Energy conversion system integration

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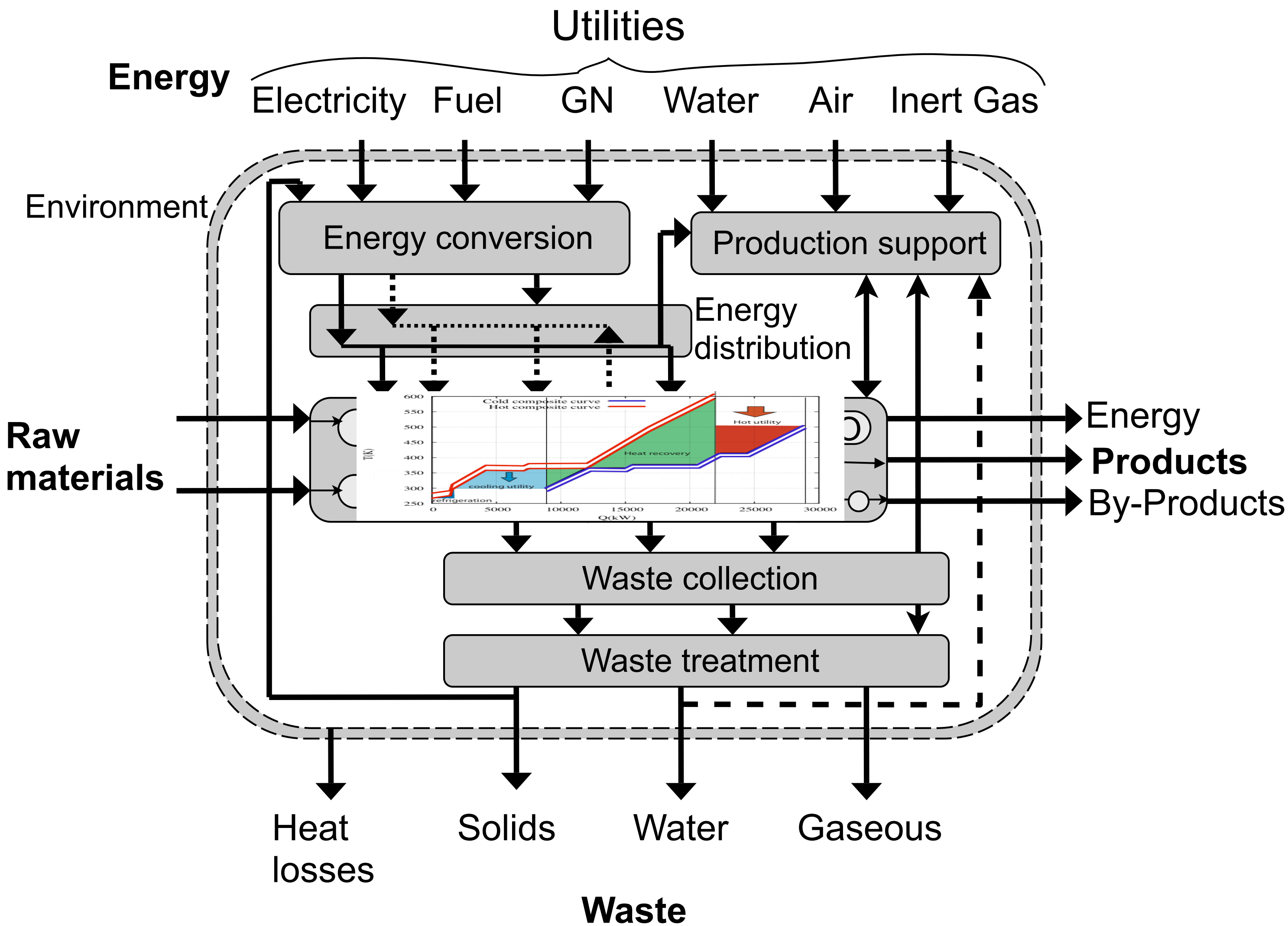
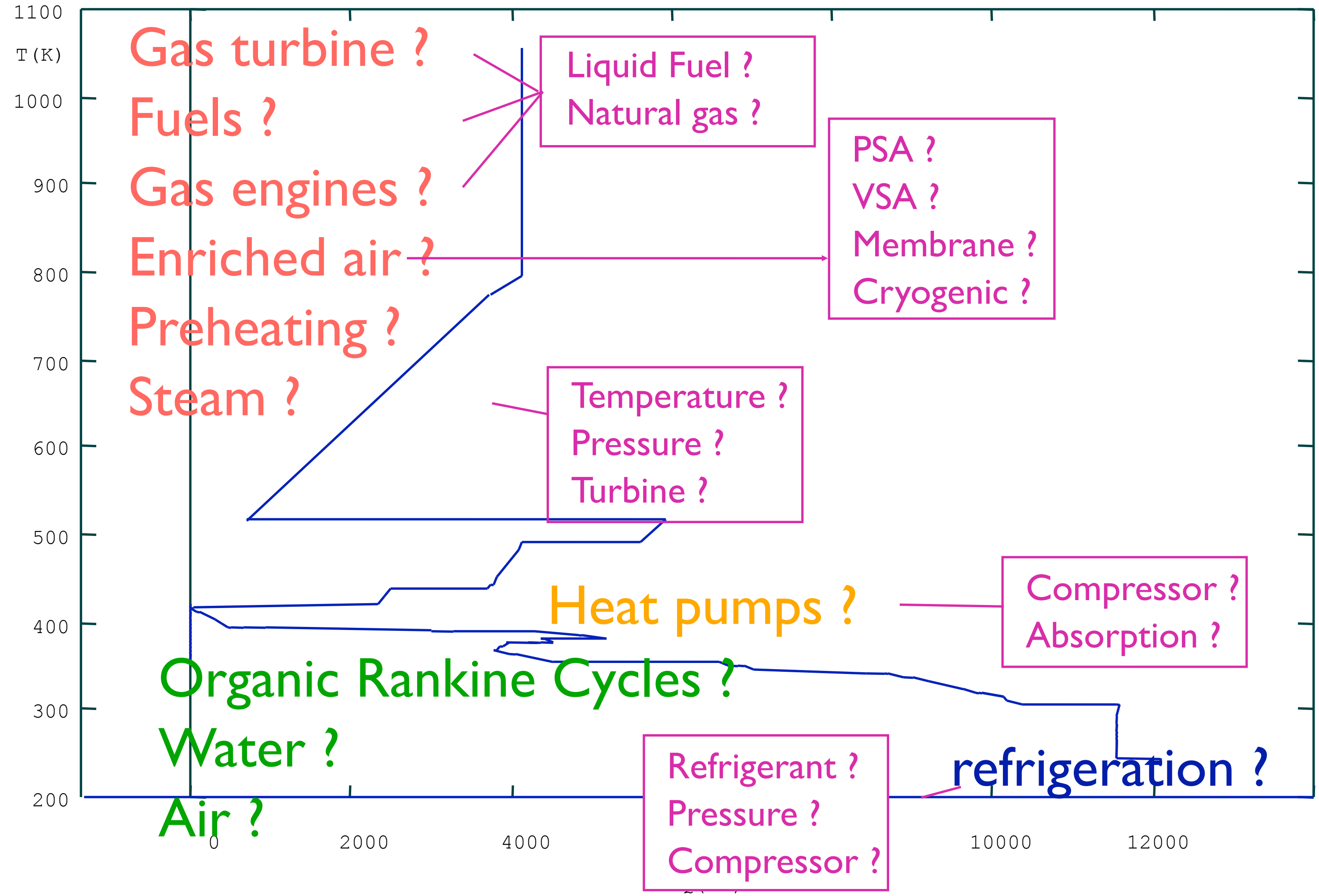
Where are we ?

