Energy integration of industrial sites with heat exchange restrictions

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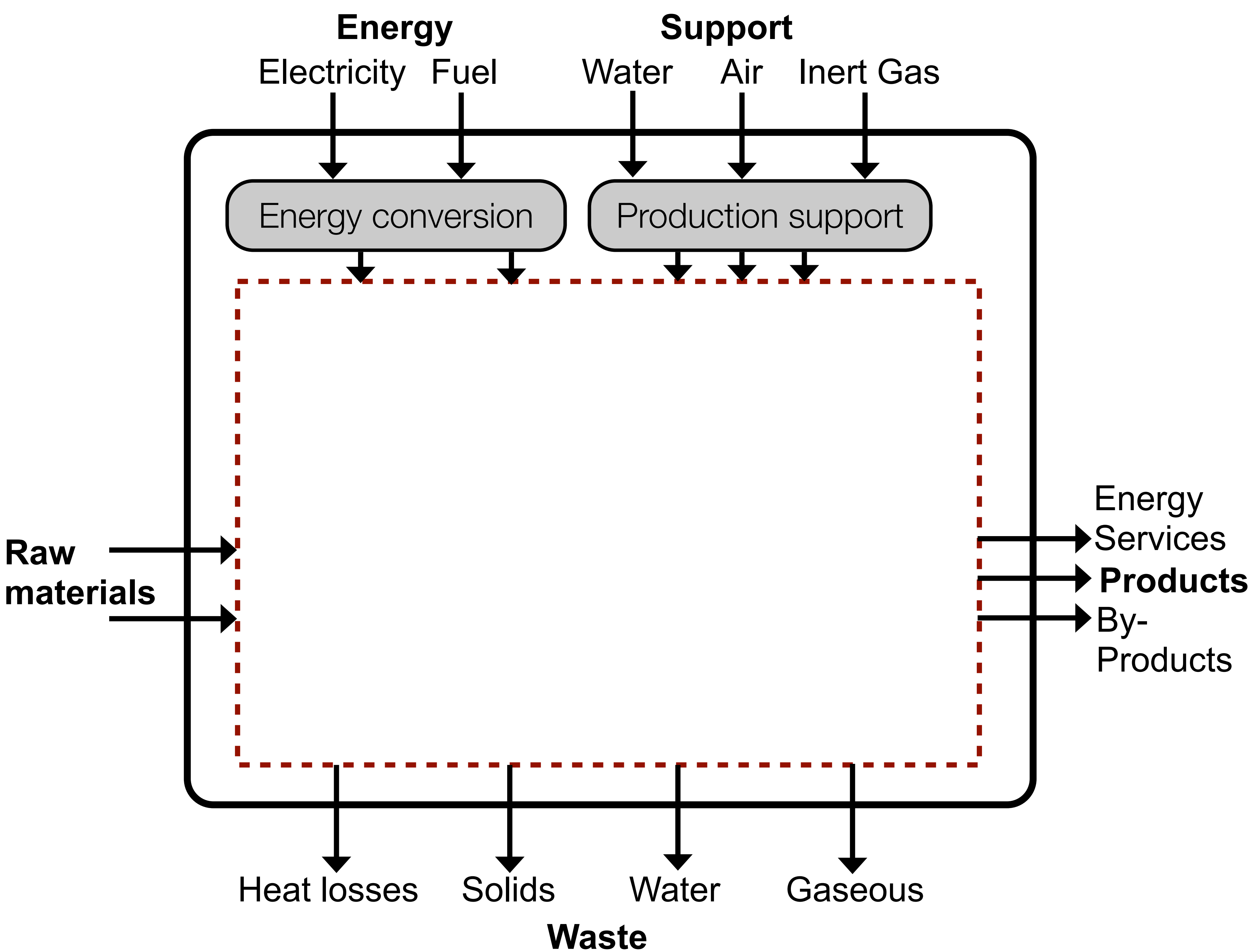
Outline

- Introduction
- Methodology
- Example of application
- Conclusion

Introduction - Process system



Optimizing industrial processes

Process Integration

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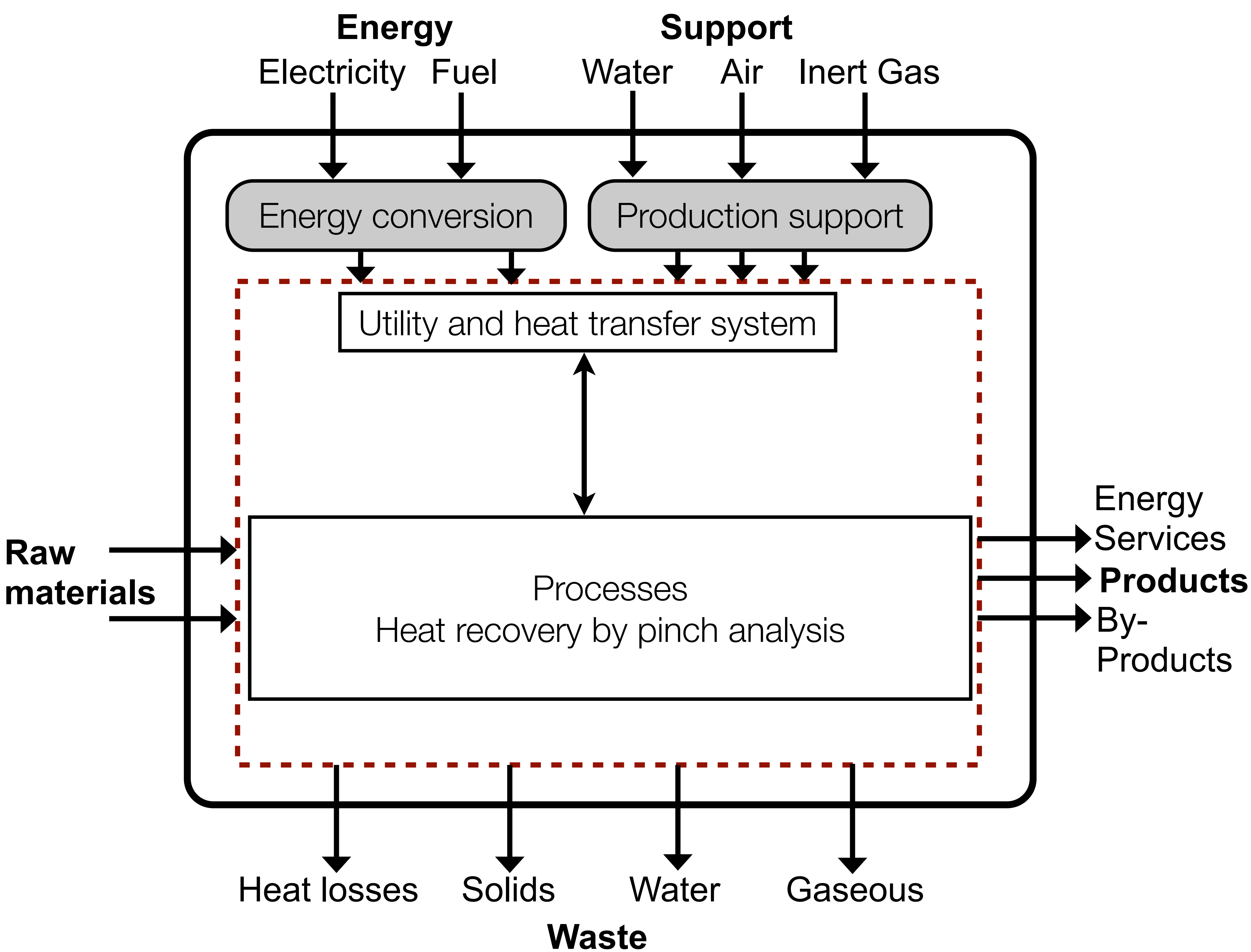
Introduction - Process system



