Process integration

Targeting the maximum heat recovery in a process

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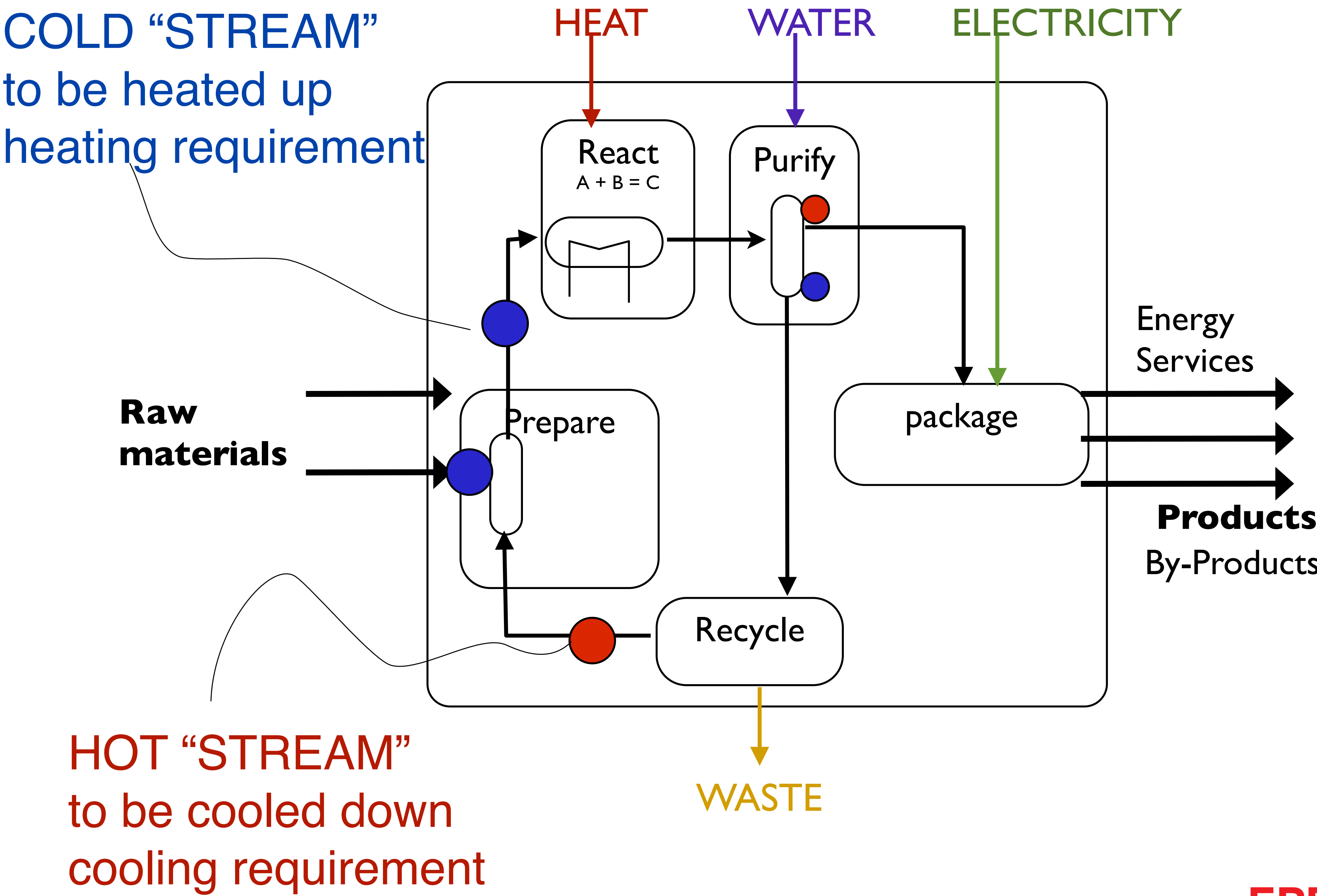
Process analysis : process units



Identify the heat transfer requirements

Heat load

$$\dot{Q} = -\dot{m}_c \int_{T_{in,c}}^{T_{out,c}} cp_c\, dT \simeq \dot{m}_c cp_c (T_{in,c} - T_{out,c})$$

Target State
- Environment
- to process unit operation

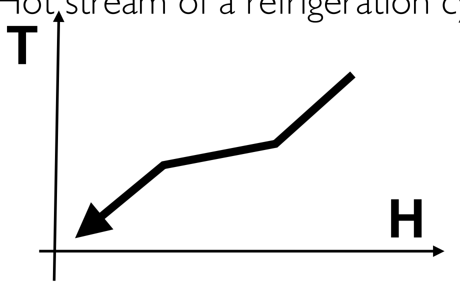
Inlet State
- Environment
- from process unit operation

Hot Streams

---> To be cooled down

Examples

- Distillation condenser
- Exothermic reactor
- Fumes
- Steam condenser
- Hot stream of a refrigeration cycle