- ✓ Energy efficiency project evaluation
- ✓ DT min
- ✓ Heat recovery
- ✓ Heat exchanger network design
- Integrating the energy conversion units
- Exergy analysis of the energy conversion system
- How can mathematical programming help us
- Evaluate energy efficiency projects

Energy conversion system



Utilities

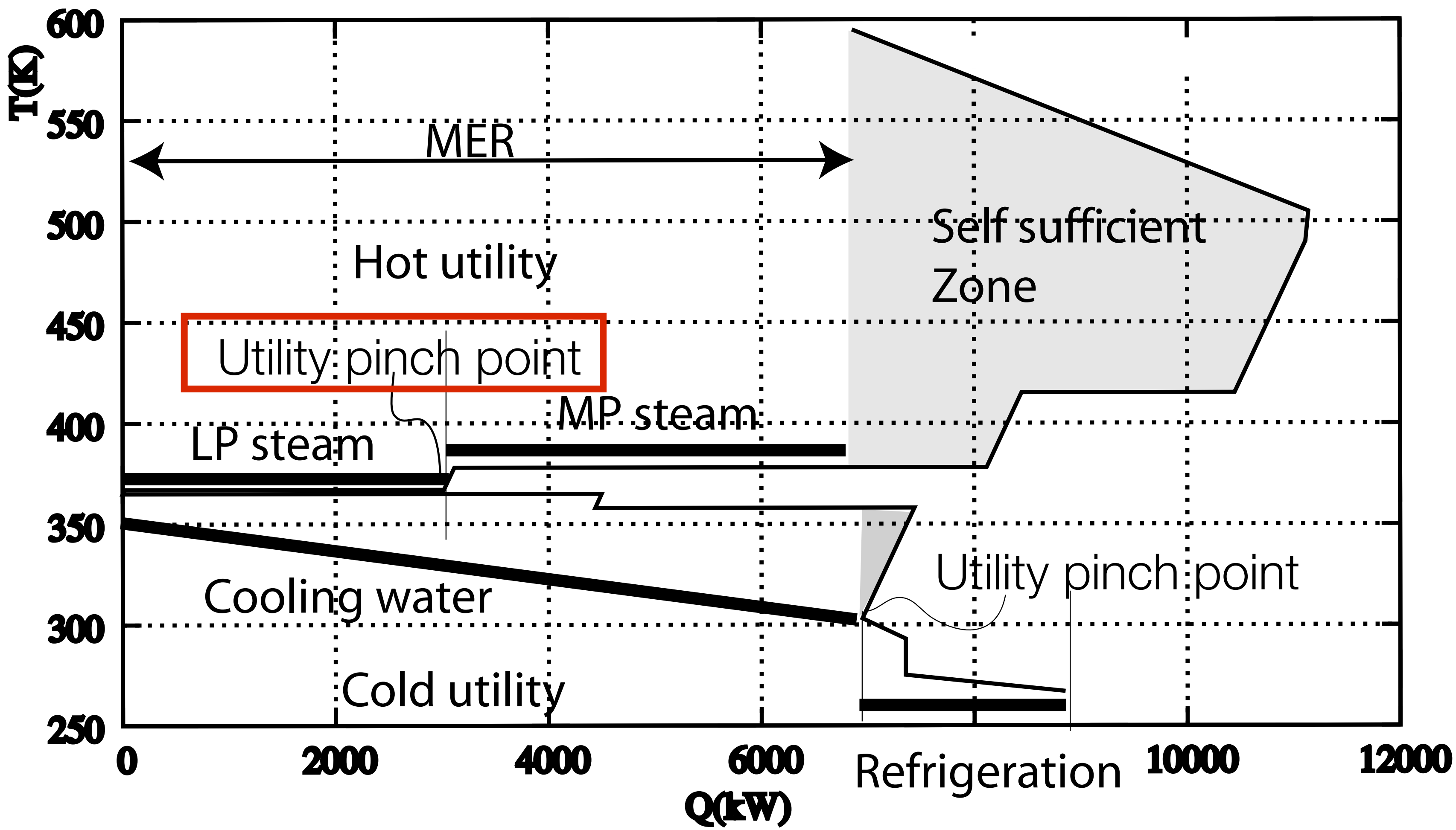


1100
T(K)
1000
900
800
700
600
500
400
300
200
0
2000
4000
10000
12000
Gas turbine ?
Fuels ?
Gas engines ?
Enriched air ?
Preheating ?
Steam ?
Liquid Fuel ?
Natural gas ?
PSA ?
VSA ?
Membrane ?
Cryogenic ?
Temperature ?
Pressure ?
Turbine ?
Heat pumps ?
Compressor ?
Absorption ?
Organic Rankine Cycles ?
Water ?
Air ?
Refrigerant ?
Pressure ?
Compressor ?
refrigeration ?