Heat exchange restrictions:

Long distances between streams

Quality / safety reasons

Flexibility

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Methodology - challenges

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- Develop a targeting method
  - Considering restricted matches
  - Minimizing energy and cost penalty of restricted matches
  - Introducing heat transfer fluid network for indirect heat exchange
  - Optimizing mass flow rates for heat transfer fluids and utilities
  - Maximizing combined heat and power production
  - Defining complete list of streams for HEN design

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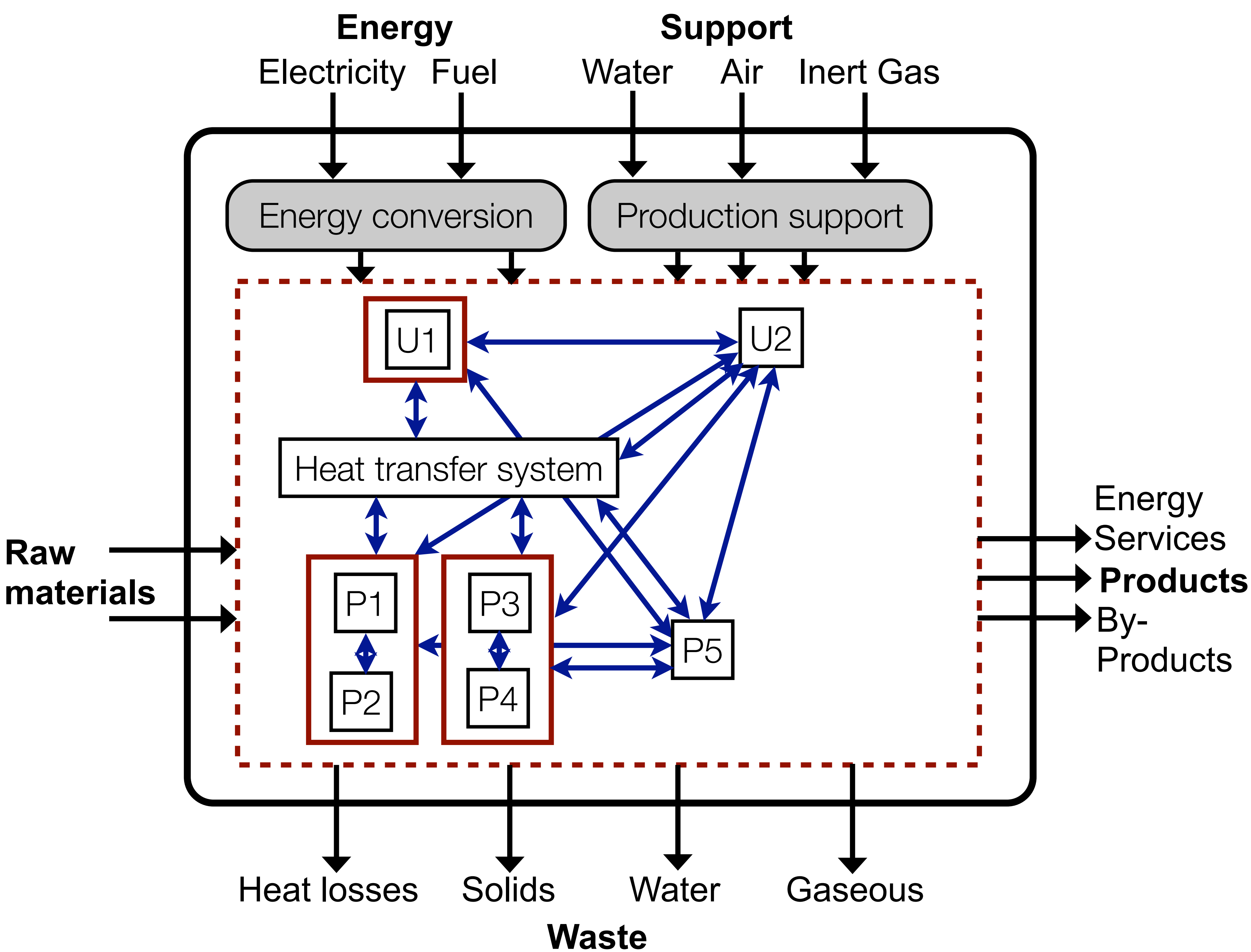
Methodology - Concept



Introducing sub-systems:

A sub-system cannot exchange heat directly with another sub-system

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Methodology - Algorithm

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- Objective function $$F_{obj} = min(c_{fuel}\dot{E}_{fuel} + c_{el}^{+}\dot{E}_{el}^{+} - c_{el}^{-}\dot{E}_{el}^{-})$$
- Fuel consumption

$$\dot{E}_{fuel} = \sum_{uw=1}^{n_{uw}} f_{uw}\dot{E}_{fuel-uw}$$

- Electricity consumption

$$\sum_{uw=1}^{n_{uw}} f_{uw}\dot{E}_{el-uw}^{+} + \dot{E}_{el}^{+} - \dot{E}_{el-p}^{-} \geq 0$$

Electricity exportation

$$\sum_{uw=1}^{n_{uw}} f_{uw}\dot{E}_{el-uw}^{+} + \dot{E}_{el}^{+} - \dot{E}_{el}^{-} - \dot{E}_{el-p}^{-} = 0$$