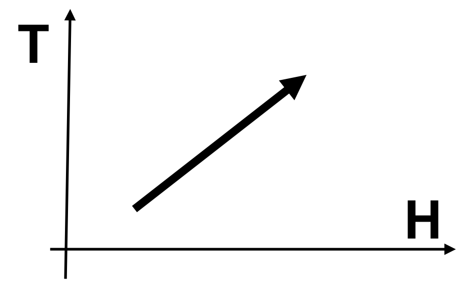
Heat/temperature profile

Cold Streams

---> To be heated up

Examples

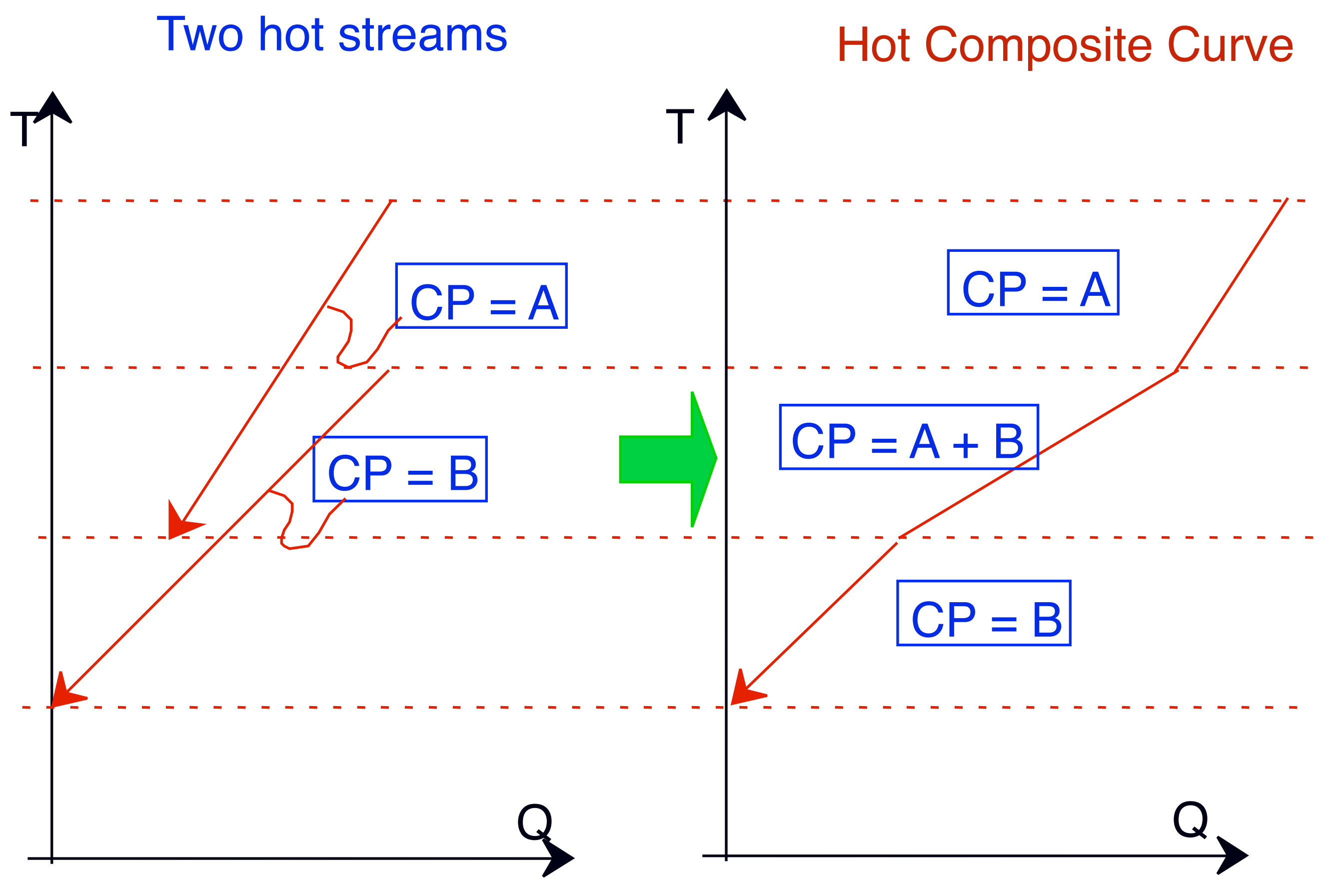
- Distillation boilers
- Reactants Preheating
- Cooling water
- Steam production
- Cold stream of a refrigeration cycle



