Heat Pump Integration in a Cheese Factory

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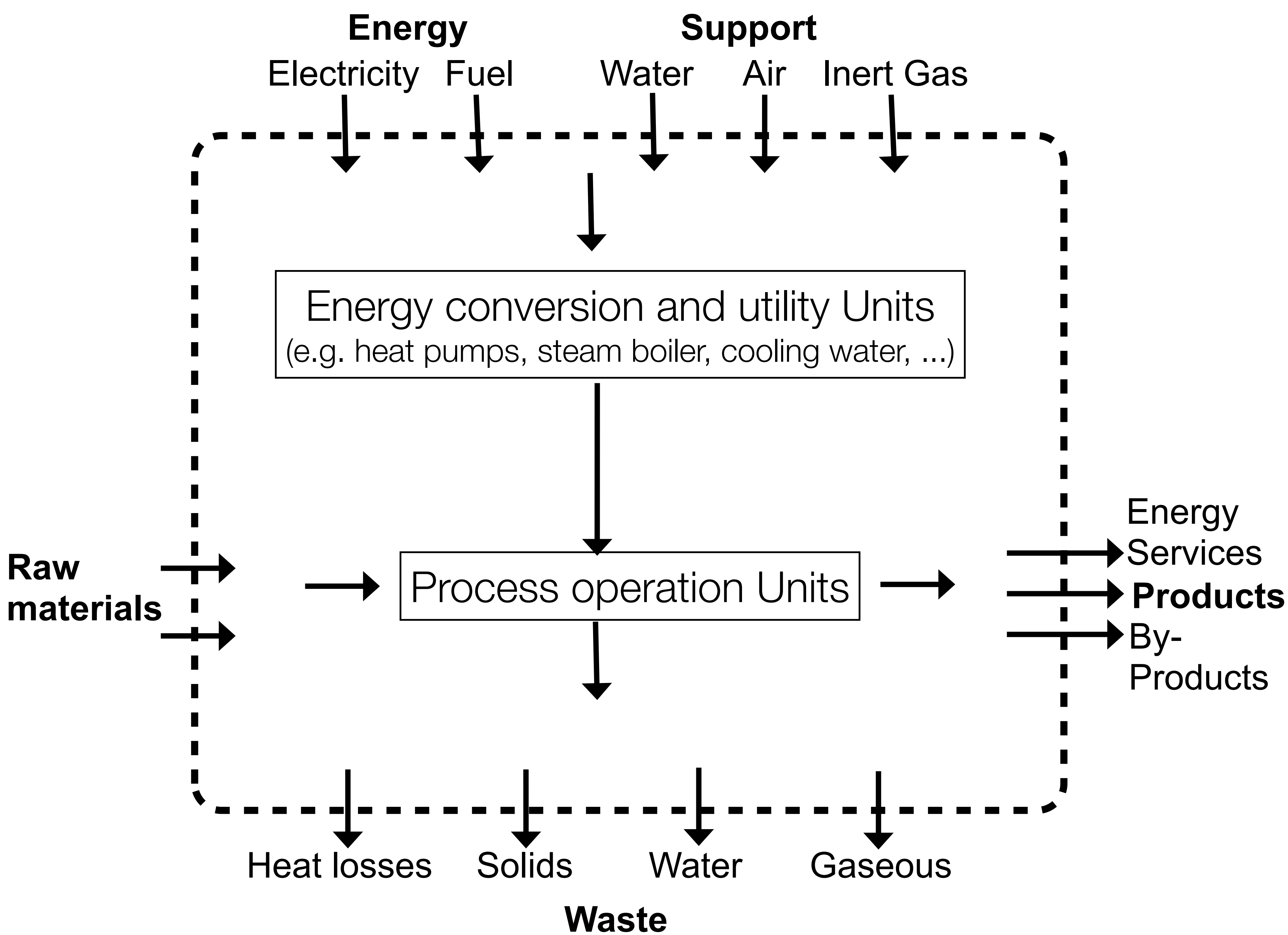
Outline

- Introduction
  - Process integration / heat pump integration
  - Example of a cheese factory
- Methodology - Heat pump integration
  - Option 1: without process modifications
  - Option 2: with process modifications
- Results
- Conclusion