Known Rules

- Composite curves
  - Utility framing the process
  - Balanced curves
- Cogeneration
  - Above or Below not across the pinch
- Heat pumping
  - Across the pinch
- Refrigeration
  - from below ambiance to ambiance
- Use pockets

Maximise the use of the cheapest utility



IPESE
INDUSTRIAL PROCESS AND

EPFL

Integration of the energy conversion system

- Energy conversion units with unknown flowrates

Technology w with nominal flow

Hot/cold streams

$$T^{in}_{w,i}, P^{in}_{w,i}, \dot{m}_{w,i}, x_{w,i}$$

$$q_w = \dot{m}_{w,i}(h^{in}_{w,i} - h^{out}_{w,i})$$

$$T^{out}_{w,i}, P^{out}_{w,i}, \dot{m}_{w,i}, x_{w,i}$$

Mechanical power/electricity

$$e_w$$

Costs

$$C1_w, C2_w, CI1_w, CI2_w$$

Decision variables

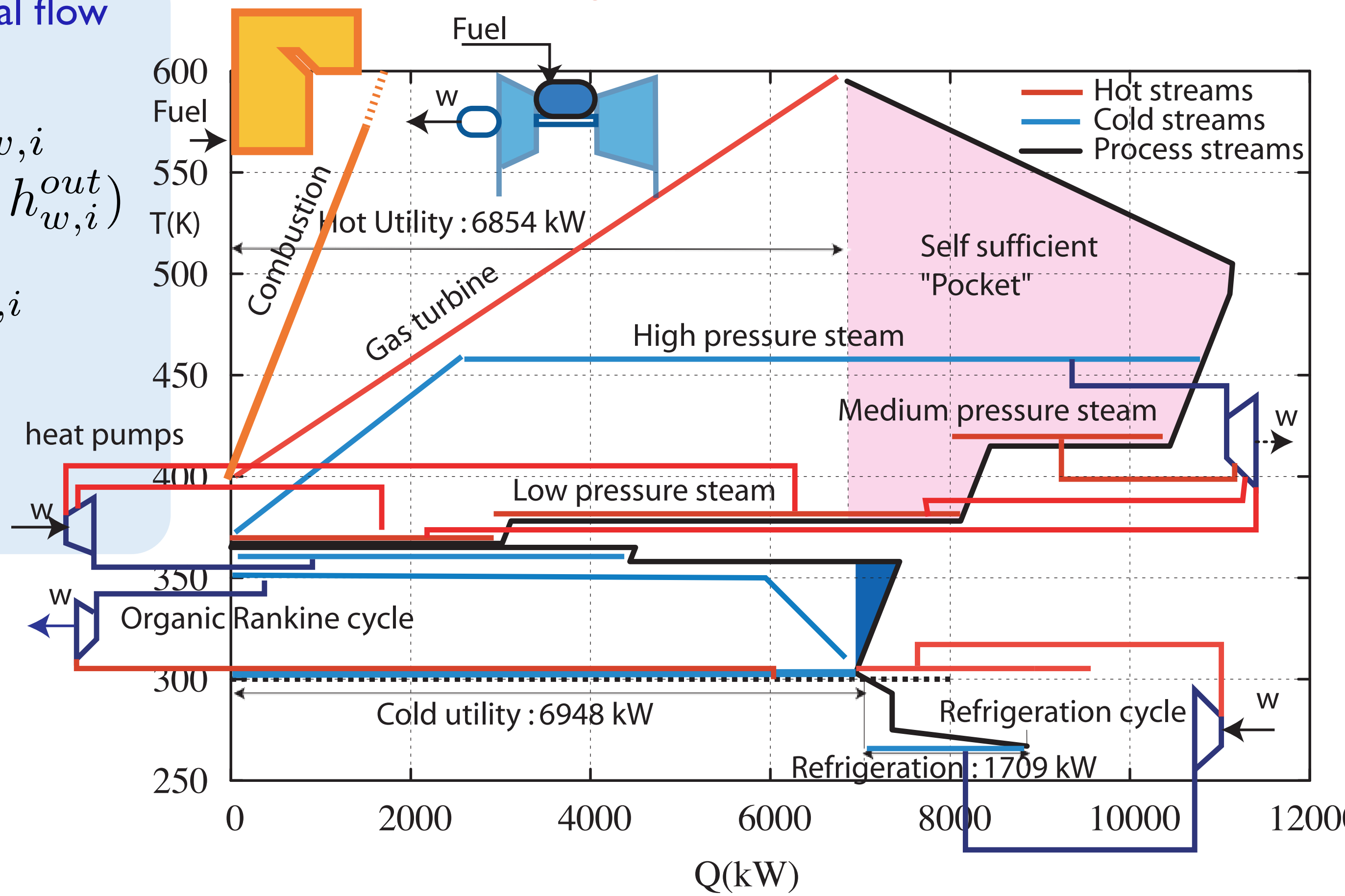
Level of usage of w

$$f_w$$

Buy/use technology w ?

$$y_w$$

Creative engineers ?



by simulation we can generate the hot and cold streams associated to a predefined level of usage (or flow).
the questions are : do I use the technology ? if yes what is the level of usage.