Heat/temperature profile

Composite curves

Integrating the heat available in the hot streams as a function of the temperature



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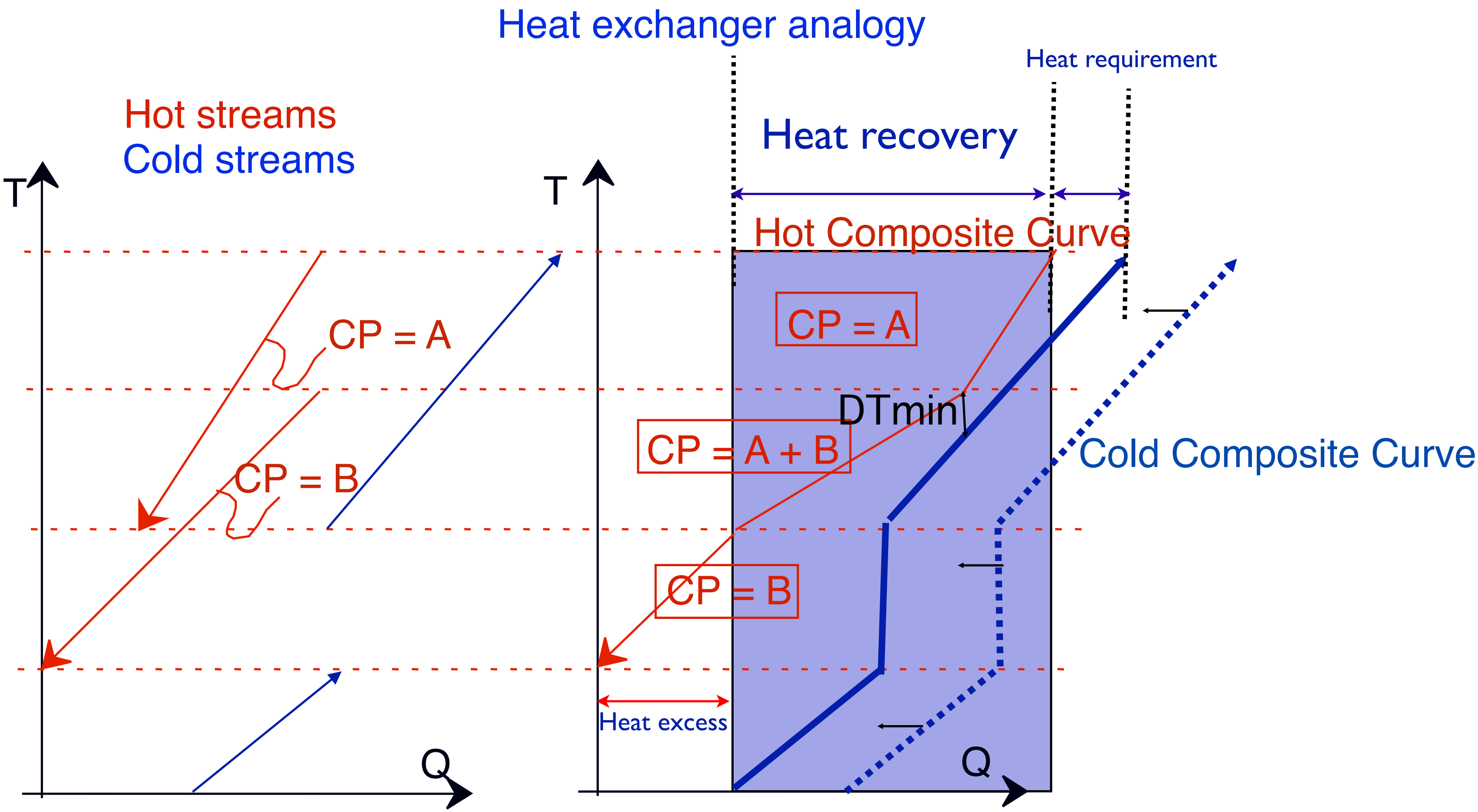
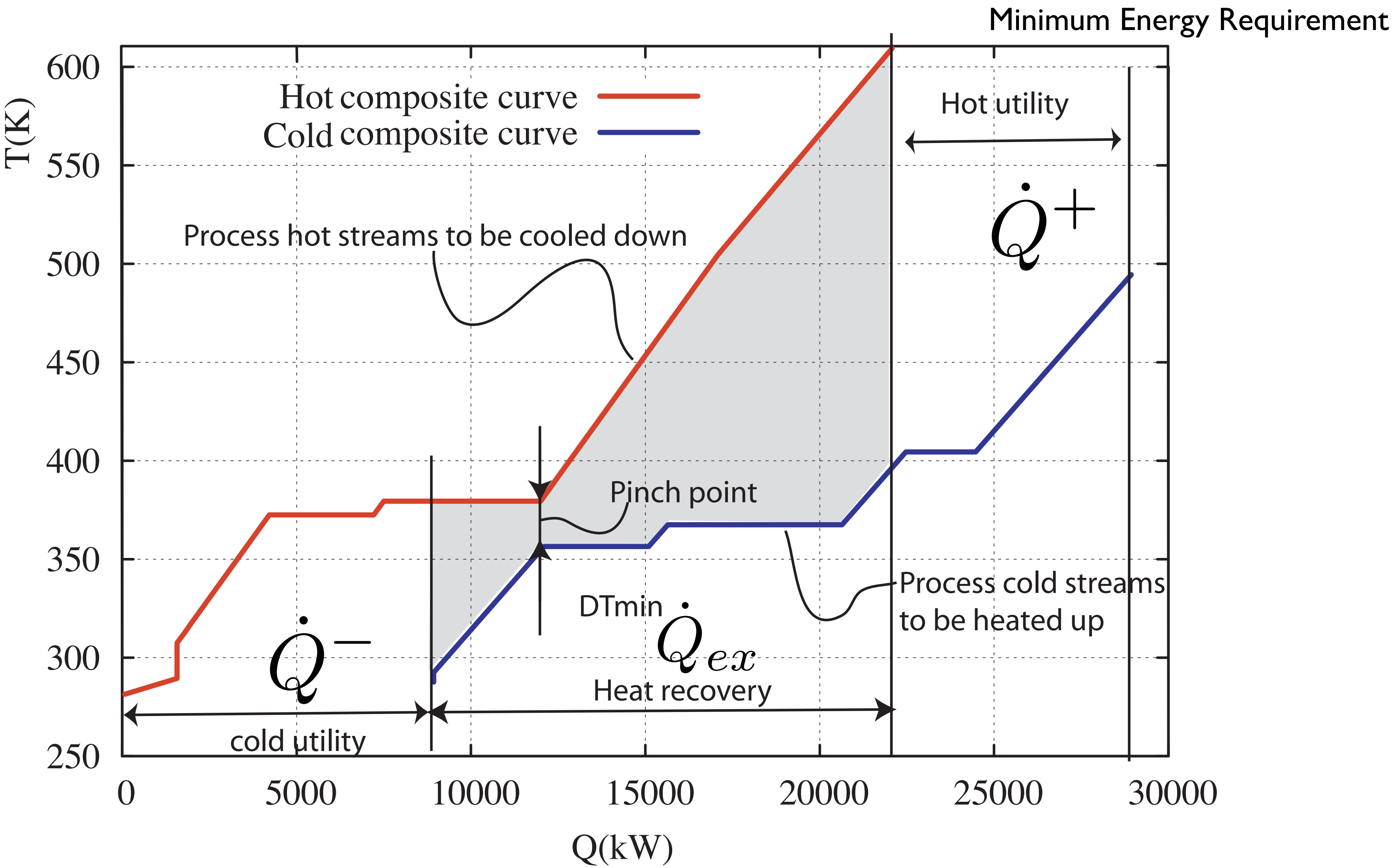
Composite curves and pinch point