Process integration: Optimize the energy efficiency

Representation of industrial processes

Reducing energy consumption and operating costs

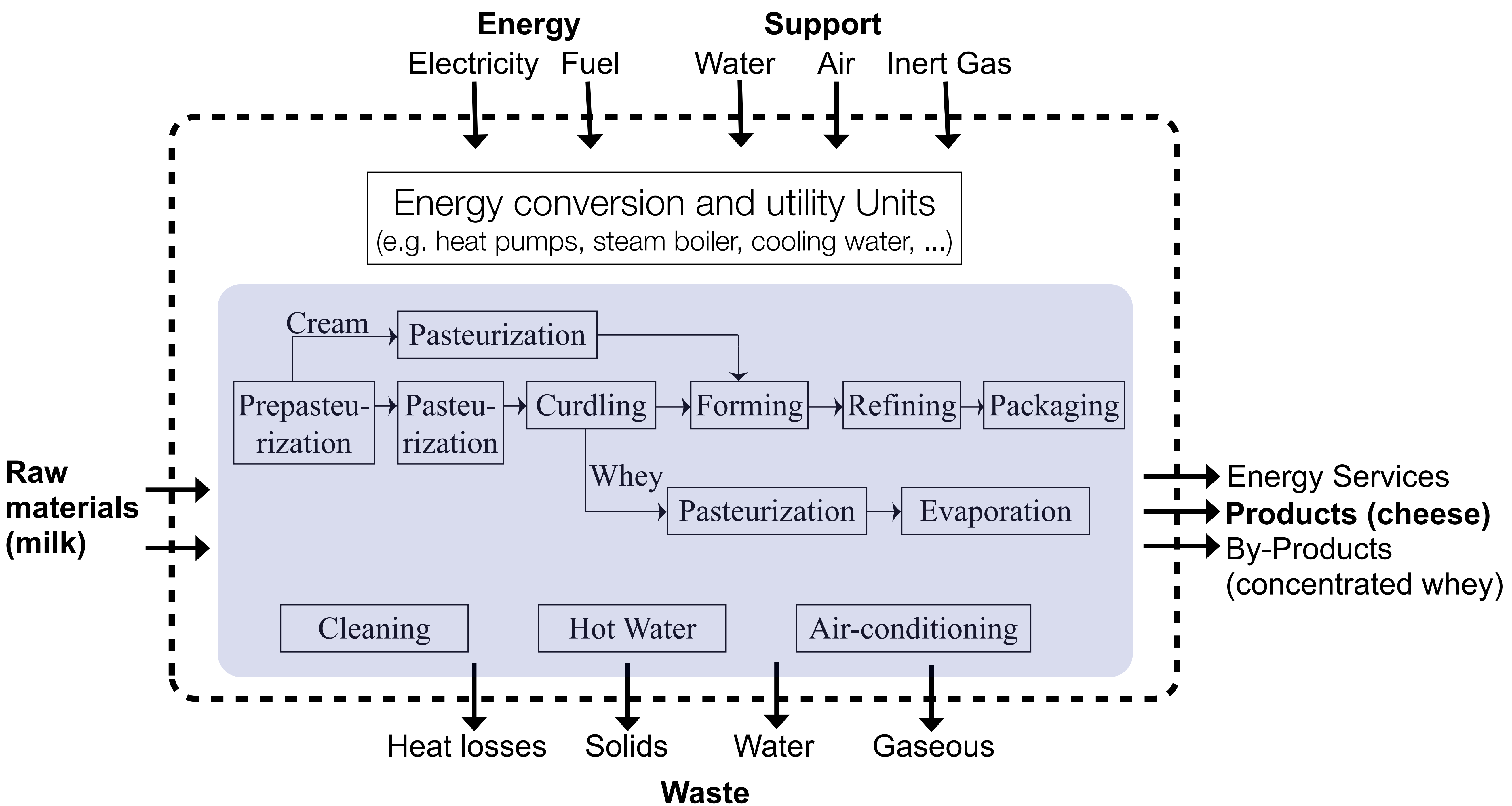


Heat pump integration

- Heat pump integration potential
- Heat pump integration options
  - No process modifications - heat exchange restrictions between process units and heat pumps --> integration of intermediate heat transfer units
    - MILP problem with additional constraints (*)
  - Process modifications - no heat exchange restrictions
    - Conventional heat cascade model (MILP problem)

* Becker H., Girardin L. and Maréchal F., 2010, Energy integration of industrial sites with heat exchange restrictions, European Symposium on Computer Aided Process Engineering - ESCAPE 20, 1141–1146.