MILP (Mixed Integer Linear Programming) formulation

$$\min_{R_r, y_w, f_w, E^+, E^-} \left(\sum_{w=1}^{n_w} C2_w f_w + C_{el^+} E^+ - C_{el^-} E^-\right) * t + \sum_{w=1}^{n_w} C1_w y_w + \frac{1}{\tau}\left(\sum_{w=1}^{n_w} (CI1_w y_w + CI2_w f_w)\right)$$

Operating cost

Fixed maintenance

Investment

Subject to : Heat cascade constraints

$$\sum_{w=1}^{n_w} f_w q_{w,r} + \sum_{s=1}^{n_s} Q_{s,r} + R_{r+1} - R_r = 0 \qquad \forall r = 1, \ldots, n_r$$

Feasibility $\quad R_r \geq 0 \qquad \forall r = 1, \ldots, n_r; R_{n_{r+1}} = 0; R_1 = 0 \qquad E^+ \geq 0; E^- \geq 0$

Electricity consumption

$$\sum_{w=1}^{n_w} f_w e_w + E^+ - E_c \geq 0$$

Electricity production

$$\sum_{w=1}^{n_w} f_w e_w + E^+ - E_c - E^- = 0$$

Energy conversion Technology selection

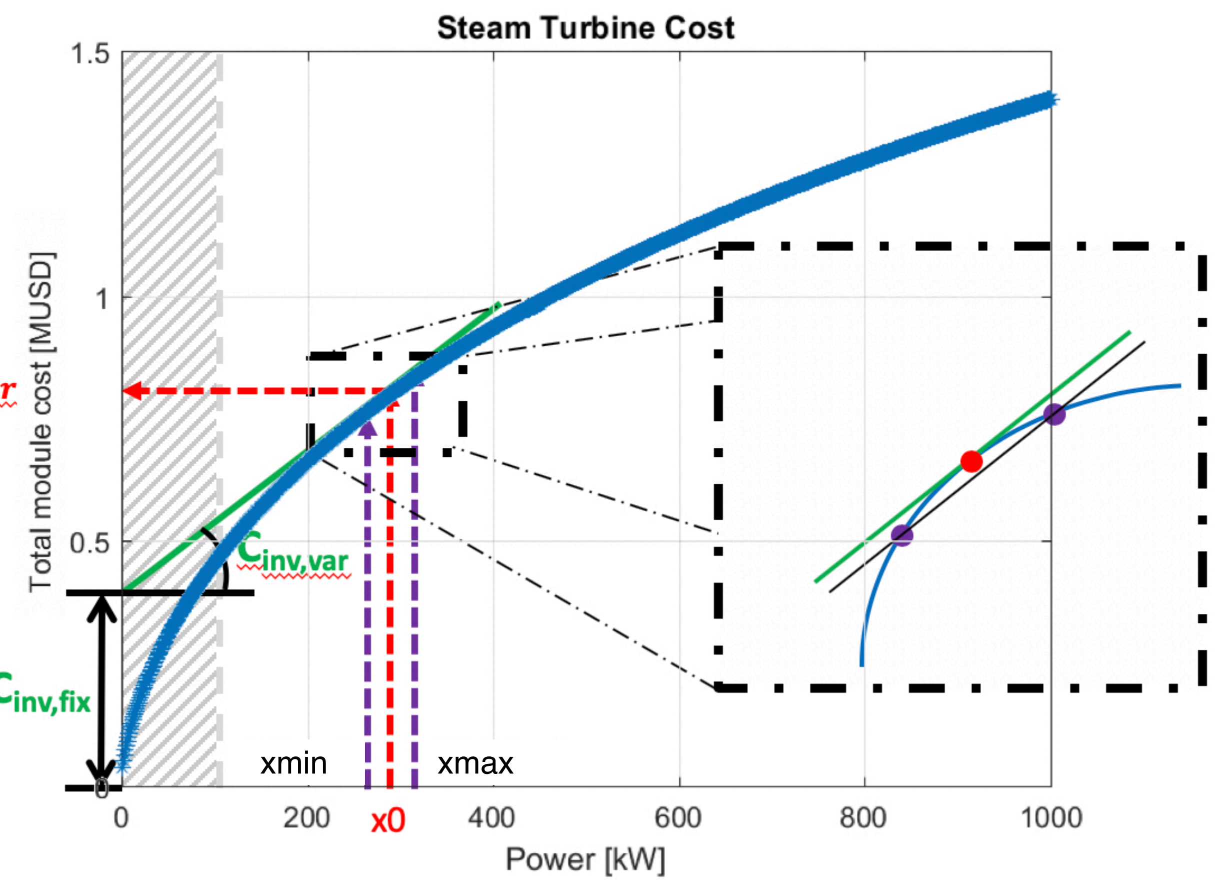
$$fmin_w y_w \leq f_w \leq fmax_w y_w \qquad y_w \in \{0, 1\}$$

The mixed integer linear programming formulation allows to solve the heat recovery by using the heat cascade in the list of constraints, the electricity balance , differentiating import and export and considering the cost of the energy resources used in the system. flows in the system are calculated to close the energy balance and existence of a energy conversion solution is decided using an integer variable. The min and max bounds are used to avoid the usage of technologies that are out of the range of their typical application

Linearising investment costs

$$C(f_w) = a(f_w)^b \rightarrow C(f_u) = cI1_w \cdot y_w + cI2_w \cdot f_w$$

$$C(x) = C_{inv,\,fix} + x \cdot C_{inv,\,var}$$



MILP optimization

- Linear programming
  - optimum defined by constraints
    - max/min
    - Pinch points
  - Cost may create strange results
    - if electricity is cheaper than the fuel, a heat pump becomes an electrical heater
  - Integer variables for technology selection
    - Can be used to select among options
- Heat balance constraints
  - if the hot and cold utility have not the appropriate levels no solution is found
  - max flows may prevent to close the balance
  - max flows may prevent convergence