- Mass flow rates $$\dot{M}_{h,w} = f_{uw} * \dot{m}_{h,w} \qquad \dot{M}_{c,w} = f_{uw} * \dot{m}_{c,w}$$
- Global heat cascade

$$\sum_{h_k=1}^{n_{h,k}} \dot{M}_{h,k}q_{h,k} - \sum_{c_k=1}^{n_{c,k}} \dot{M}_{c,k}q_{c,k} + \dot{R}_{k+1} - \dot{R}_k = 0 \qquad \forall k = 1..., n_k$$

variables	*parameters*

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Methodology - Algorithm

- Heat cascade for each sub-system

$$\sum_{h_{s,k}=1}^{n_{h,s,k}} \dot{M}_{h,s,k} q_{h,s,k} - \sum_{c_{s,k}=1}^{n_{c,s,k}} \dot{M}_{c,s,k} q_{c,s,k} + \dot{Q}^{-}_{hts,s,k} - \dot{Q}^{+}_{hts,s,k} + \dot{R}_{s,k+1} - \dot{R}_{s,k} = 0$$

$$\dot{R}_{s,k} \geq 0 \qquad \forall k = 1..., n_k, \forall s = 1..., n_s$$

- Additional constraints: Heat balance in the heat transfer system

$$\sum_{h=1}^{n_{h,hts,k}} \dot{M}_{h,hts,k} q_{h,hts,k} + \dot{R}_{hts,k+1} - \dot{R}_{hts,k} - \sum_{s=1}^{n_s} \dot{Q}^{-}_{hts,s,k} \geq 0 \qquad \forall k = 1..., n_k$$

$$- \sum_{c=1}^{n_{c,hts,k}} \dot{M}_{c,hts,k} q_{c,hts,k} + \dot{R}_{hts,k+1} - \dot{R}_{hts,k} + \sum_{s=1}^{n_s} \dot{Q}^{+}_{hts,s,k} \leq 0 \qquad \forall k = 1..., n_k$$

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Example of application

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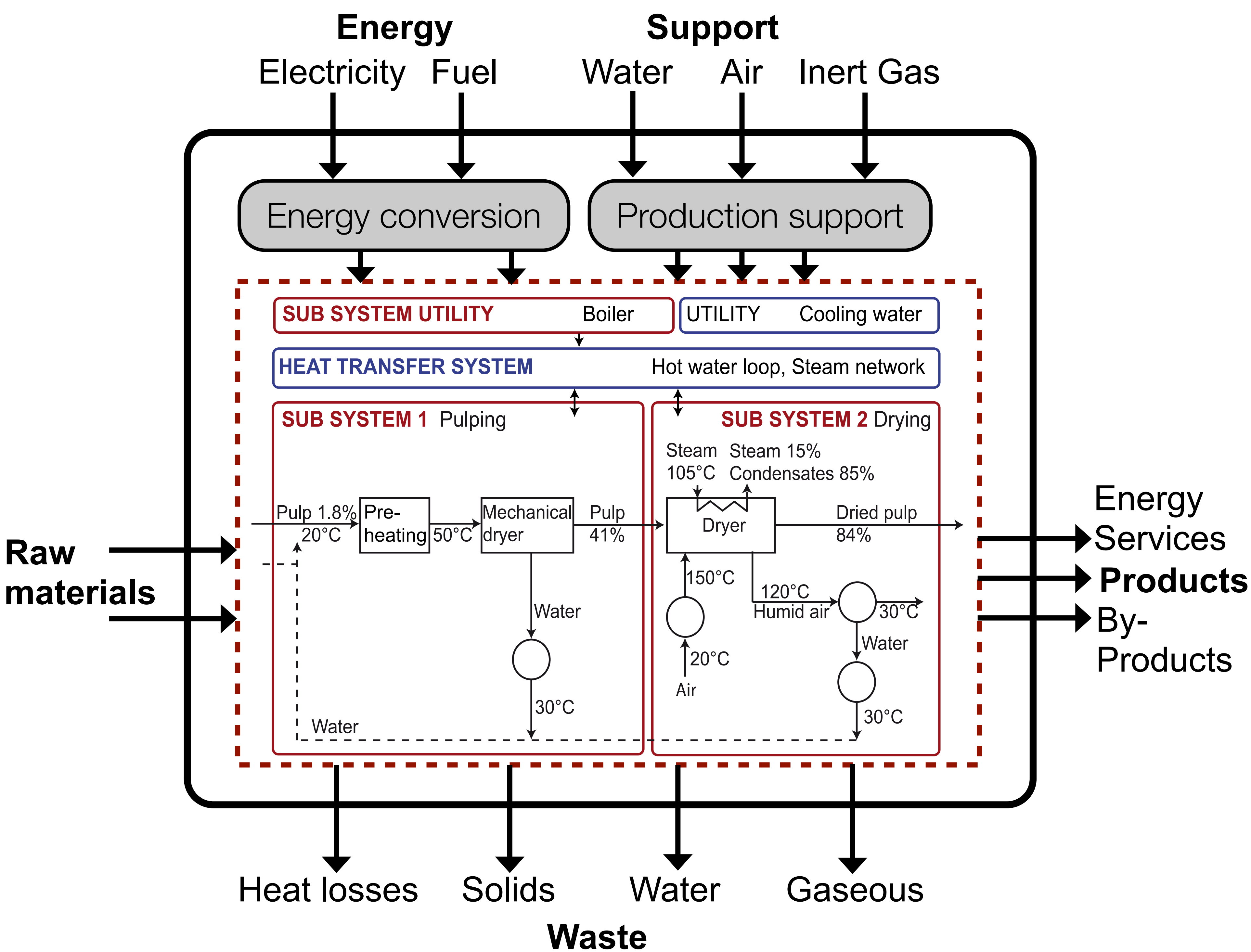