Example of a cheese factory



Process heat requirement definition

- Process operation units
- Definition of process streams for heat integration

★ Evaporation unit is modeled considering the existing thermal vapour compression

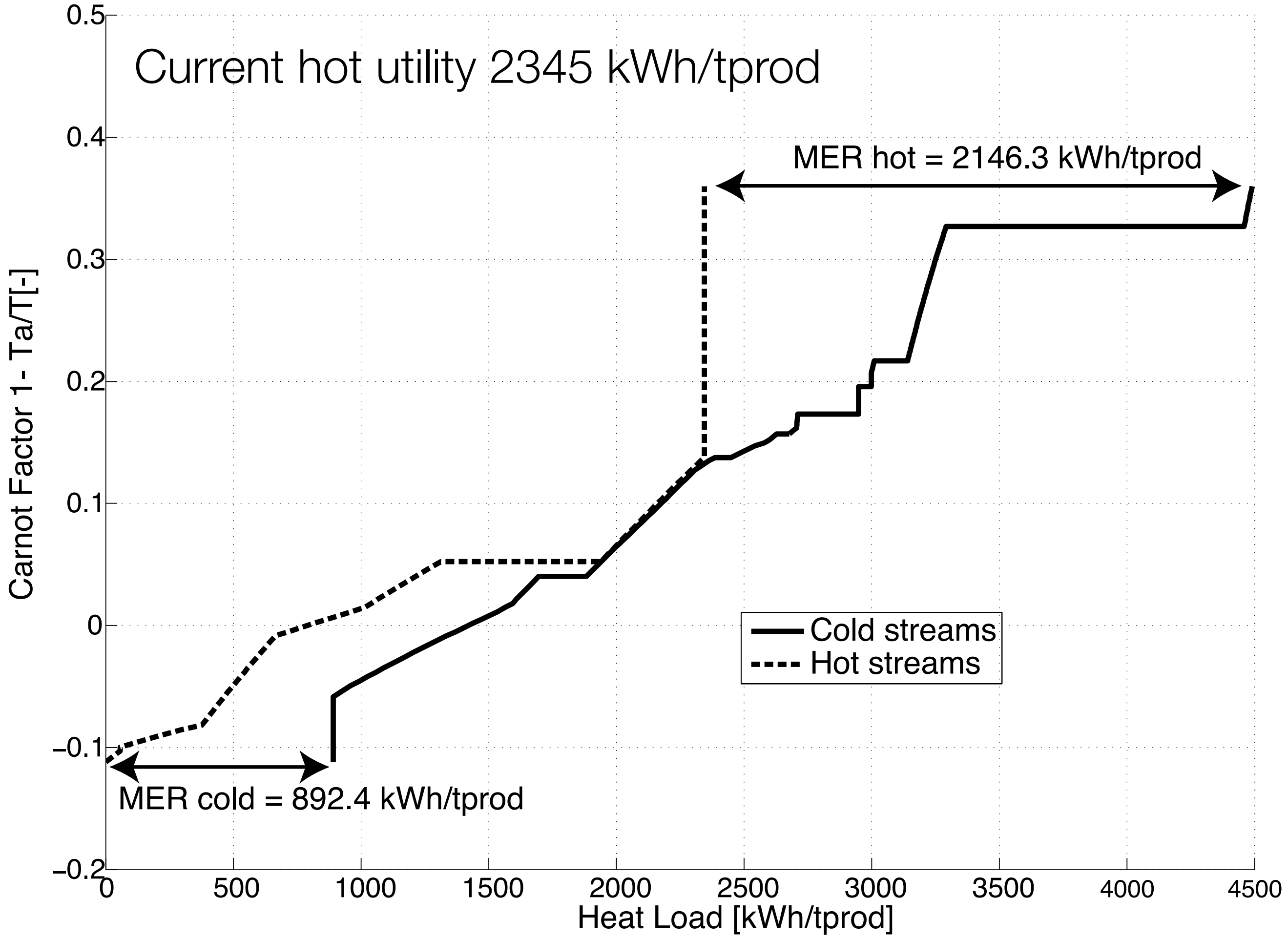
Table 1: Process streams, $\Delta T_{min/2}$ values: 2.5 °C (liquids), 1 °C (gases)

Unit	Name	Tin [°C]	Tout [°C]	Heat load [kWh/tprod]	Unit	Name	Tin [°C]	Tout [°C]	Heat load [kWh/tprod]
other	other_c1	100	190	367.8	pasto3	pasto3_c1	74	80	84.1
	other_h1	5	0.5	307		pasto3_c2	6	28	308.2
	other_h2	-0.3	-2.5	56.9	pasto4	pasto4_c1	69	75	32.1
★ evapo tech	evapo_c1	100	190	993.7		pasto4_c2	8.5	26	83.3
	evapo_h1	44	5	32.9	pasto5	pasto5_c1	66	76	54.2
	evapo_h2	44	25	198.1	proc6	proc6_c1	105	105	131
	evapo_h3	44	44	627.8		proc6_c2	78	78	49.6
pasto1	pasto1_c1	6	48	568.2		proc6_c3	95	95	49.6
	pasto1_c2	48	75	344	proc7	proc7_c1	15	55	40.4
	pasto1_h1	75	4	904.6	proc8	proc8_c1	70	70	62.6
pasto2	pasto2_c1	79	85	5	proc9	proc9_c1	35	35	33.8
	pasto2_h1	54	4	41.9	proc10	proc10_c1	32	25	175.5
heat	heat_c1	35	35	153	CIP	clean_c1	85	85	238

