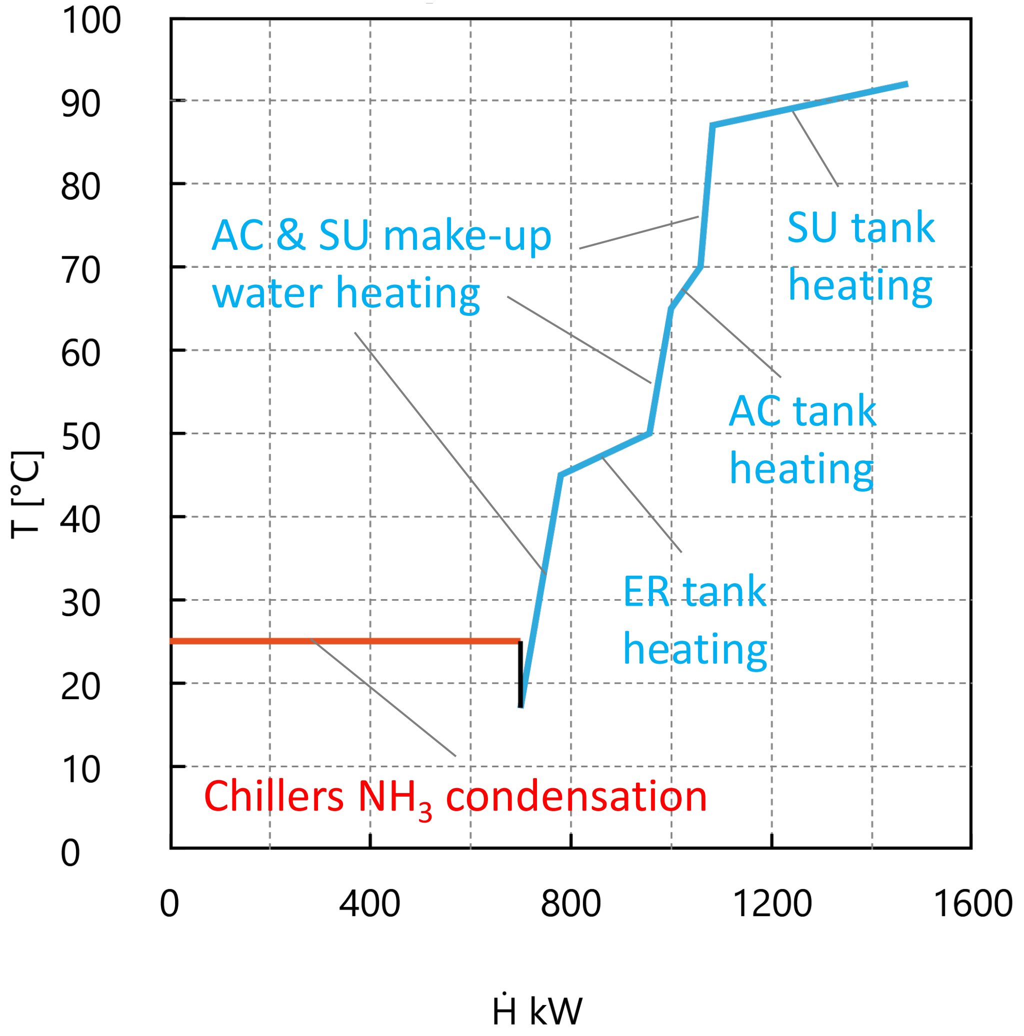


Time-averaged composites curves

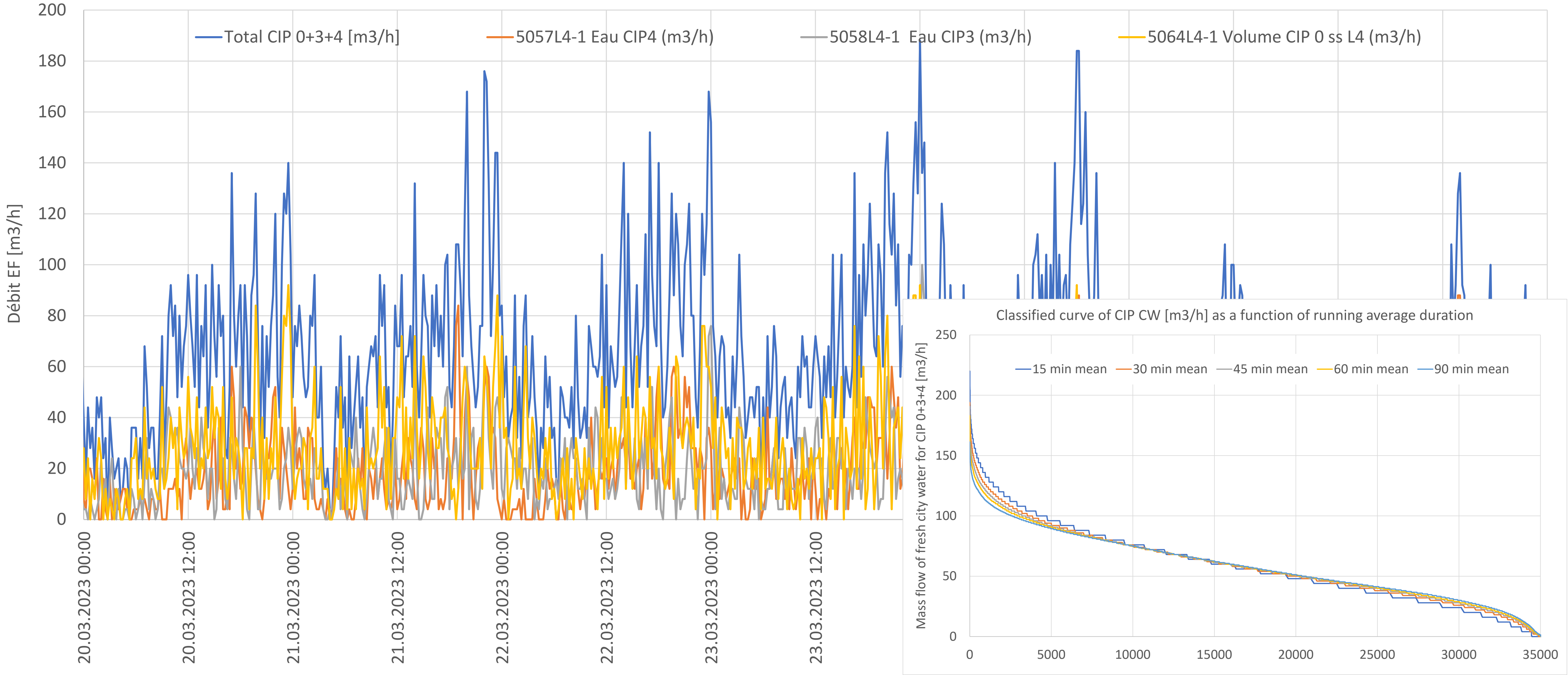
Yearly average composites curves !

These CCs **don't include**:

- CIP wastewater (ELSA constraint → focus on NH_3 condensation)
- Residual final heating to CIP-circuits specific T set-point by steam heated in-line HEX (remaining 25% not shifted to ER, AC & SU tanks + final rinse heating)
- Remaining need for injected steam for AC tank T holding (30% conservative):
  - HP not sized for largest required heat duty, even with heat storage (lack of space)
  - Around midnight, NH_3 heat source may be too limited for the peak of CIP activity