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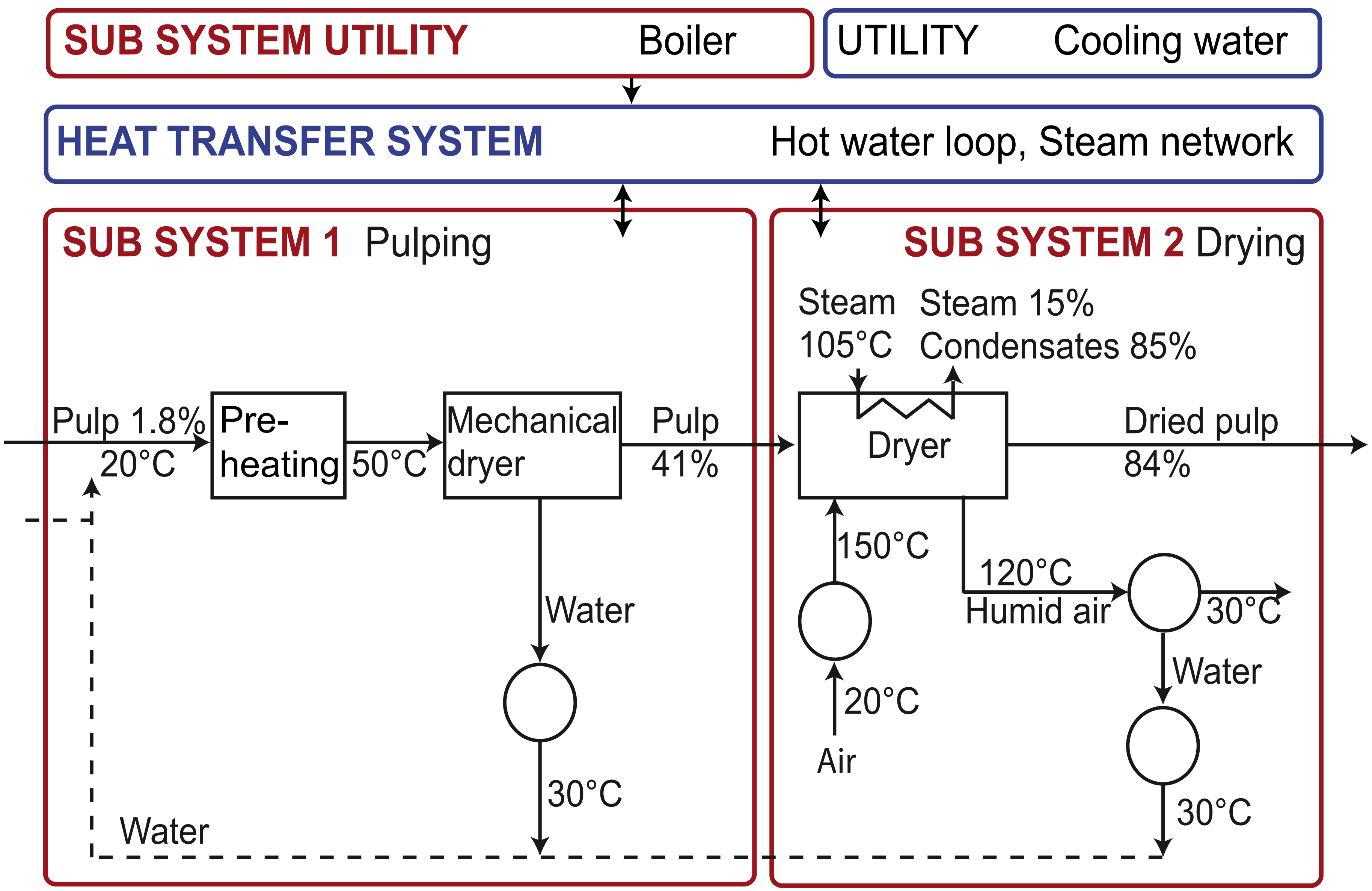
Example of application



Streams definition:

Name	Tin [°C]	Tout [°C]	Heat Load [kW]
Preheating	20	50	11262
Water cooling	50	30	-7297
Air heating	20	150	664
Steam demand	95	105	6058
Condensation of 15% steam	105	105	-892
Cooling of condensates	105	95	-112
Humid air cooling	120	30	-5319

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Process Integration (1)

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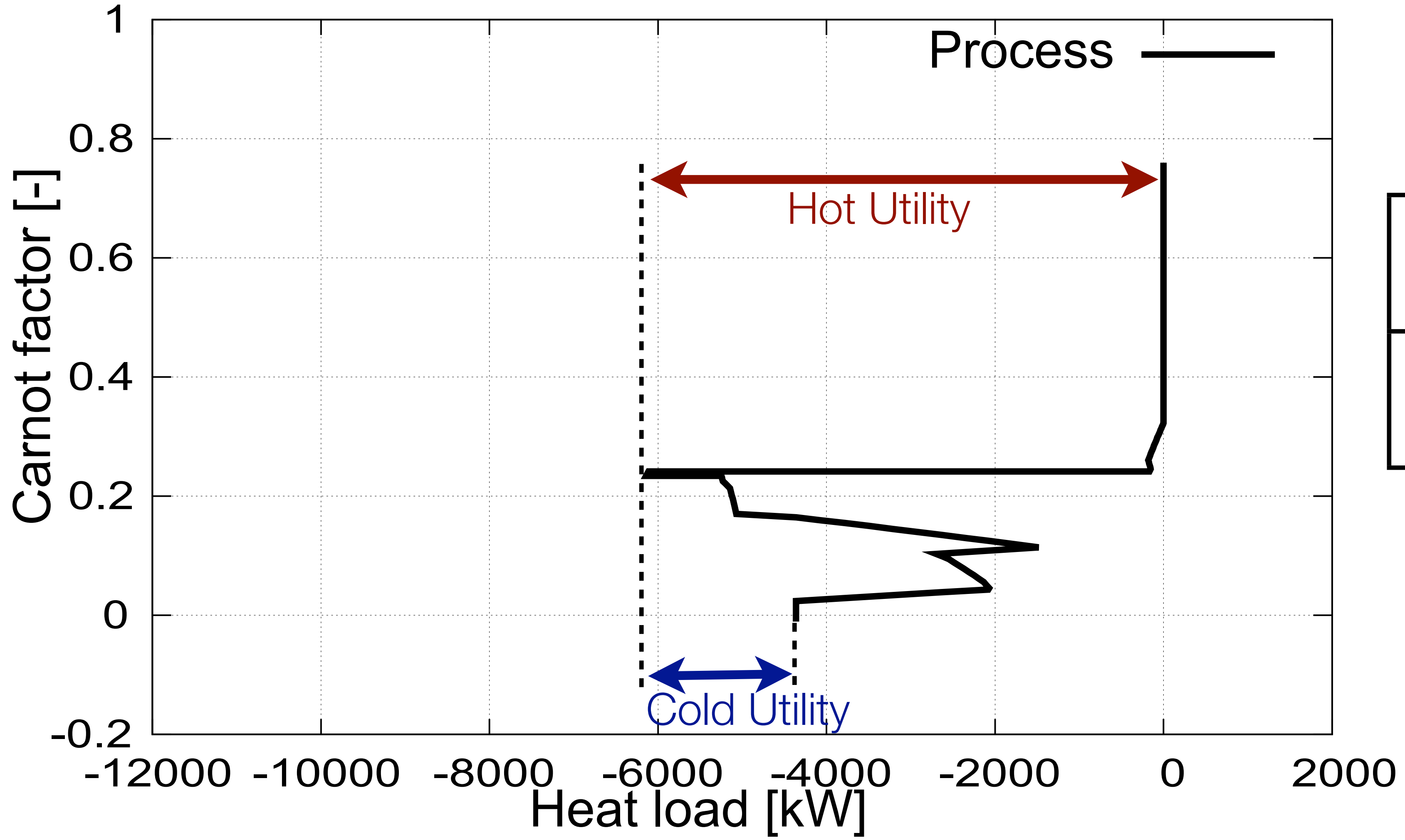
1. MER - (without industrial constraints)