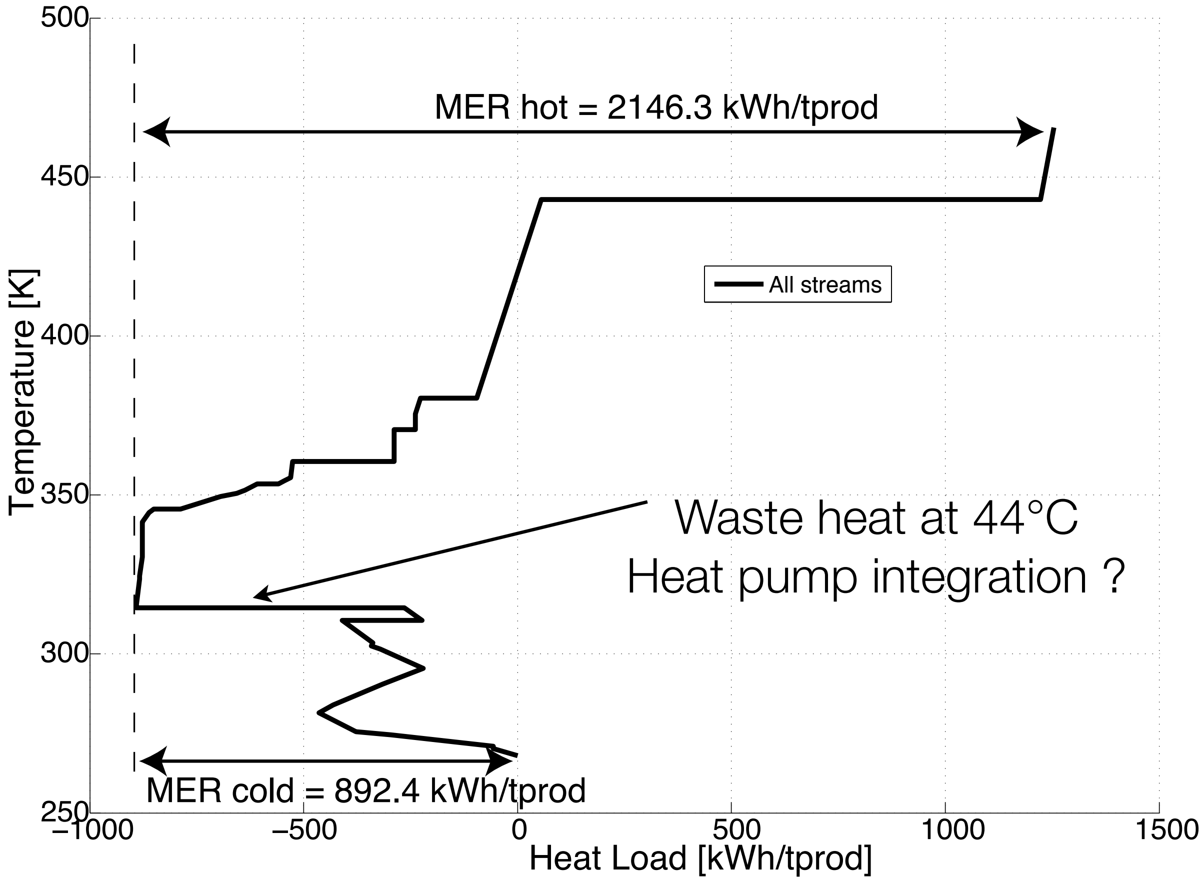
tprod
tons of product

Energy Integration

Hot and cold composite curves



Grand composite curve



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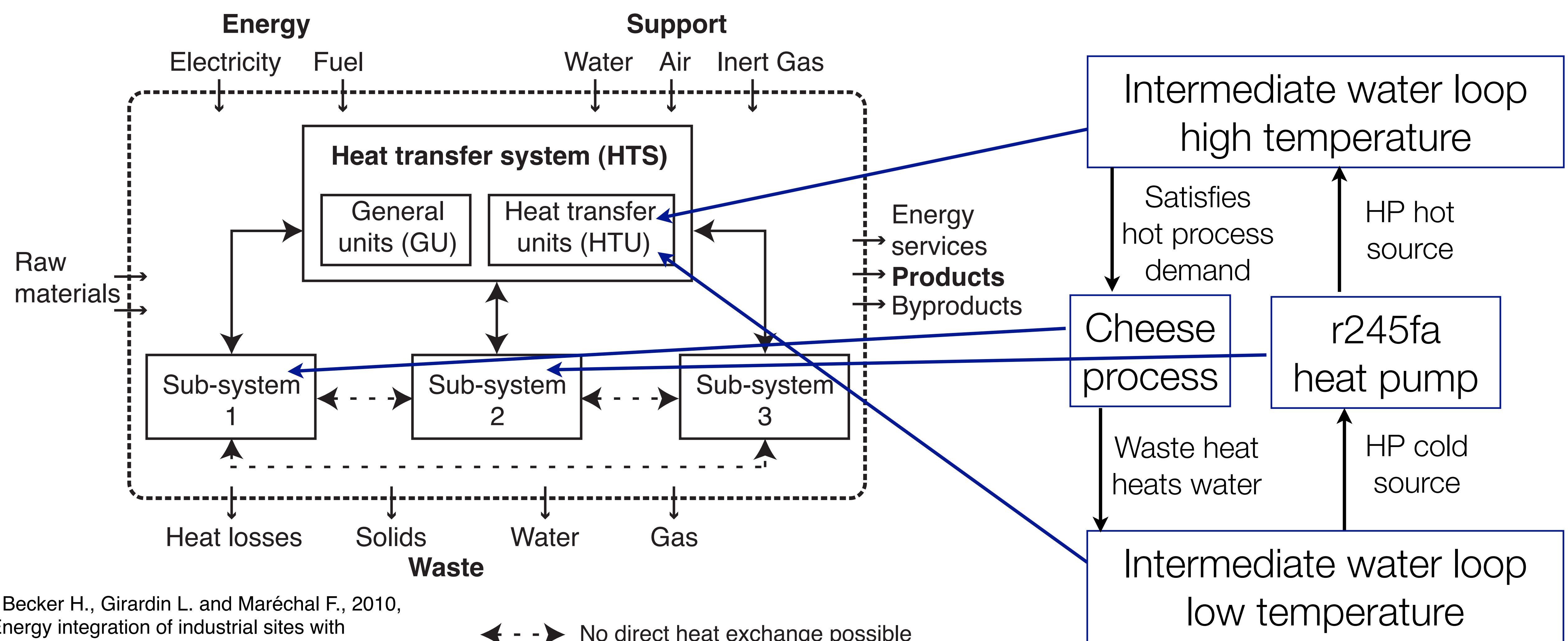
Methodology - indirect and direct heat pump integration

- Indirect heat pump integration
  - Heat pump cannot exchange directly with the process
  - Closed cycle heat pump
  - Process modifications are not allowed
  - Transfering heat via intermediate heat transfer units
- Direct heat pump integration
  - Heat pump can exchange directly with process
  - Open cycle heat pump / mechanical vapour compression
  - Process modifications are allowed
  - Modifying layout of evaporation unit

Indirect heat pump integration

- Introduction of subsystems with restricted matches *
- Introduction of intermediate heat transfer units (two water loops)