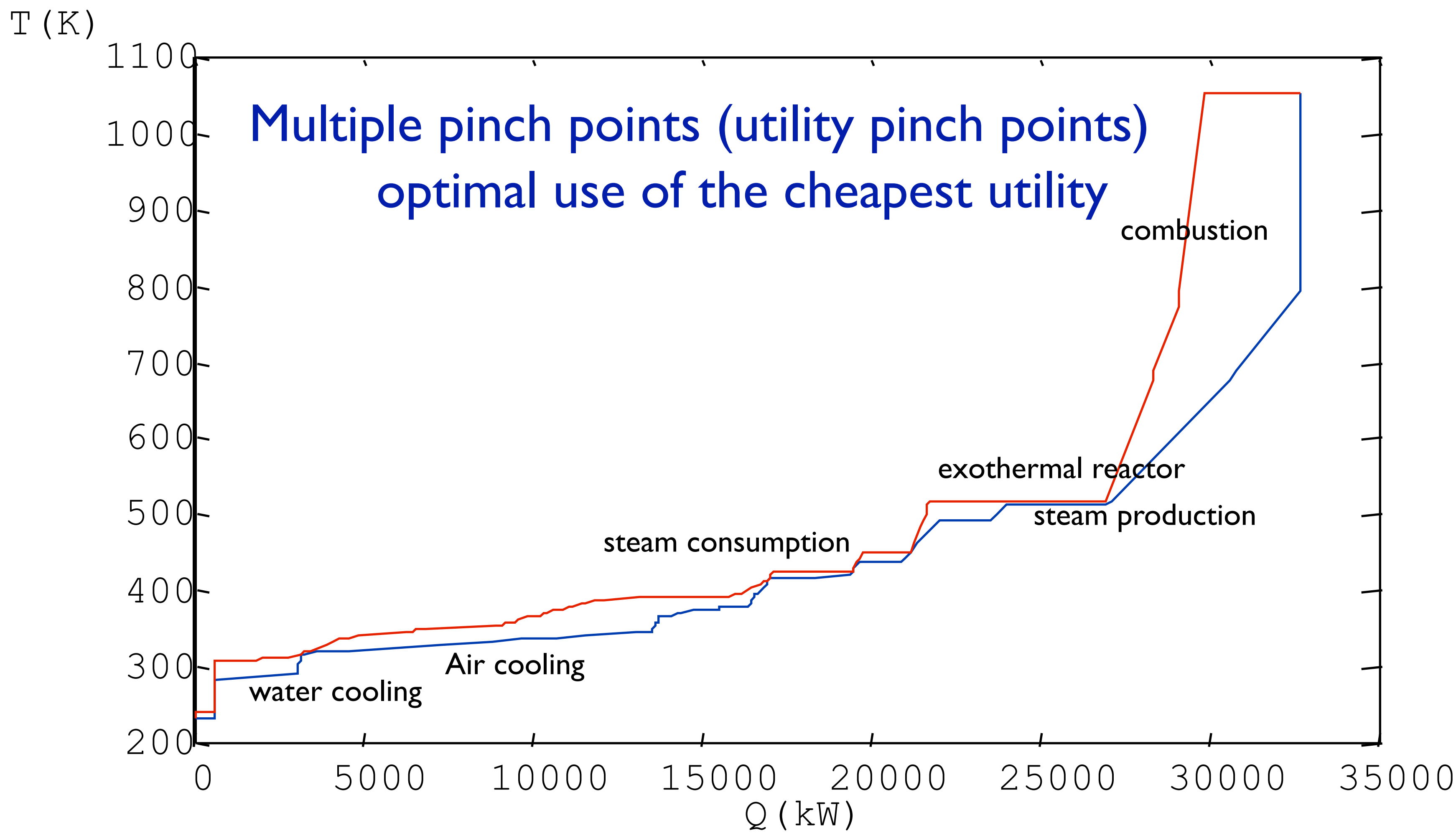
$$y_i \cdot f_{min} \leq f \leq y_i \cdot f_{max}$$