Heat excess and Heat by energy balance from the hot and cold streams needs

Hot and cold composite curves



Minimum Energy Requirement results

- Heat Balances

$$\text{Heat from the hot streams : } \dot{Q}^{+}_{hot} = \sum_{i=1}^{n_{hot}} \dot{Q}^{+}_{i}$$

$$\text{Heat to the cold streams : } \dot{Q}^{-}_{cold} = \sum_{j=1}^{n_{cold}} \dot{Q}^{-}_{j}$$

- Pinch point constraint
  - DTmin Value
- Results

Minimum heat requirement as hot utility: $\dot{Q}^{+}$

Maximum heat recovery in heat exchangers :

$$\dot{Q}_{ex} = \dot{Q}^{-}_{cold} - \dot{Q}^{+} = \dot{Q}^{+}_{hot} - \dot{Q}^{-}$$

Minimum cooling requirement as cold utility:

$$\dot{Q}^{-} = \dot{Q}^{+} + \dot{Q}^{+}_{hot} - \dot{Q}^{-}_{cold}$$

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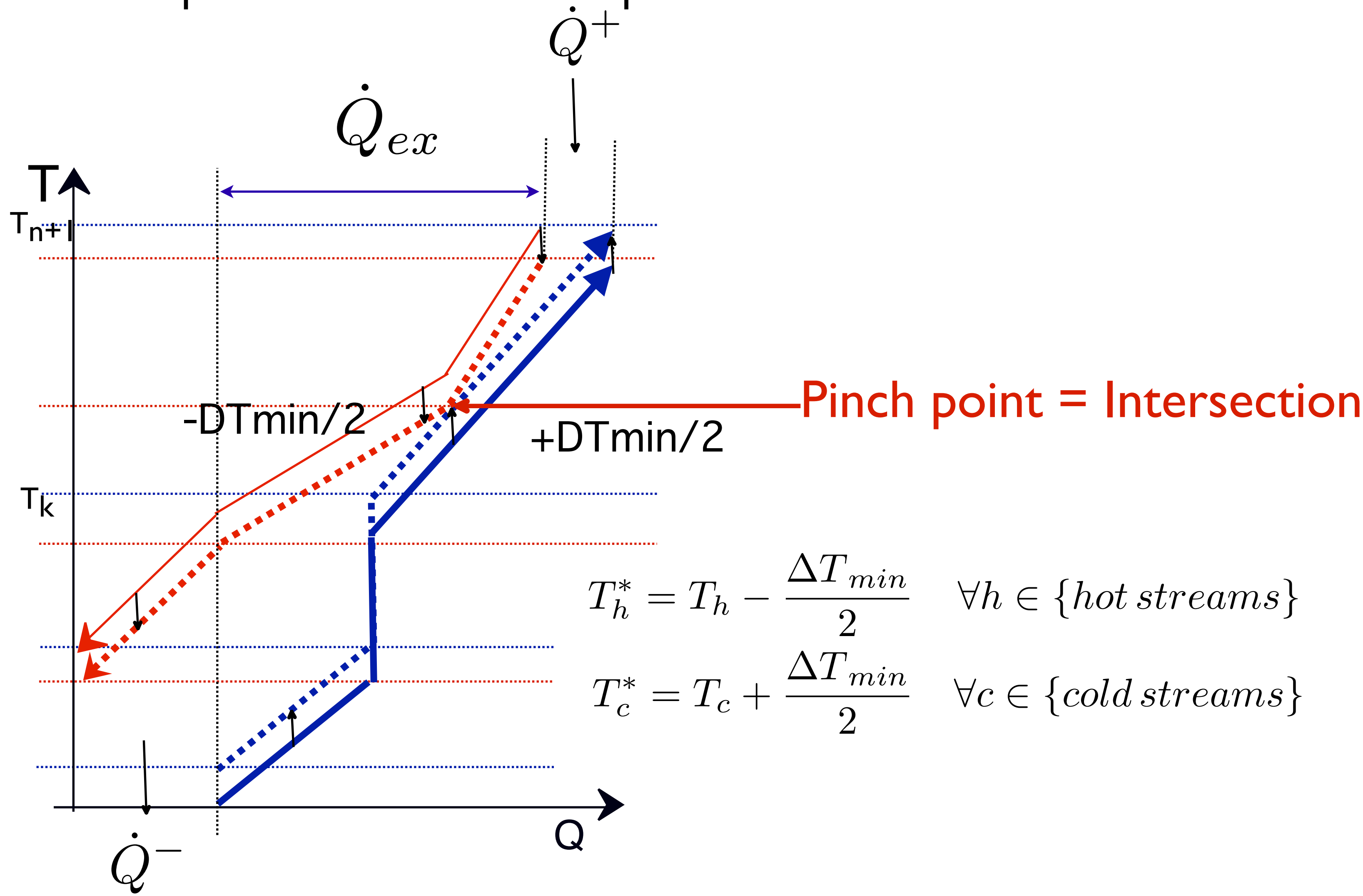
Calculation of the minimum energy requirement