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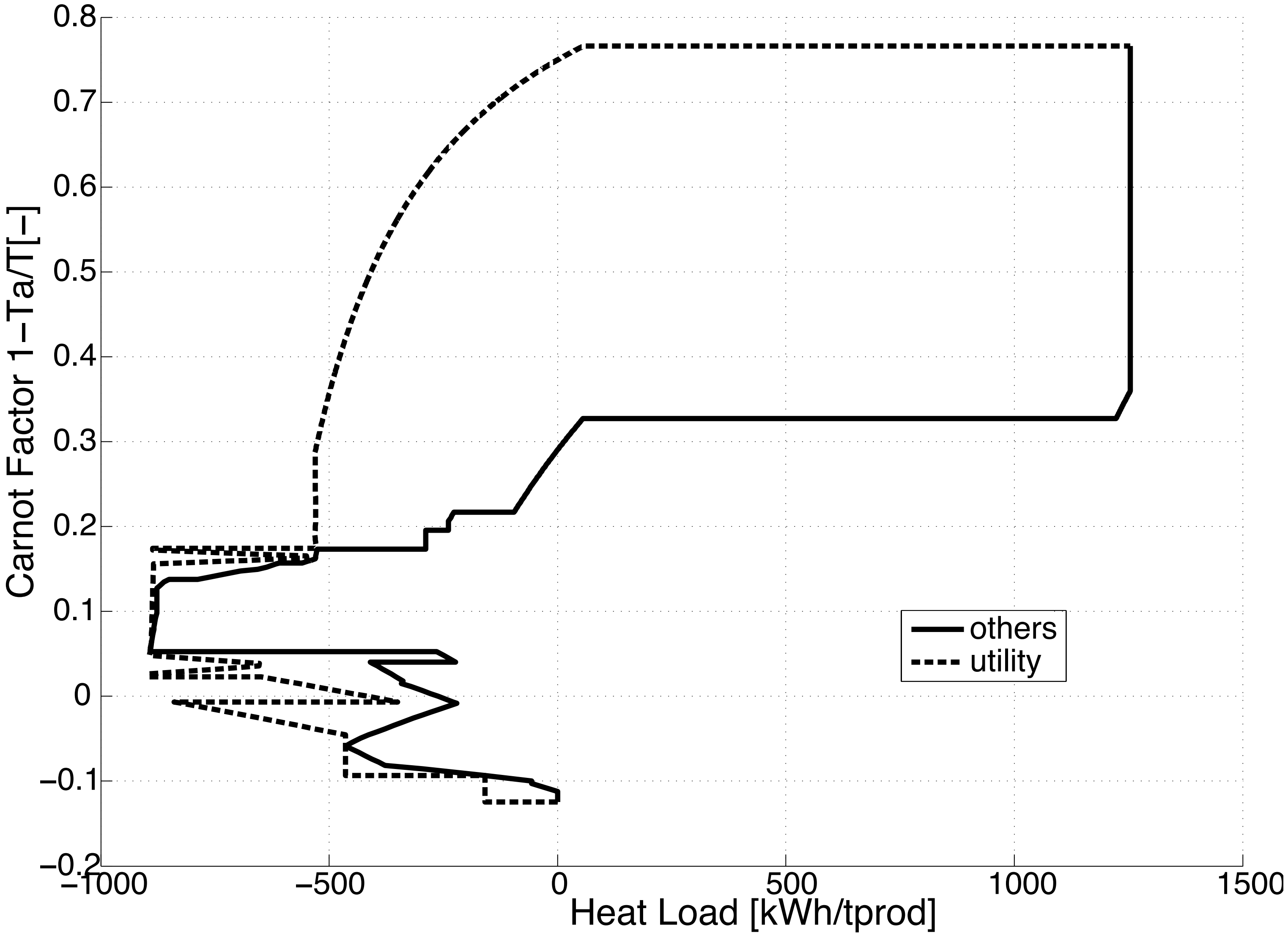
< - - > No direct heat exchange possible
<——> Direct heat exchange possible

Indirect heat pump integration



Natural gas consumption: 2157 kWh/tprod
Current natural gas consumption: 2895 kWh/tprod