Hot Utility	6014 kW
Cold utility	1651 kW

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Process Integration (2)

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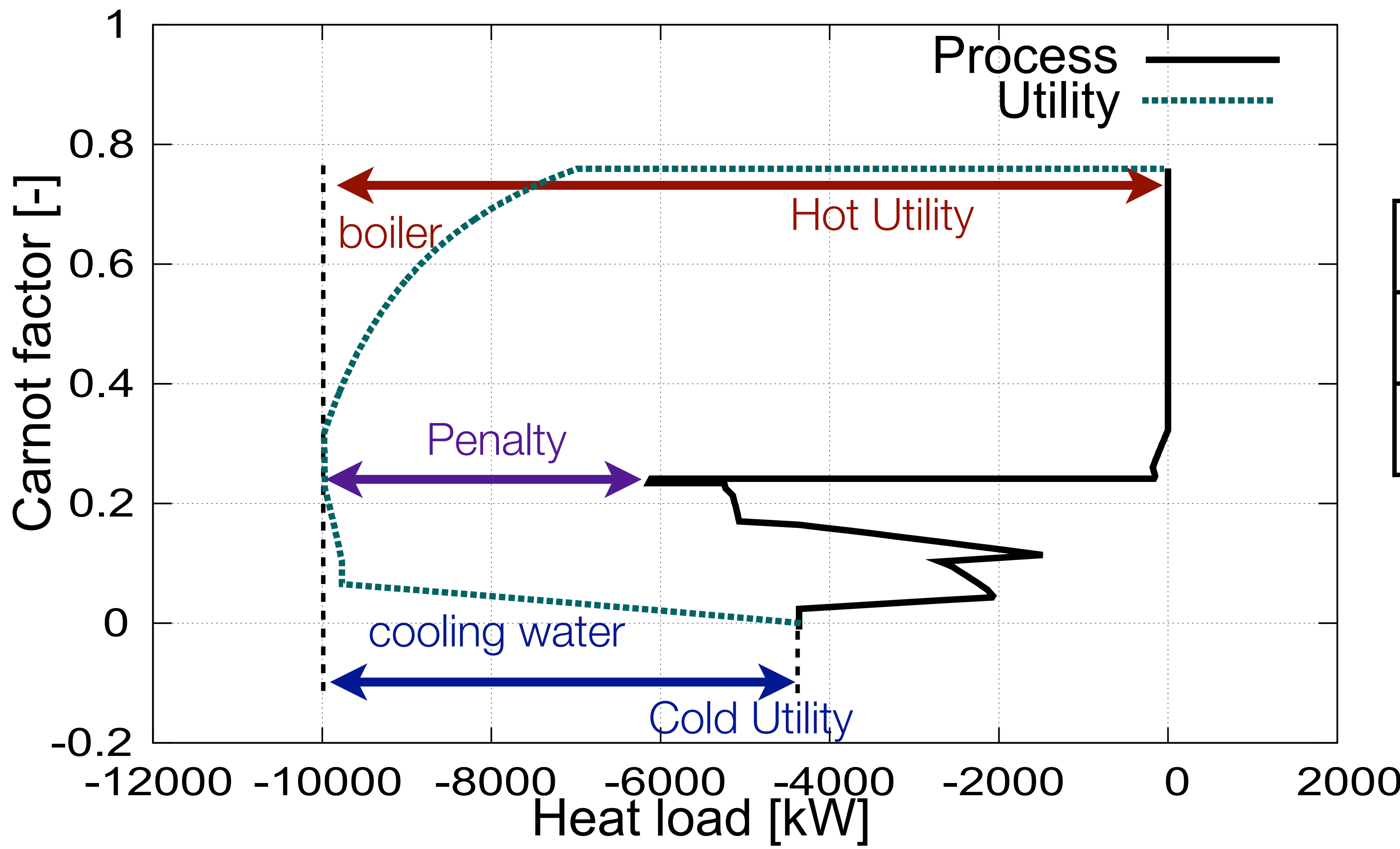
2. Utility Integration with restricted matches



Hot utility	9868 kW
Cold utility	5505 kW
Penalty	3854 kW

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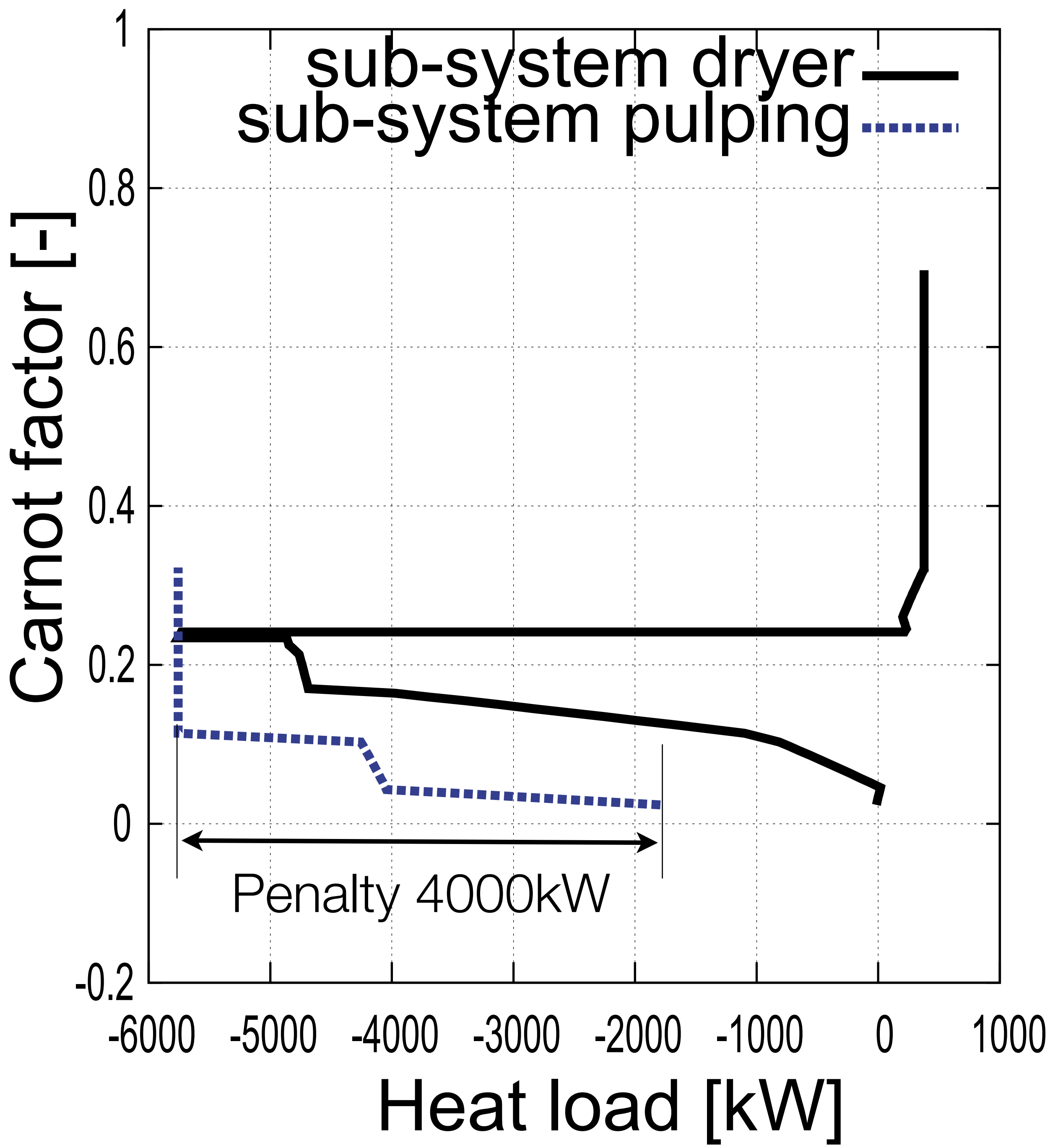
Integration of heat transfer networks (1)