Variability in level of CIP activity



HP integration concept #1

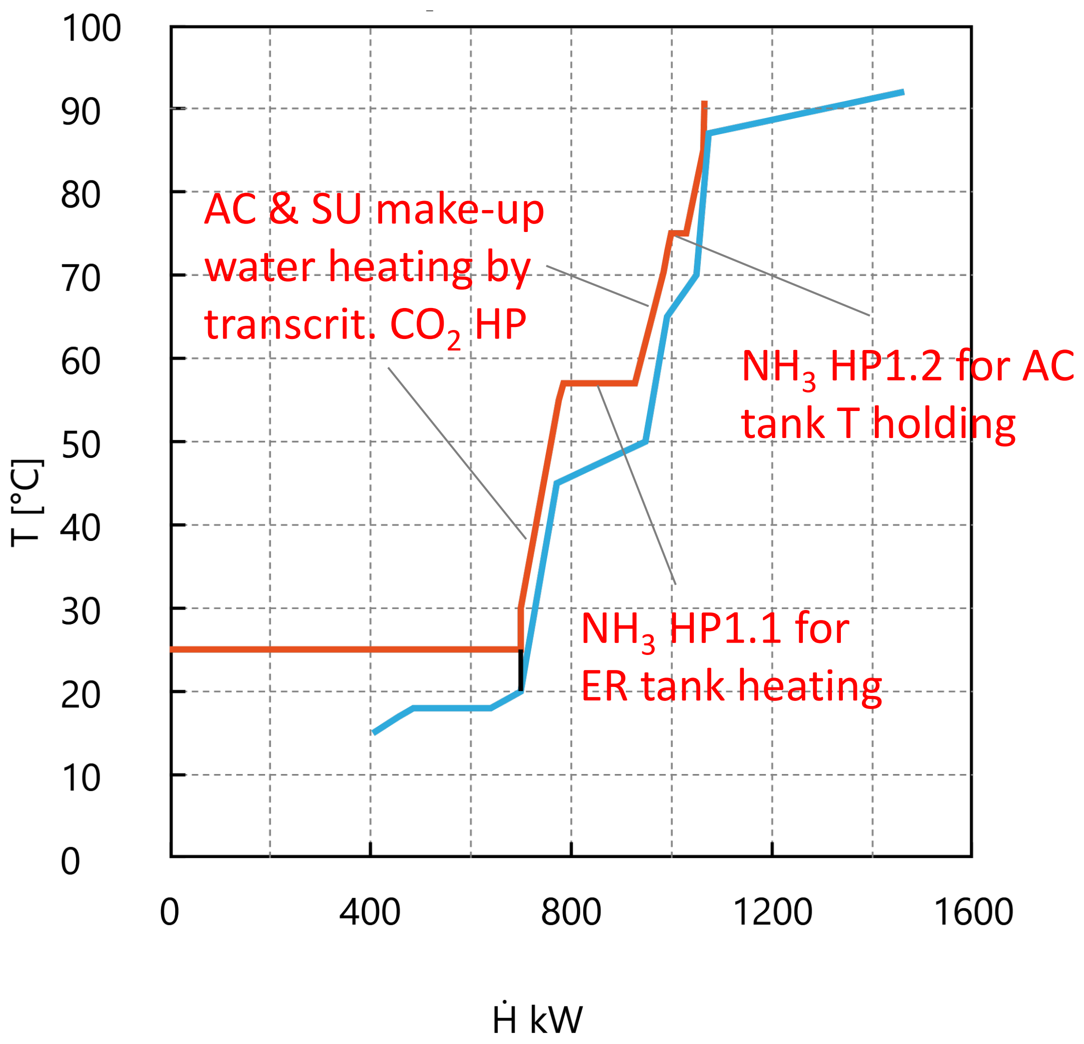
Solution combining two HPs with different cycles to match requirements:

- Transcritical CO_2 HP (+ heat storage) to heat make-up water up to 75°C:
  - High COP = 4.45
  - Confirmed technology, of-the-shelf machine
- NH_3 2 circuits-HP (+ 2 heat storages):
  1. Heating ER tank (HP1.1), COP = 4.6
  2. T holding AC tank (HP1.2), COP = 3.0