Saving potential 25 %

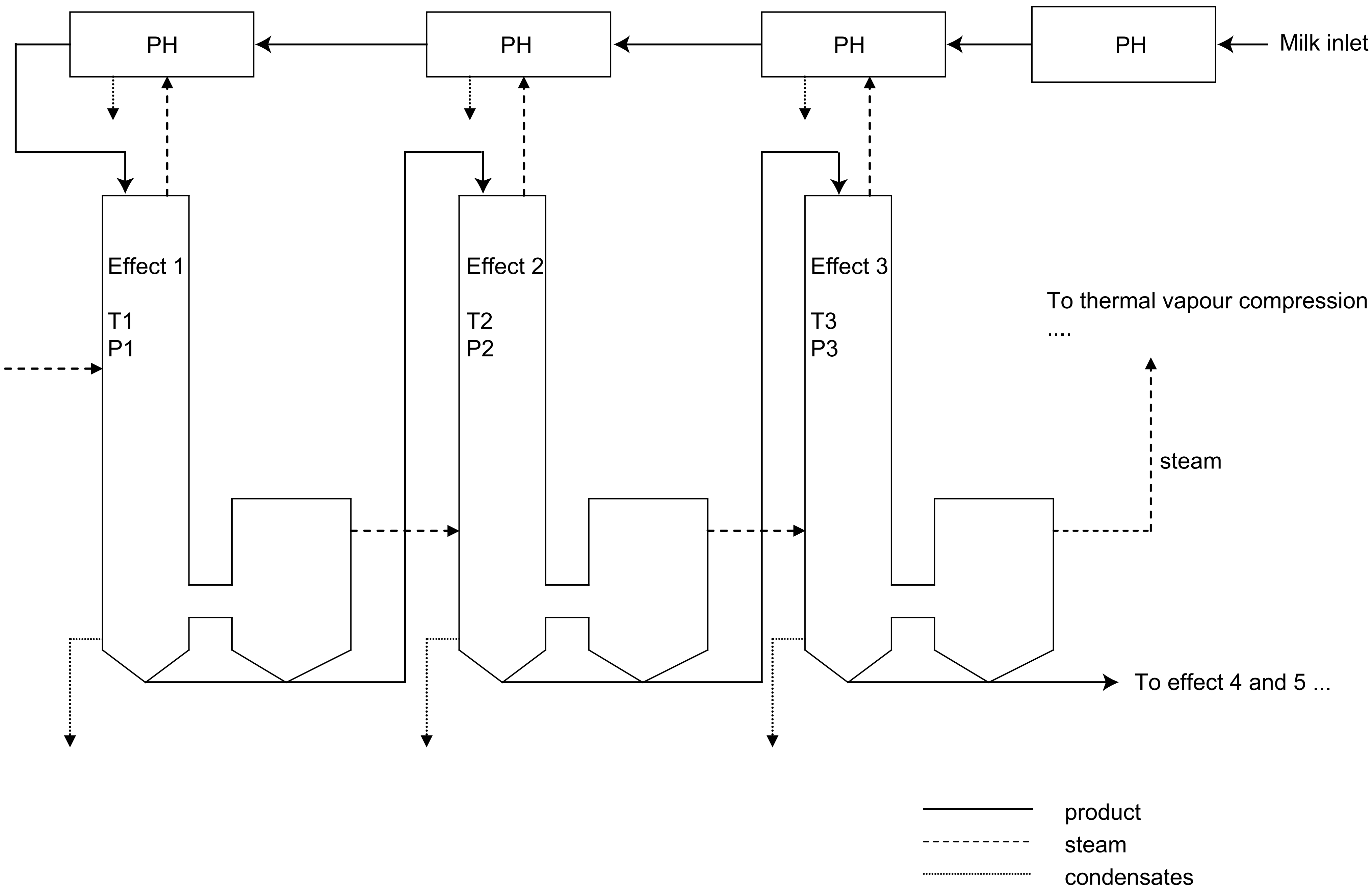
- Advantages
  - No process modifications --> no supplementary investment costs
  - Safety and product quality
- Disadvantages
  - High temperature lift --> small COP
  - Considering storage problem --> supplementary costs

Direct heat pump integration - Analyzing evaporation unit

Waste heat producer for heat pump

Optimizing evaporation unit ?

Replacing thermal vapour compression with a MVR unit ?



Direct heat pump integration - Process modifications

- Keep evaporation layout
  - CASE A : Thermal vapour compression is replaced with mechanical vapour compression (MVR)
- Modify pressure of effects
  - CASE B: Realizing all effects in parallel & integration of a MVR unit
  - CASE C: Optimizing layout of evaporation & integration of 3 MVR units
    - Constant area of each evaporator $Q_i = U_i \cdot A_i \cdot (T_{vap} - T_{prod})$