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Integration of heat transfer networks (2)

- Hot water loop
  - Water loop between 35°C to 80°C
  - Heat can be exchanged indirectly between sub-systems
  - Penalty is decreased
  - Sub-systems can work independently
- Steam network
  - Steam from boiler cannot exchange heat directly with the process
  - Combined heat and power

Integration of heat transfer networks (3)

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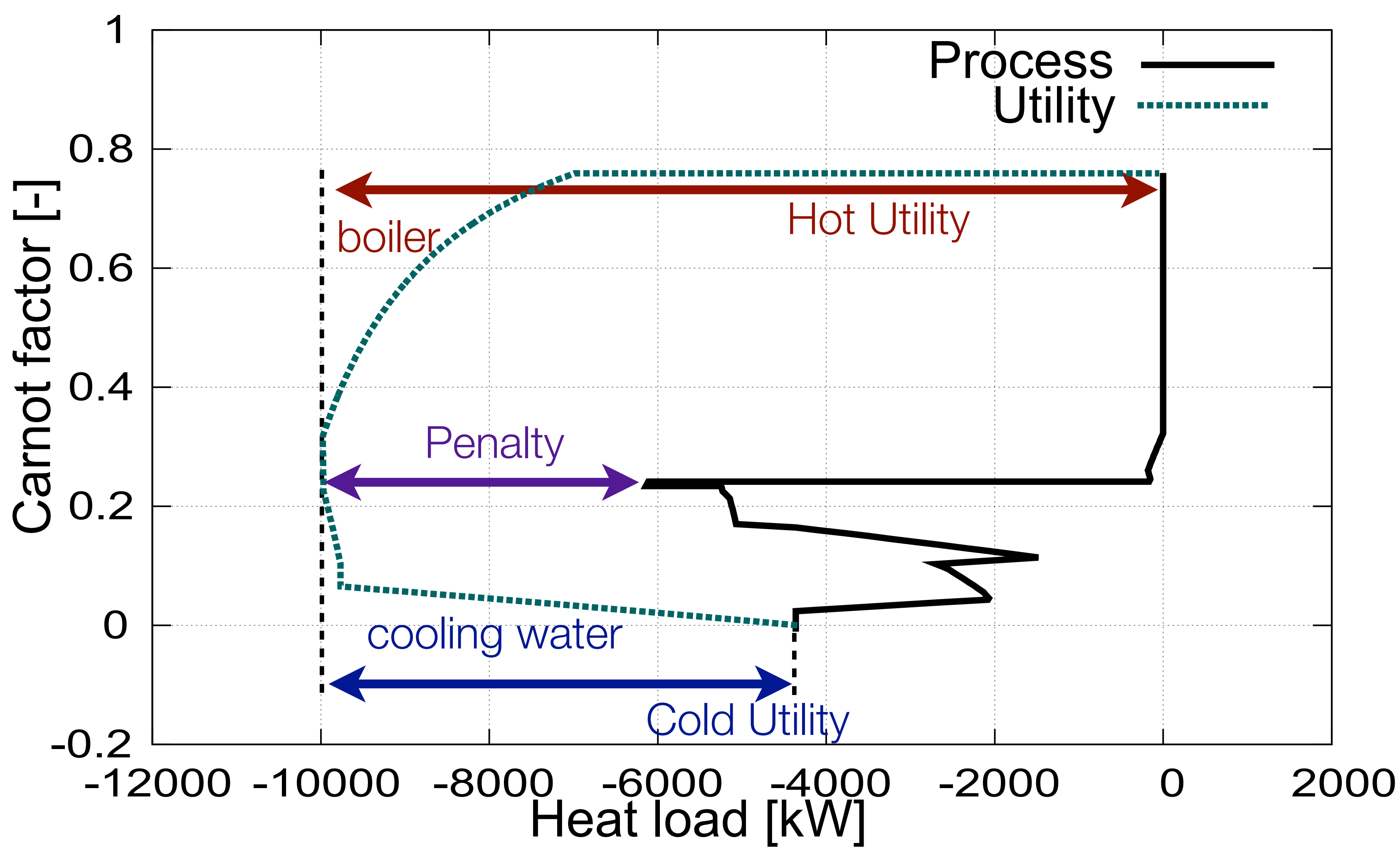
3. Heat transfer networks