Corrected Temperatures or shifted temperatures



$$T_h^* = T_h - \frac{\Delta T_{min}}{2} \quad \forall h \in \{hot\ streams\}$$

$$T_c^* = T_c + \frac{\Delta T_{min}}{2} \quad \forall c \in \{cold\ streams\}$$

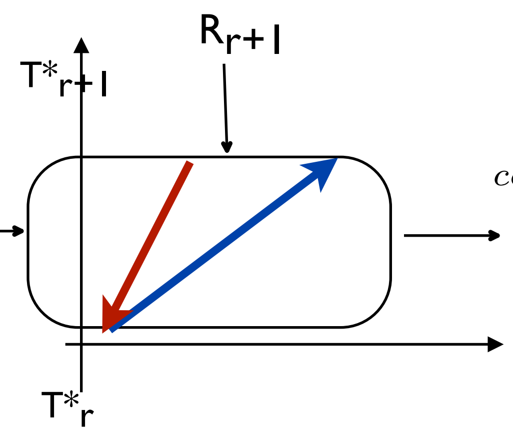
Heat balance in one corrected temperature interval

Change in the scale : Corrected temperatures !

Heat from the hot streams between T^*_{r+1} et T^*_r

Heat to the cold streams between T^*_{r+1} and T^*_r

$$\sum_{j_r=1}^{hot\ streams_r} \dot{M}_{j_r} c_{p_{j_r}} (T^*_{r+1} - T^*_r)$$



$$\sum_{i_r=1}^{cold\ streams_r} \dot{M}_{i_r} c_{p_{i_r}} (T^*_{r+1} - T^*_r)$$

Heat deficit

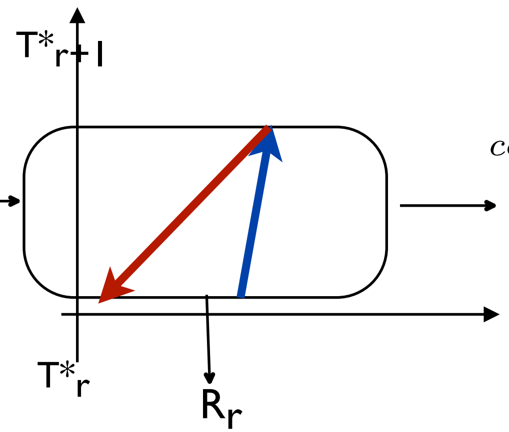
Heat balance in one corrected temperature interval

Change in the scale : Corrected temperatures !

Heat from the hot streams between T^*_{r+1} et T^*_r

Heat to the cold streams between T^*_{r+1} and T^*_r

$$\sum_{j_r=1}^{hot\ streams_r} \dot{M}_{j_r} c_{p_{j_r}} (T^*_{r+1} - T^*_r)$$



$$\sum_{i_r=1}^{cold\ streams_r} \dot{M}_{i_r} c_{p_{i_r}} (T^*_{r+1} - T^*_r)$$

Heat Surplus

Heat balance in one corrected temperature interval

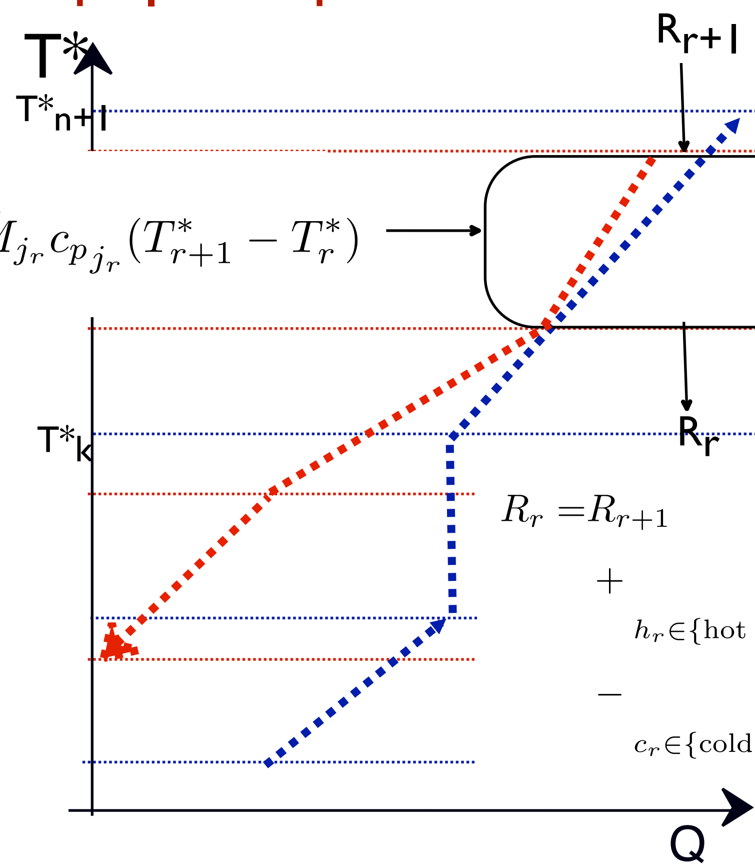
Change in the scale : Corrected temperatures !

Heat from the hot streams between T^*_{r+1} et T^*_r

Heat to the cold streams between T^*_{r+1} and T^*_r

$$\sum_{j_r=1}^{hot\ streams_r} \dot{M}_{j_r} c_{p_{j_r}} (T^*_{r+1} - T^*_r)$$

$$\sum_{i_r=1}^{cold\ streams_r} \dot{M}_{i_r} c_{p_{i_r}} (T^*_{r+1} - T^*_r)$$



$$R_r = R_{r+1} + \sum_{h_r \in \{\text{hot streams in interval } r\}} \dot{M}_{h_r} c_{p_{h_r}} (T^*_{r+1} - T^*_r) - \sum_{c_r \in \{\text{cold streams in interval } r\}} \dot{M}_{c_r} c_{p_{c_r}} (T^*_{r+1} - T^*_r) \quad \forall r = 1, ..., n_r$$

Heat cascade : [R_r, T^*_r]