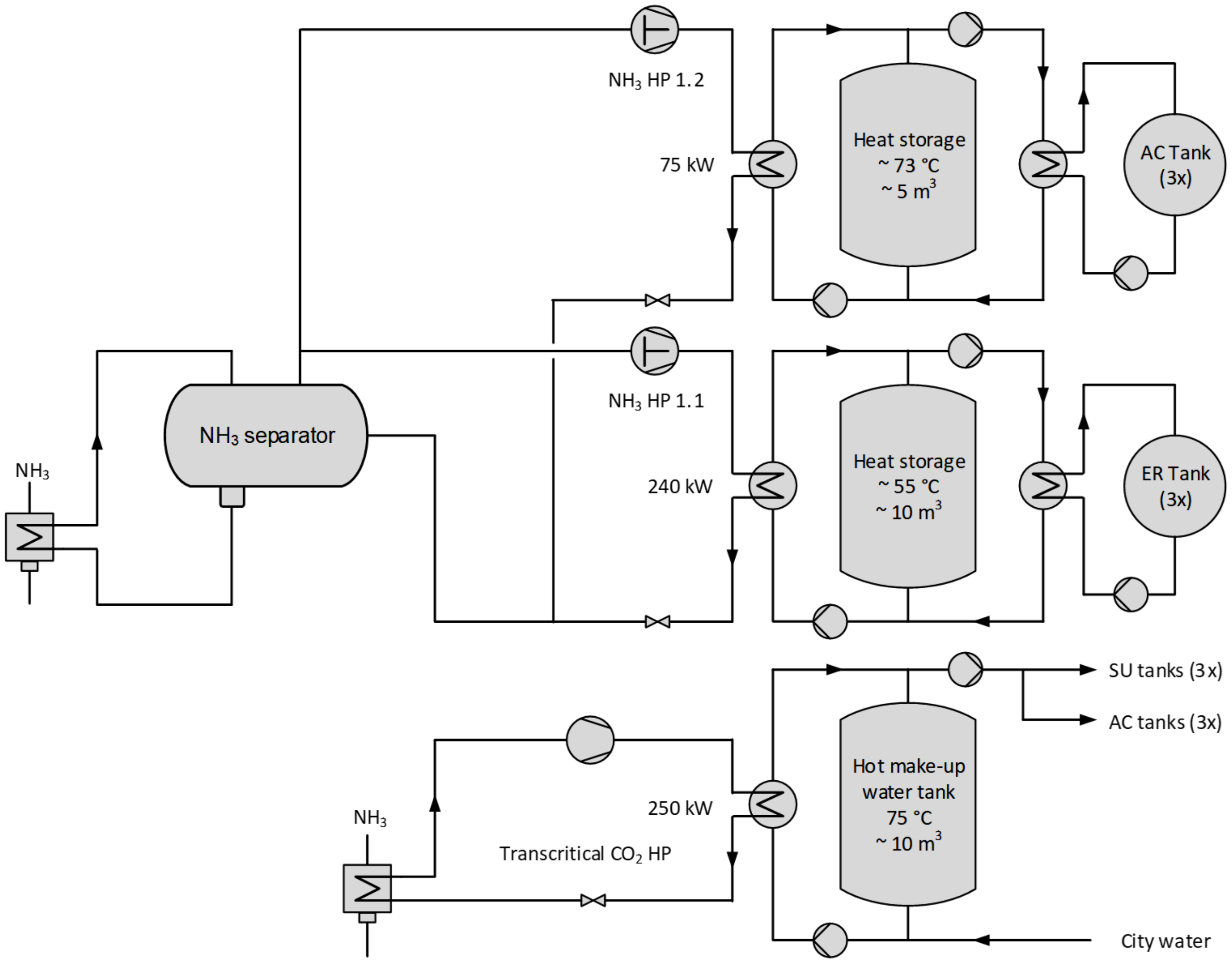
Overall COP = 4.3 … but quite complex

- **No HP for T holding of SU tank since**:
  1. Large temperature lift, low COP = 2.2 – 2.4
  2. Lack of free space for required heat storage

CIP 0+3+4 Time-averaged composites curves



Schematic diagram



Comparison of concepts

HP concept	Design data ($Q_{rated} \cong 1.5 \times Q_{mean}$)	COP [1]	Savings [2, 3]	Evaluation
Steam generating HP 4.5 bara	$Q_{rated} \cong$ 1'200 kW @ 4.5 bara	≅ 1.6	≥ 6'000 MWh/y ≥ 309 to CO_2/y	++ Largest savings ++ Simple integration, «no change» - No storage capacity on stean side - - - Poor profitabilty, if any
1-T NH_3 HP Make-up water to 60°C ER tank heating	$Q_{rated} \cong$ 400 kW	≅ 4.0	≥ 2'365 MWh/y ≥ 122 to CO_2/y	++ Standard technology ++ High COP (low OPEX) + Large savings + Limited CAPEX (mutualisation of HP capacity, but 2 storages)
CO_2 + NH_3 2-T HP Make-up water to 75°C ER tank heating AC tank T holding	CO_2 HP : $Q_{rated} \cong$ 250 kW NH_3 HP1.1 : $Q_{rated} \cong$ 240 kW NH_3 HP1.2 : $Q_{rated} \cong$ 75 kW **Overall**	≅ 4.4 ≅ 4.6 ≅ 3.0 **≅ 4.3**	≥ 1'460 MWh/y ≥ 75 to CO_2/y ≥ 1'420 MWh/y ≥ 73 to CO_2/y ≥ 324 MWh/y ≥ 17 to CO_2/y **≥ 3'204 MWh/y ≥ 165 to CO_2/y**	++ Standard technology ++ High overall COP (low OPEX) + Large savings (CO_2 + NH_3 HP1.1) - HP1.2 for AC tank not worth - High CAPEX

[1] Not including the electricity savings resulting from reduced load of cooling towers (lack of data regarding their operation)

[2] Based on conservative assumptions, energy savings (and CO_2 emissions reduction) can be up to 30% larger

[3] CO_2 emissions reduction calculated assuming saved steam stemming 20% from gas and 80% from wood, and CO_2 free electricity

Conclusions

- CIP process is energy intensive and tricky too (stochastic operations) !
- Process knowledge is key for energy efficiency → HTHP not needed, HP OK
- Several reasonably interesting concepts with different «profiles»
- Transcritical CO_2 HP + NH_3 HP with 2 circuits ensure optimal matching of CIP heating requirements and high COP, but is CAPEX-intensive (includes 3 storages)
- OPEX and CAPEX not yet calculated (size *vs.* savings trade-off difficult to calculate)
- HP and wood ships steam boiler are competing in CO_2 emissions reduction
- Heat recovery / heat upgrading before resources substitution, not vice-versa !

Thank you for your attention !