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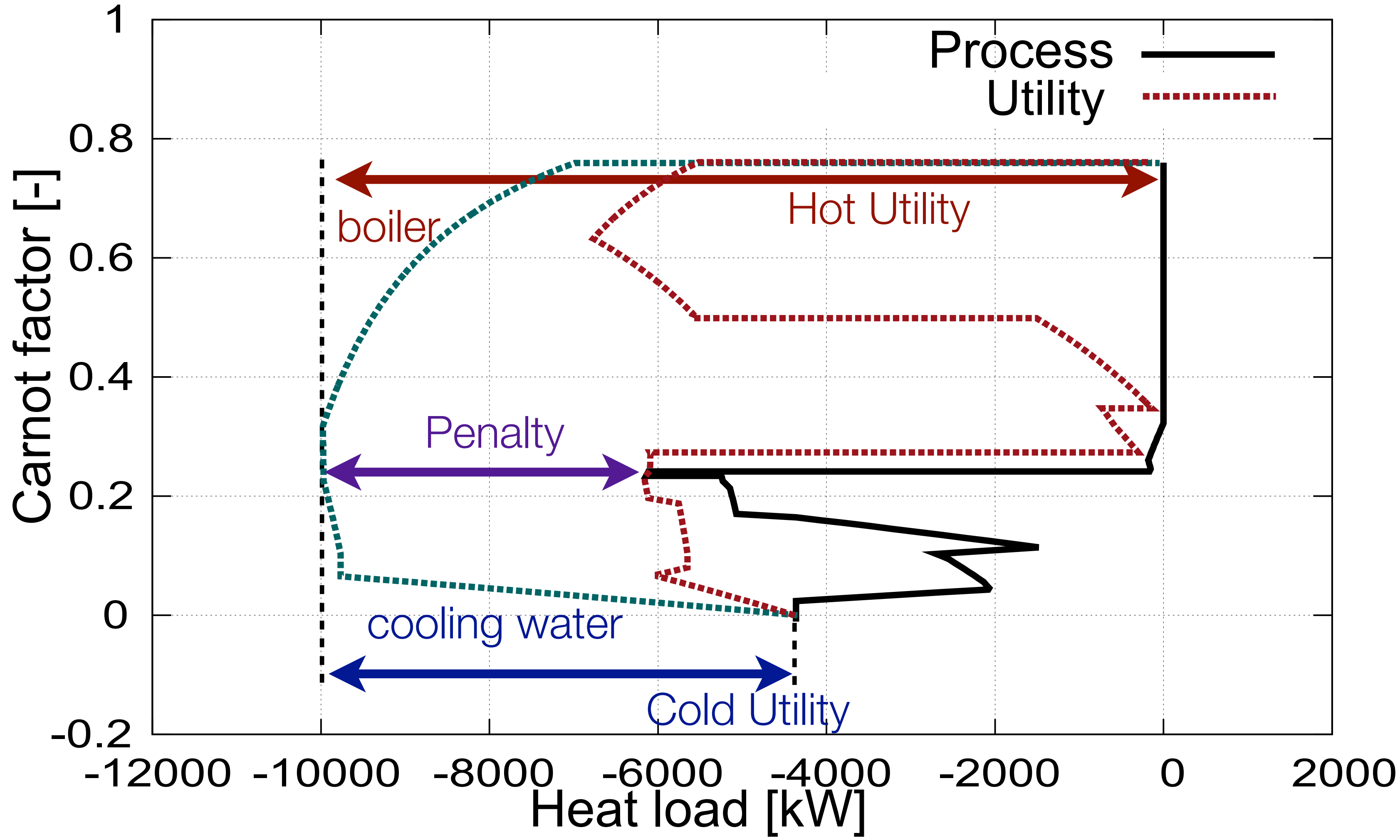
Integration of heat transfer networks (4)

3. Heat transfer networks



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Integration of heat transfer networks (5)

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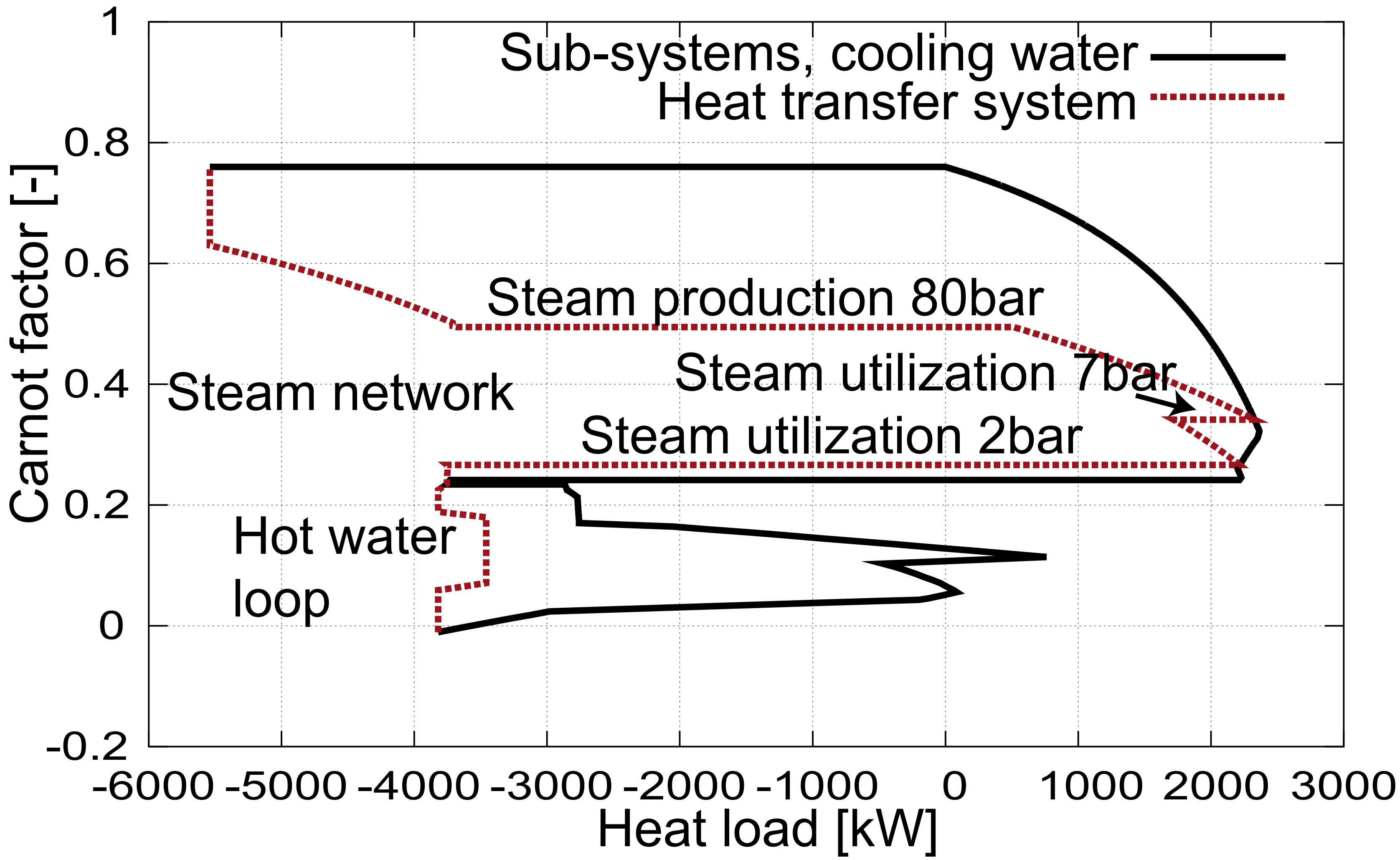