Heat cascade

$$\min_{R_r} \dot{Q}^+ = R_{n_r+1}$$

subject to heat balance of the temperature intervals :

$$\begin{aligned} R_r =& R_{r+1} \\ &+ \sum_{h_r \in \{\text{hot streams in interval } r\}} \dot{M}_{h_r} c_{p_{h_r}} (T^*_{r+1} - T^*_r) \\ &- \sum_{c_r \in \{\text{cold streams in interval } r\}} \dot{M}_{c_r} c_{p_{c_r}} (T^*_{r+1} - T^*_r) \end{aligned} \quad \forall r = 1, ..., n_r$$

and the heat cascade feasibility

$$R_r \geq 0 \quad \forall r = 1, ..., n_r + 1$$

$$T^*_h = T_h - \frac{\Delta T_{min}}{2} \quad \forall h \in \{hot\, streams\}$$

$$T^*_c = T_c + \frac{\Delta T_{min}}{2} \quad \forall c \in \{cold\, streams\}$$

Heat balance in one corrected temperature interval

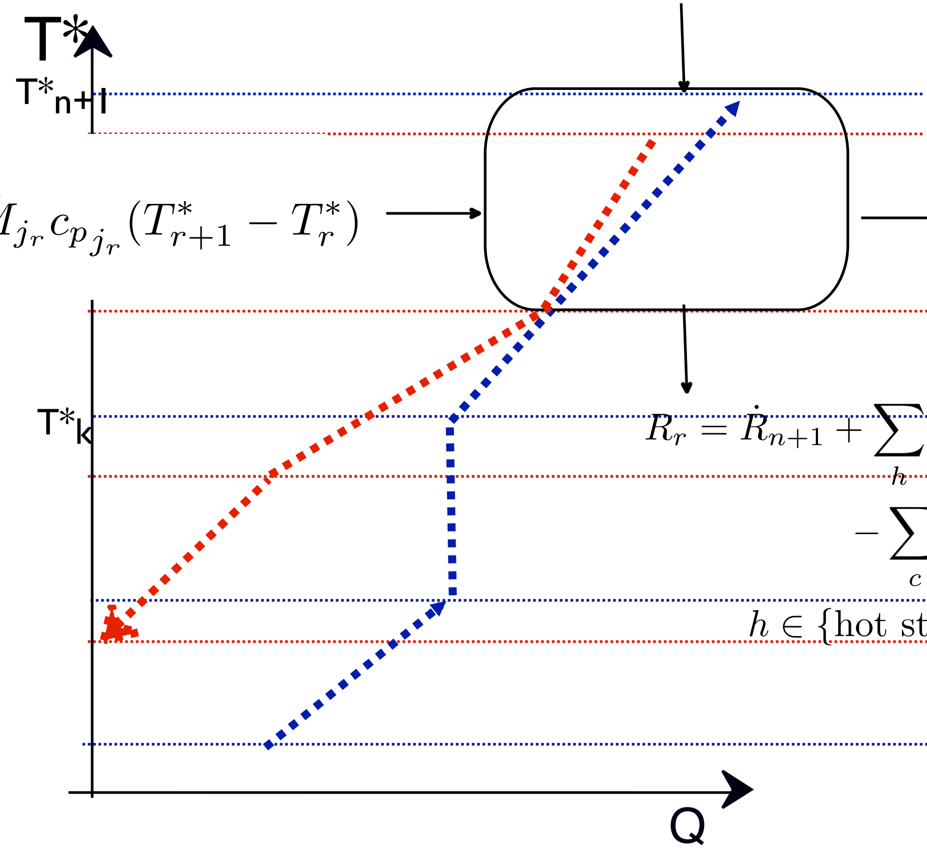
Change in the scale : Corrected temperatures !

Heat from the hot streams between T*$_{r+1}$ et T*$_r$

Heat to the cold streams between T*$_{r+1}$ and T*$_r$

$$\sum_{j_r=1}^{hot\ streams_r} \dot{M}_{j_r} c_{p_{j_r}} (T^*_{r+1} - T^*_r)$$

$$\sum_{i_r=1}^{cold\ streams_r} \dot{M}_{i_r} c_{p_{i_r}} (T^*_{r+1} - T^*_r)$$



$$R_r = \dot{R}_{n+1} + \sum_h \dot{M}_h c_{p_h} (max(T^*_r, T^*_{h,in}) - max(T^*_r, T^*_{h,target}))$$
$$- \sum_c \dot{M}_c c_{p_c} (max(T^*_r, T^*_{c,target}) - max(T^*_r, T^*_{c,in}))$$

$$h \in \{\text{hot stream segments}\}, c \in \{\text{cold stream segments}\}$$

Heat cascade : [R$_r$, T*$_r$]

Alternative definition

$$\dot{Q}^{+} = -\min_{s}(0, R_s^*), \forall s \in \{\text{hot and cold stream segments}\}$$

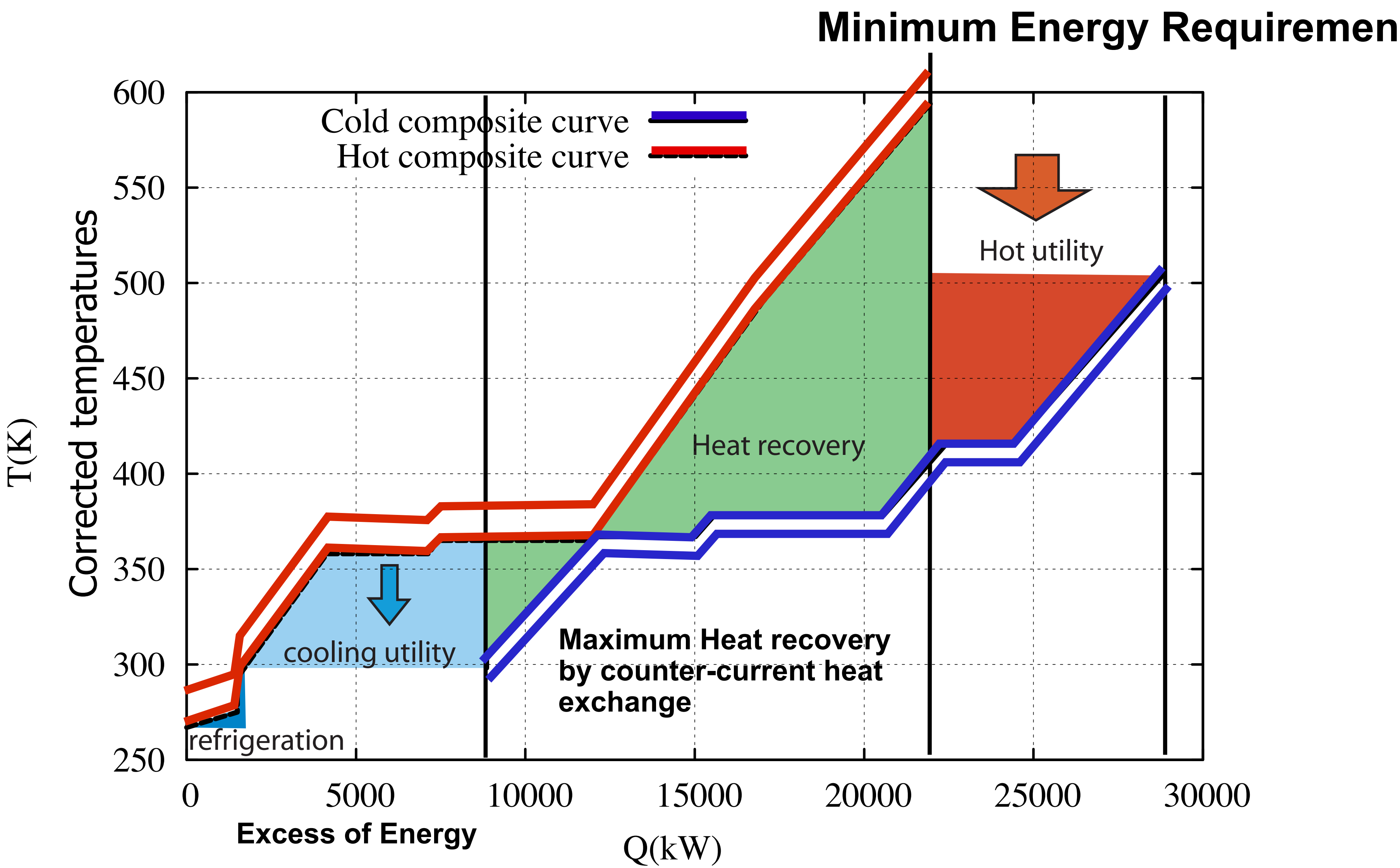
$$R_s^* = \sum_h \dot{M}_h c_{p_h} (max(T_s^*, T_{h,in}^*) - max(T_s^*, T_{h,target}^*))$$