$$1. \leq 0.000001 \cdot 1'000'000$$

$$\text{is } y_i = 0.000001 =? \; 0 \text{ or } 1$$

- Additional constraints
  - have to be satisfied
- Need to analyze solutions

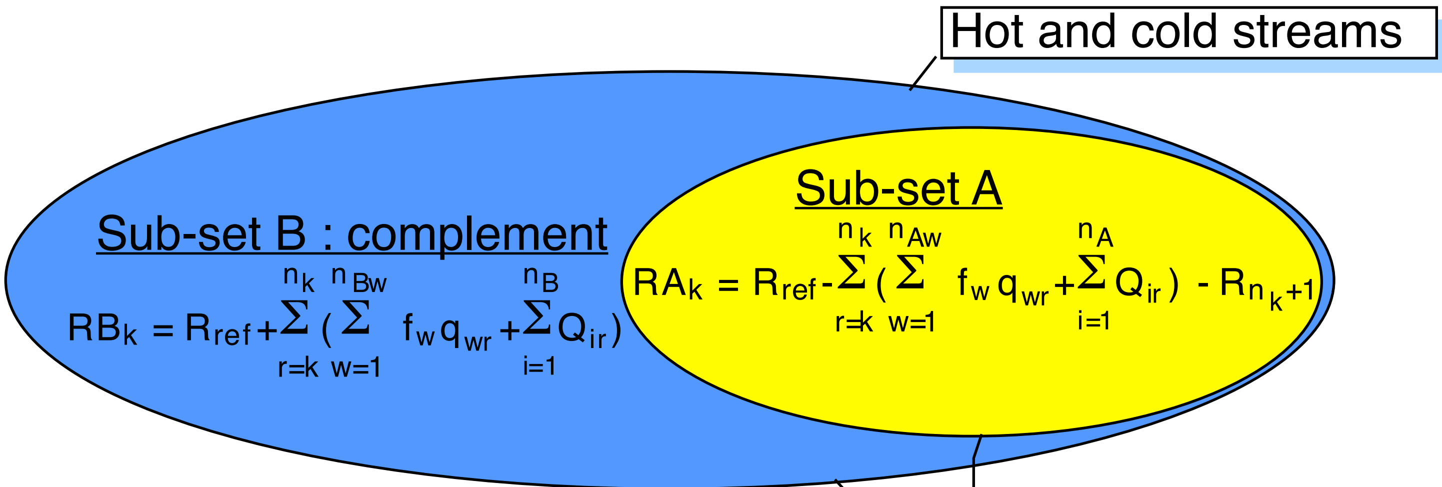
Results : Balanced composite curves



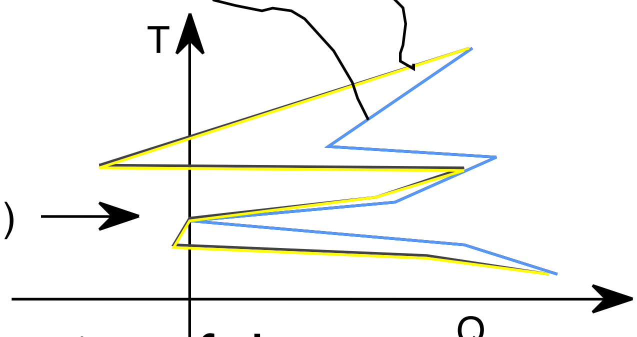
The balanced composite curves include the process and the utility streams. The balance is now closed has no magic hot or cold utility is used.

Evaluate : the Integrated Composite Curves

The goal is to understand the solutions



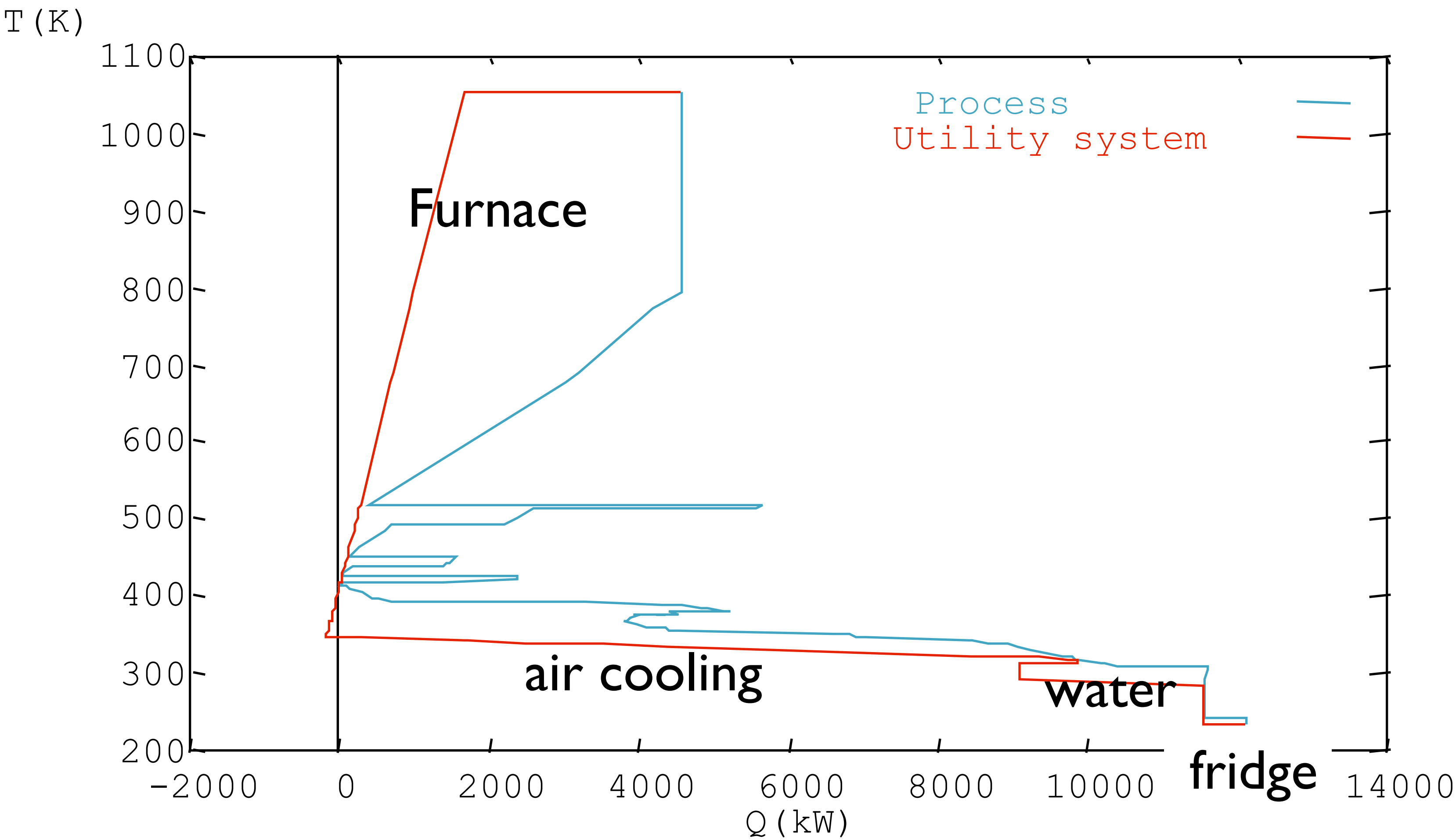
$$RB_{kp} = 0 \Rightarrow R_{ref} = - \sum_{r=kp}^{n_k} \left(\sum_{w=1}^{n_{Bw}} f_w q_{wr} + \sum_{i=1}^{n_B} Q_{ir} \right) \rightarrow$$