Direct heat pump integration

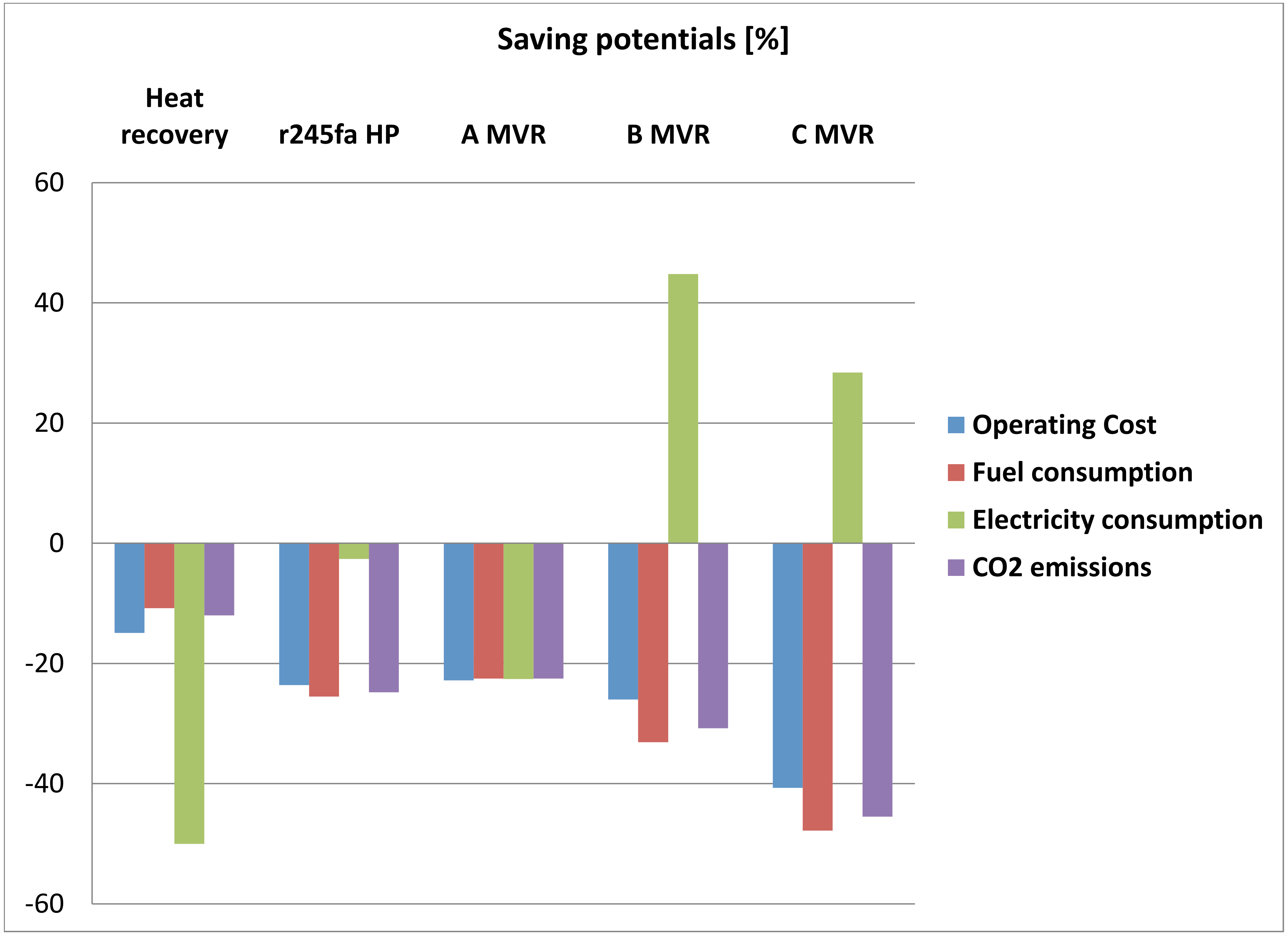
- Advantages
  - Better energy efficiency
  - No storage problem
- Disadvantages
  - Process modifications may give higher investment costs
  - MVR is in direct contact with the product

Comparison of scenarios

- Current consumption: 2895 kWh/tprod of natural gas, 194 kWh/tprod of electricity
- Results with heat pump integration

		Heat recovery ↓	r245fa HP ↓	A MVR ↓	B MVR ↓	C MVR ↓
	Unit	Case1	Case2	Case3	Case4	Case5
Operating Cost	[Euro/tprod]	107	96	97	93	75
Fuel consumption	[kWh/tprod]	2582	2157	2245	1935	1513
Electricity consumption	[kWh/tprod]	97	189	150	281	249
Cooling water	[kWh/tprod]	934	682	996	449	495
CO2 emissions	[kg/tprod]	530	453	467	417	328

Saving potentials - Results



Investment cost estimation

- Used equation $$InvC = f \cdot 1500 \cdot 160^{0.1} \cdot \dot{E}_{hp}^{0.9} \quad [Euro]$$
- Heat pump size for r245fa heat pump
  - max: peak power of the heat source
  - mean: heat source is stored and progressively upgraded

	Case2 (r245fa HP)	Case3 (A MVR)	Case4 (B MVR)	Case5 (C MVR)
$\dot{E}_{hp}$ [kW]	372 (max) 239 (mean)	241	698	297 + 136 + 152
$InvC$ [kEuro]	771.6 (max) 516.2 (mean)	519.9	1354.8	1285.1
Payback [Years]	3.6 (max) 2.4 (mean)	2.7	5.0	2.6

Conclusions

- Operating cost saving potentials
  - Heat recovery & Optimized refrigeration cycle 15%
  - Closed cycle indirect heat pump integration 25%
  - Optimized evaporation unit & MVR 20% - 40%
- Heat pump potential & Improvement of process efficiency
- Possibility of two different approaches
- Investment cost relation & Rentability
  - Closed cycle indirect heat pump integration (2.4-3.6 years)
  - Evaporation & MVR (2.6-5 years)

Thank you for your attention !