$$-\sum_c \dot{M}_c c_{p_c} (max(T_s^*, T_{c,target}^*) - max(T_s^*, T_{c,in}^*))$$

$$h \in \{\text{hot stream segments}\}, c \in \{\text{cold stream segments}\}$$

$$\dot{Q}^{-} = \dot{Q}^{+} + \sum_h \dot{Q}_h - \sum_c \dot{Q}_c$$

Maximum heat recovery Target



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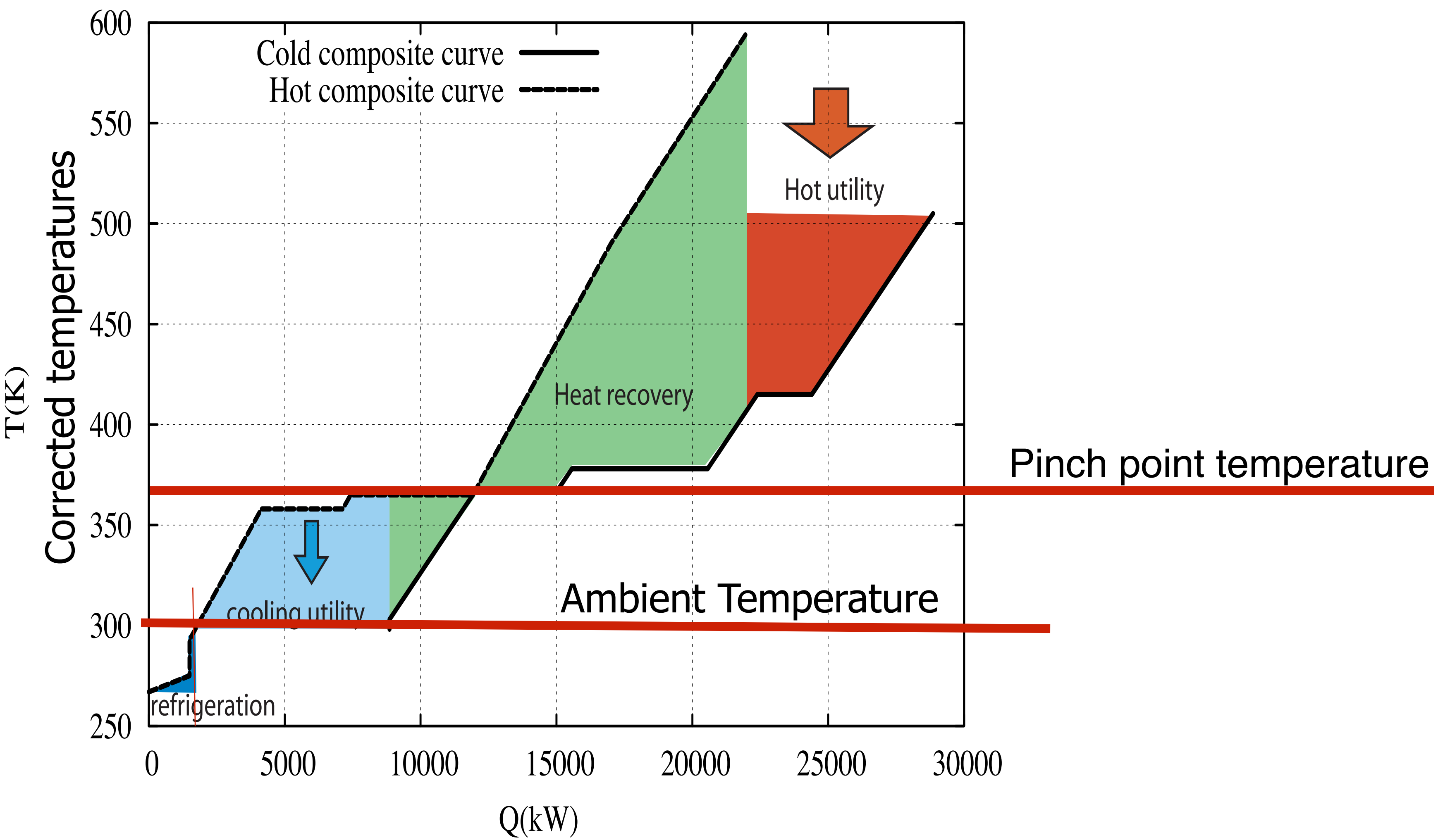
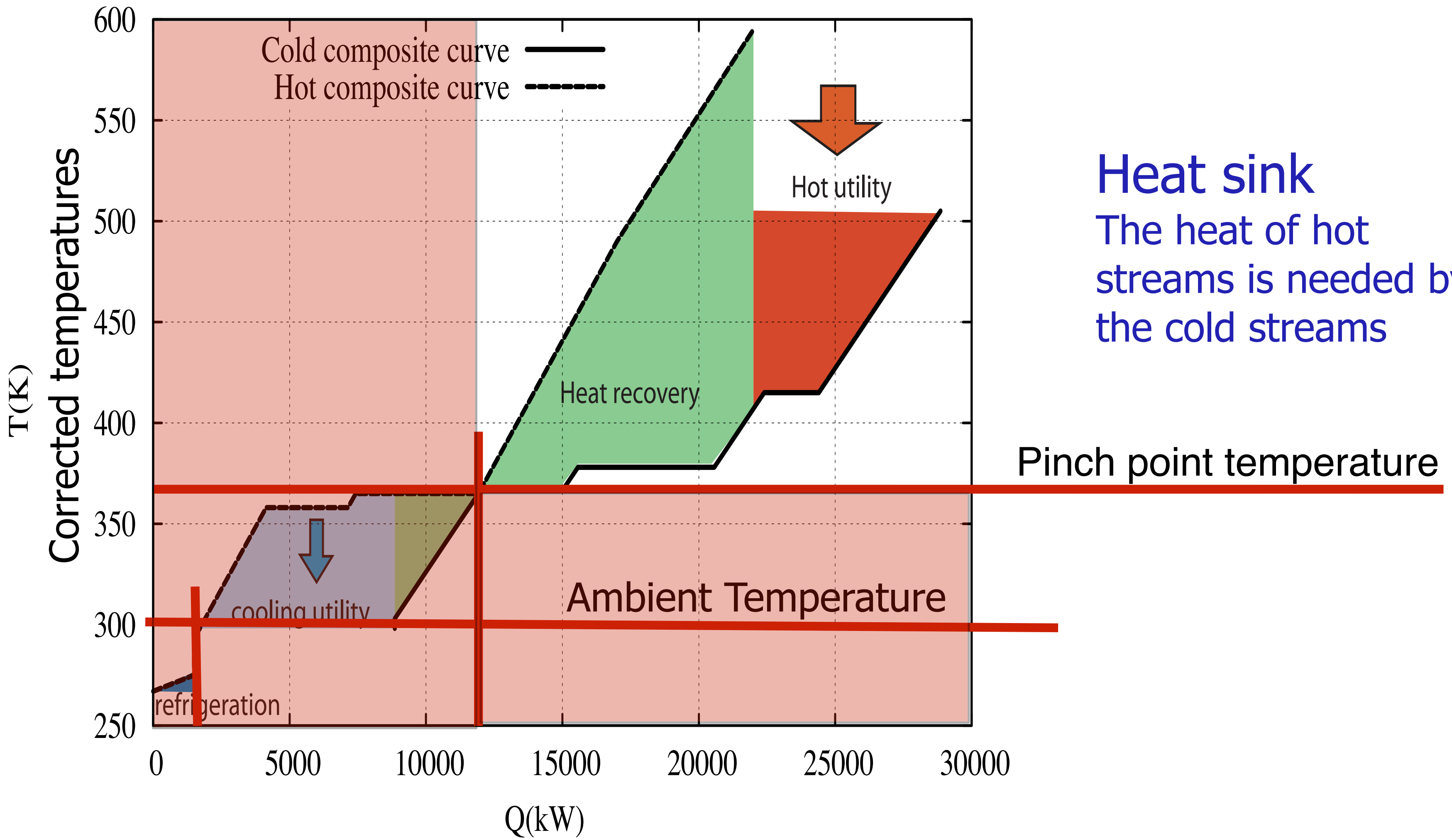
3 Independent sub-systems