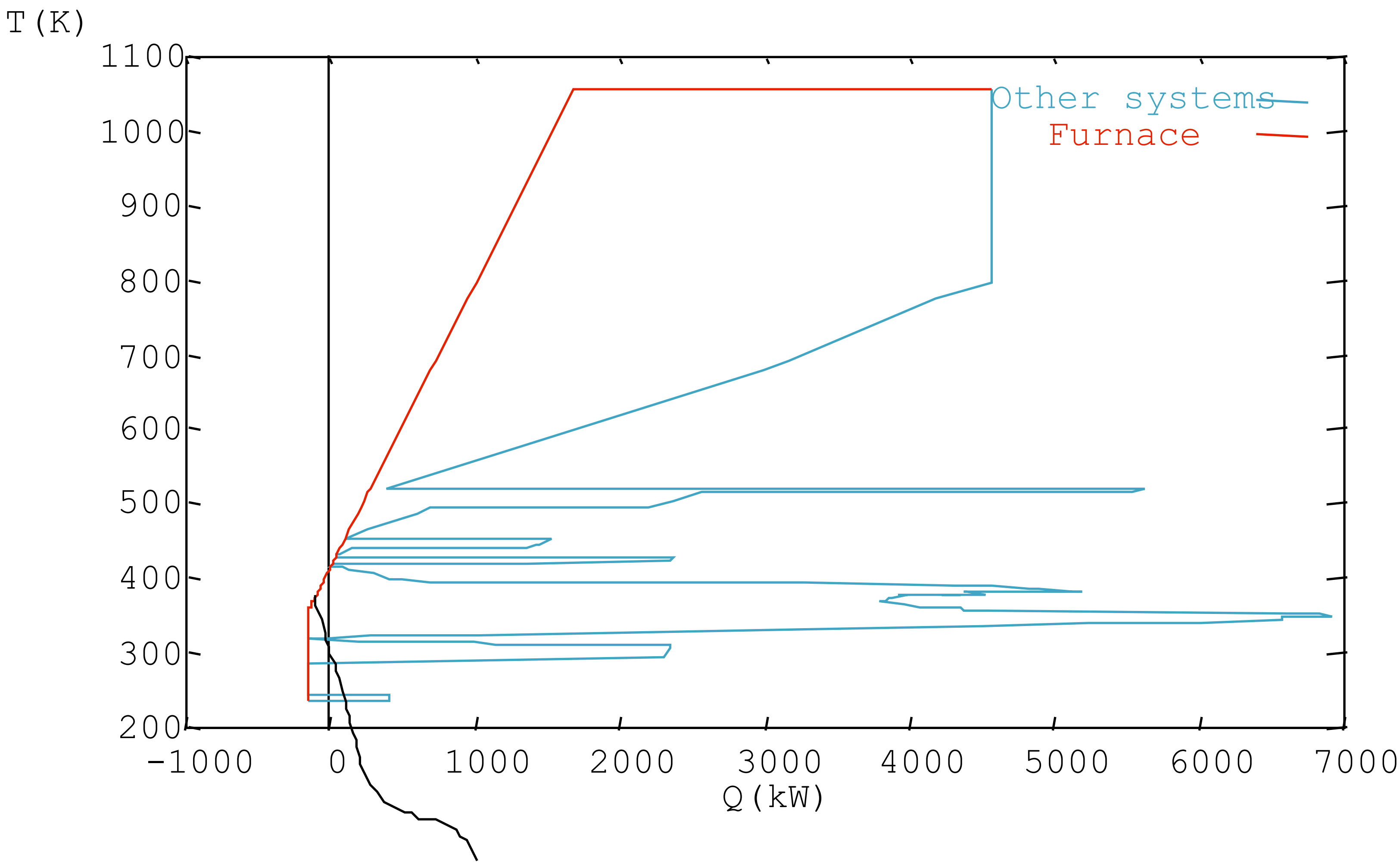
Choose a reference : pinch point of the process streams

The integrated composite curve represent the way a sub-system is integrated with the remaining system.