Results

	Fuel [kW]	Cooling water [kW]	Elec-tricity [kW]
No constraint	6014	1651	-
With constraints	9868	5505	-
With heat networks	7760*	1676	-1684

*includes cogenerated electricity

Heat load of hot water loop: 4066 kW

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Heat load distribution (1)

- minimize number of connections

$$\min_{y_{ij} Q_{ikj}} CT = \sum_{j=1}^{nftc} \{ \sum_{i=1}^{nfth} y_{ij} \}$$

- Heat balance of hot stream i in interval k $\sum_{j=1}^{nftc} Q_{ikj} = Q_{ik} \quad i = 1...nfth \quad k = k_{p1}...k_{p2}$

- Heat balance of cold stream j $\sum_{i=1}^{nfth} \{ \sum_{k=k_{p1}}^{k_{p2}} Qikj \} = Qj \quad j = 1...nftc$

- Existence of connection ij $\sum_{k=k_{p1}}^{k_{p2}} Q_{ikj} - y_{ij} Q_{max} \leq 0 \quad i = 1...nfth \quad j = 1...nftc$

$$Q_{ikj} \geq 0 \quad i = 1...nfth \quad j = 1...nftc \quad k = k_{p1}...k_{p2}$$

- Restricted matches

$$y_{ij} = 0 \qquad Q_{ikj} = 0$$

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Heat load distribution (2)

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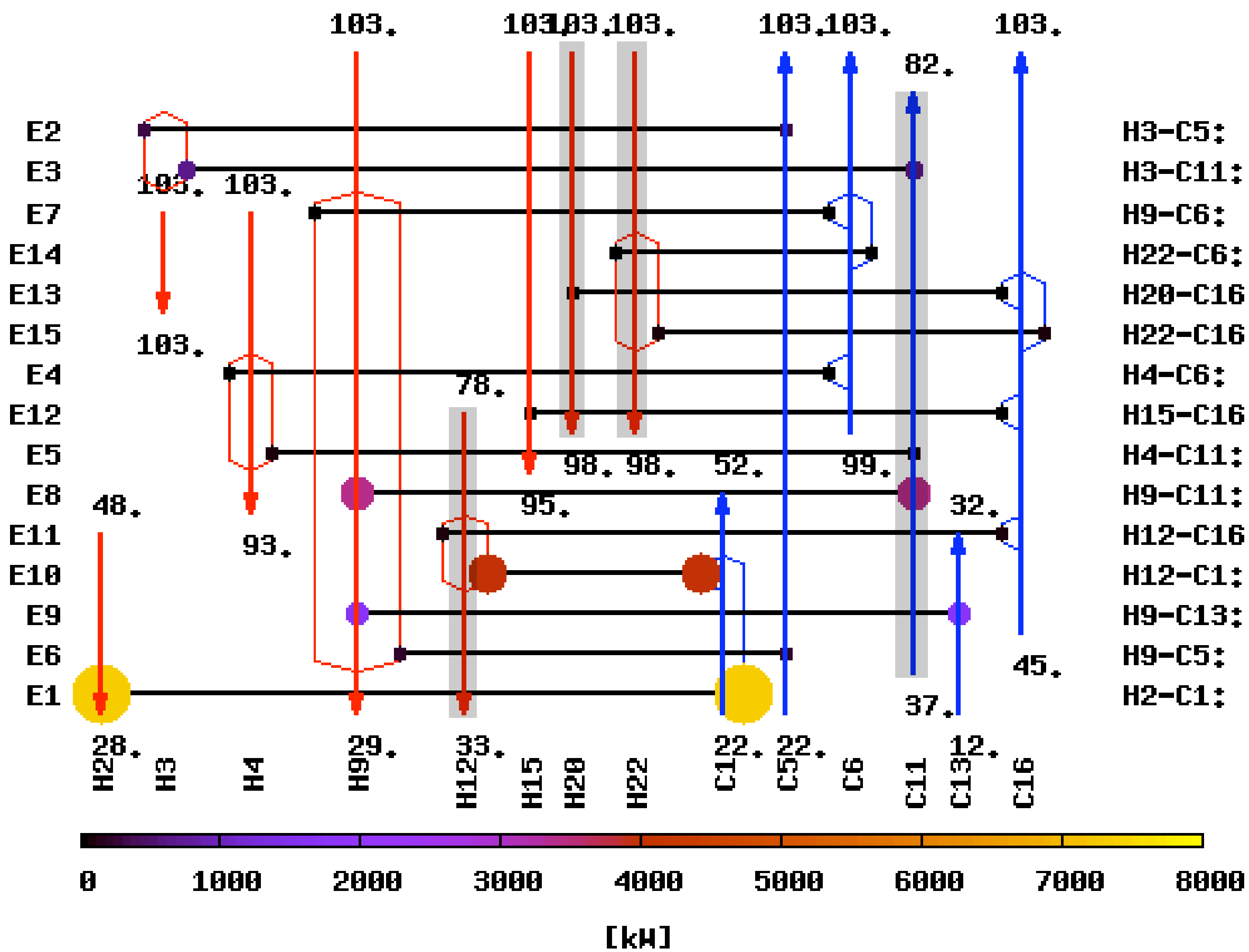

[kW]	
H3-C5:	260.5
H3-C11:	631.5
H9-C6:	0.8
H22-C6:	4.3
H20-C16:	6.4
H22-C16:	53.5
H4-C6:	48.3
H15-C16:	25.8
H4-C11:	63.7
H9-C11:	3370.4
H12-C16:	101.6
H12-C1:	3964.0
H9-C13:	1675.5
H9-C5:	156.6
H2-C1:	7298.0

Utility streams:

Cooling water (C13)
Boiler cooling (H15)
Boiler preheat air (C16)

Heat transfer system

Steam network
(H20 & H22)
Hot water loop
(C11 & H12)

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Conclusions

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- Division of the process into sub-systems
- Combined heat and power production
- Simultaneous optimization of the utility integration and the heat transfer system
- Easier design of the heat exchanger network

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Thank you for your attention !