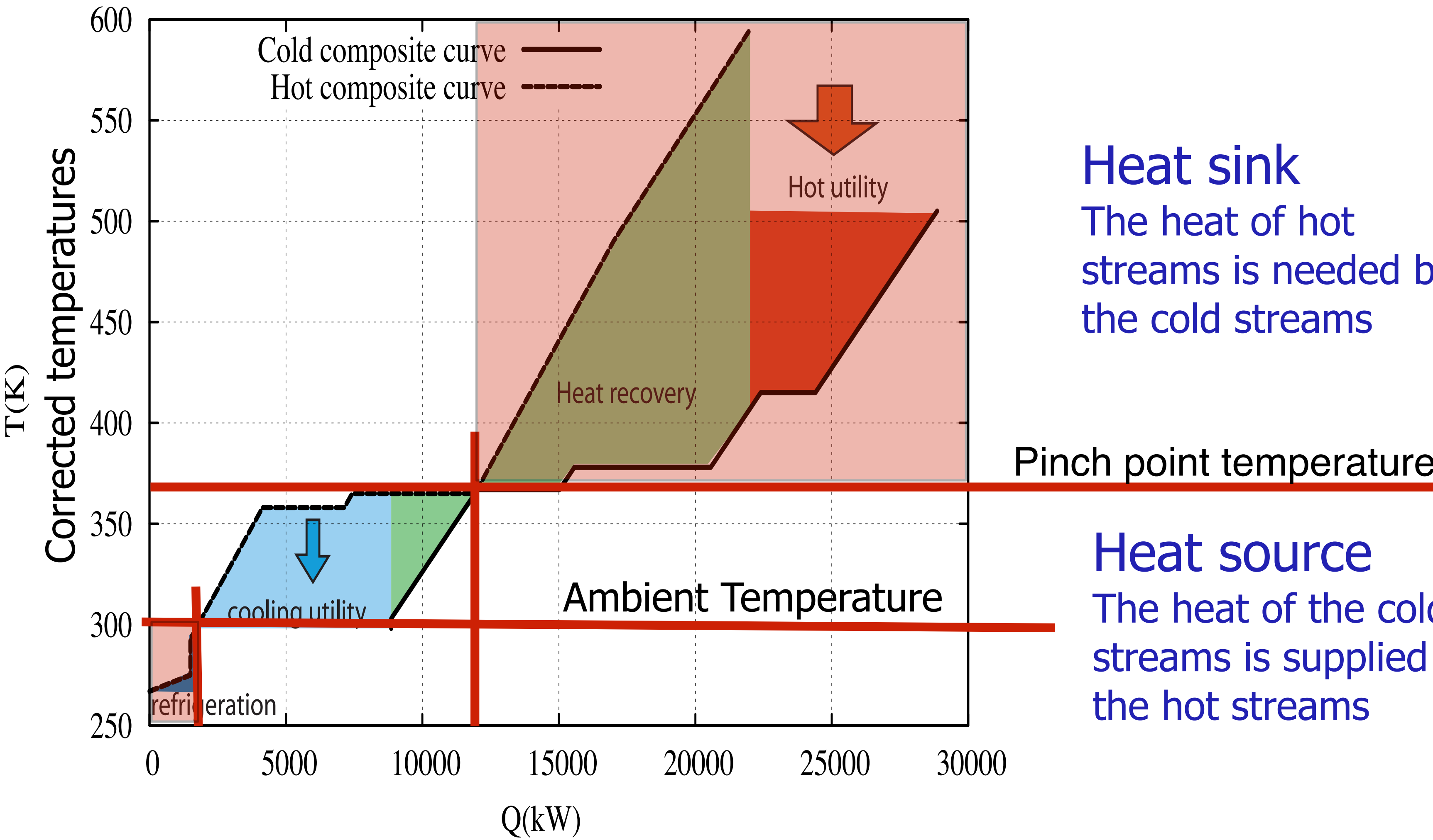
3 Independent sub-systems



Heat sink

The heat of hot streams is needed by the cold streams

3 Independent sub-systems



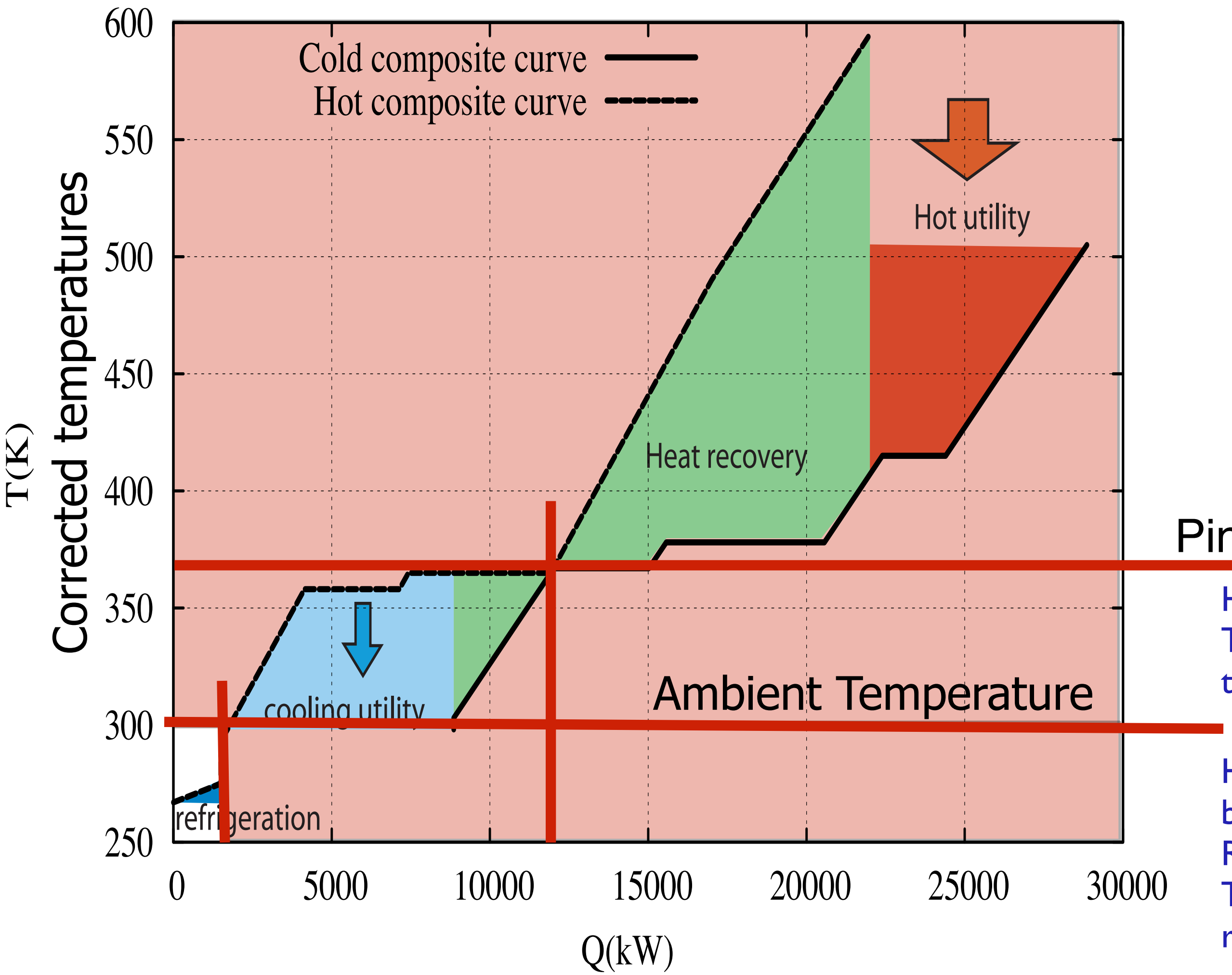
Heat sink

The heat of hot streams is needed by the cold streams

Heat source

The heat of the cold streams is supplied by the hot streams

3 Independent sub-systems



Pinch point temperature

Heat sink

The heat of hot streams is needed by the cold streams

Heat source

The cold streams are heated by the hot streams

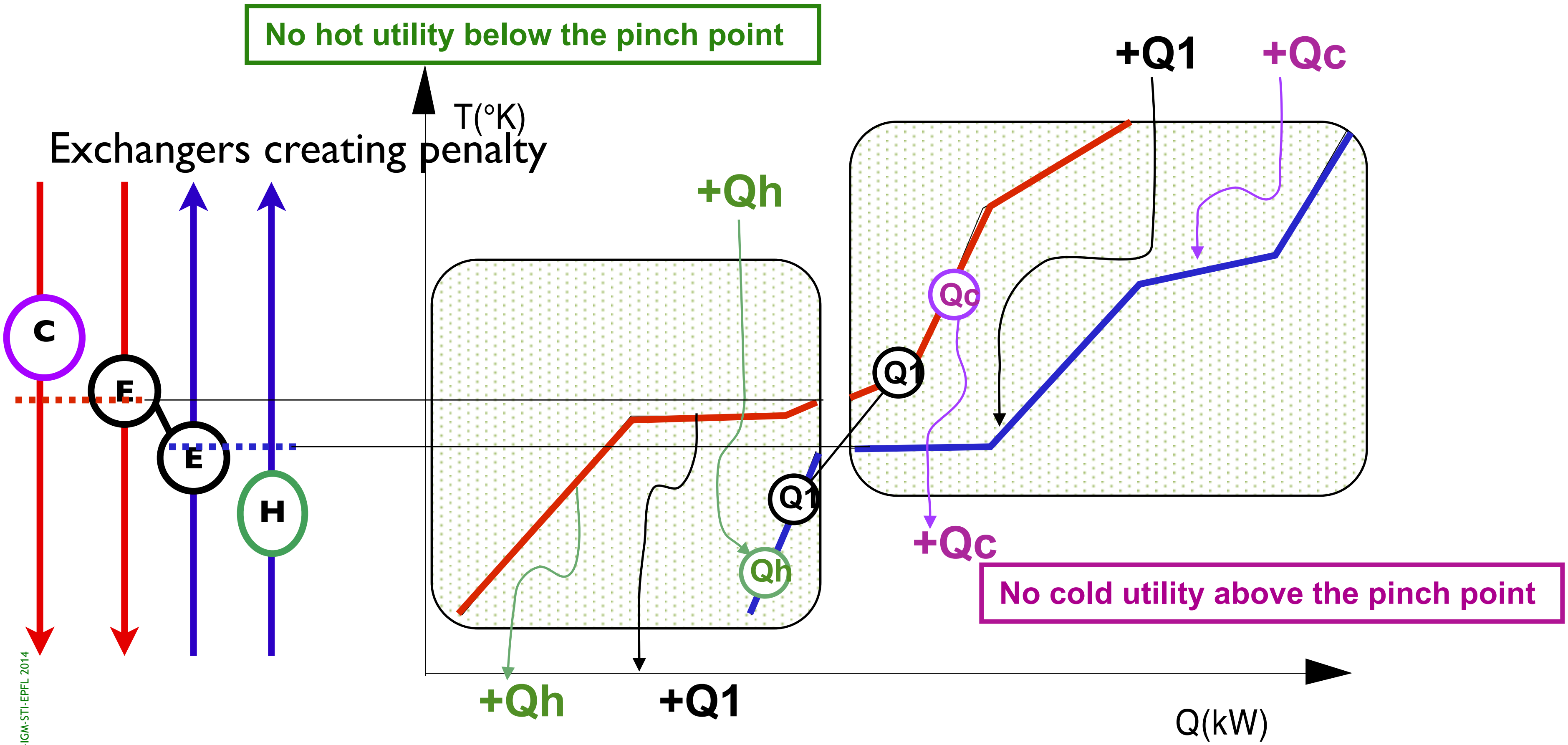
Heat source

below ambient temperature

REFRIGERATION

The cold streams can supply refrigeration by heat recovery

Penalizing heat exchangers



No heat exchange across the pinch point
The heat load across is the penalty

Mixing unit is a heat exchanger