ICC for utility system integration

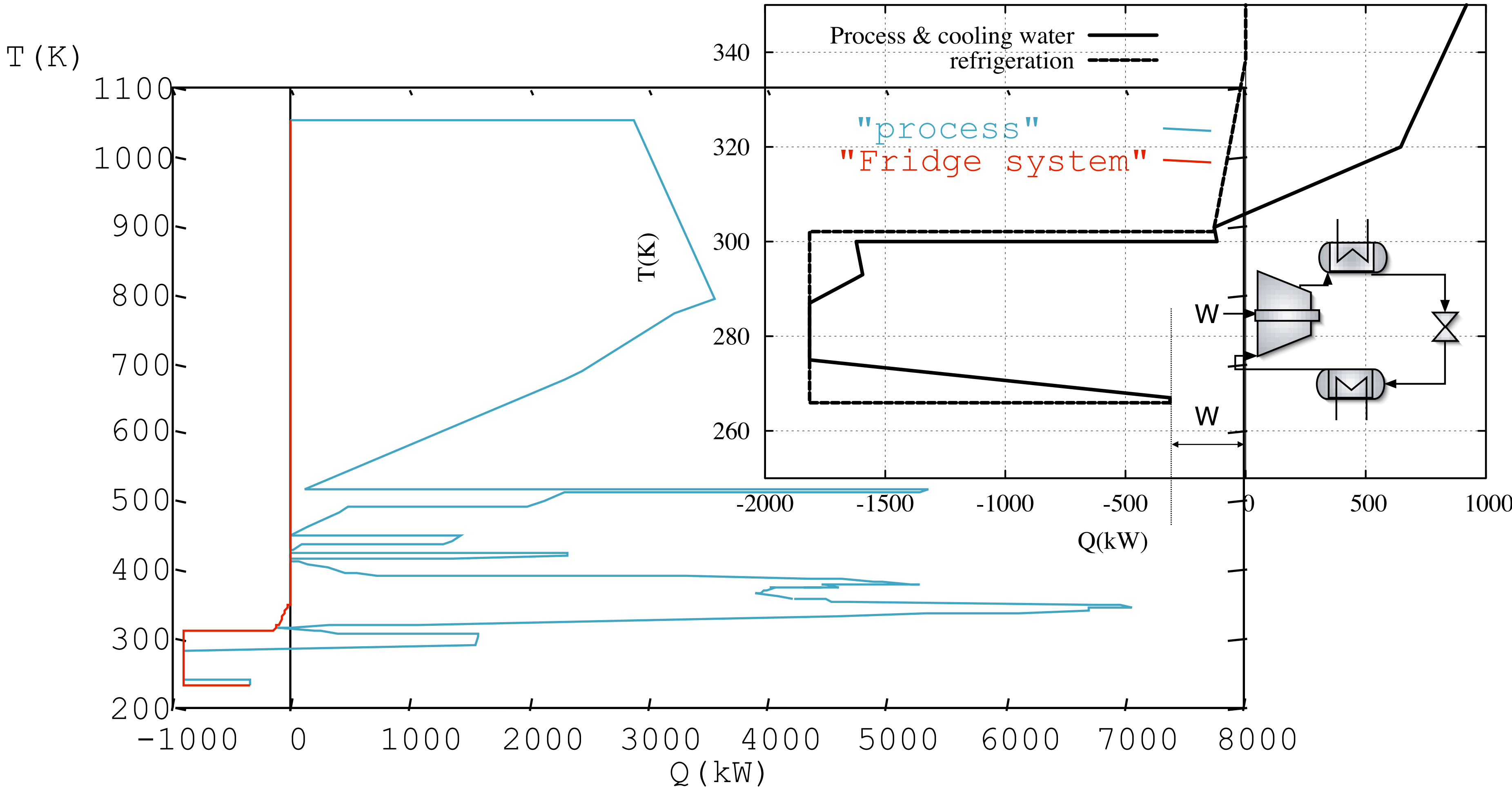


ICC for the integration of the furnace alone



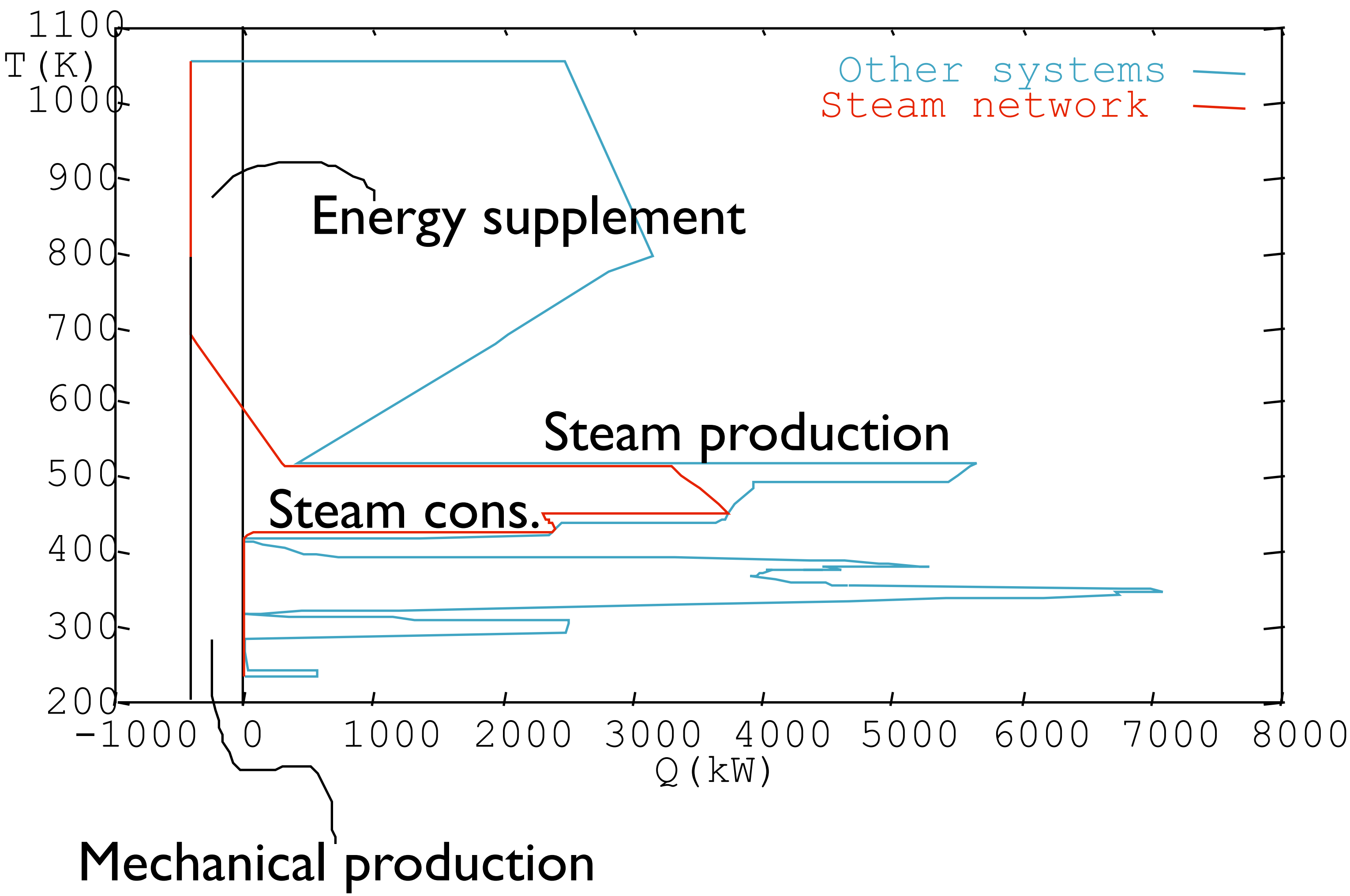
Excess of heat in the fumes

ICC for refrigeration cycle integration



Note that for a closed cycle like refrigeration or Rankine, the sum the hot stream - the sum of the cold stream is the net mechanical power (i.e. the distance between the two extreme points is equal to the mechanical power).

ICC of the steam network



Note that for a closed cycle like refrigeration or Rankine, the sum the hot stream - the sum of the cold stream is the net mechanical power (i.e. the distance between the two extreme points is equal to the mechanical power). Here for the steam cycle. Note that it is therefore easy to very that the cogeneration cycle is well located wrt the pinch point.