Energy conversion system integration

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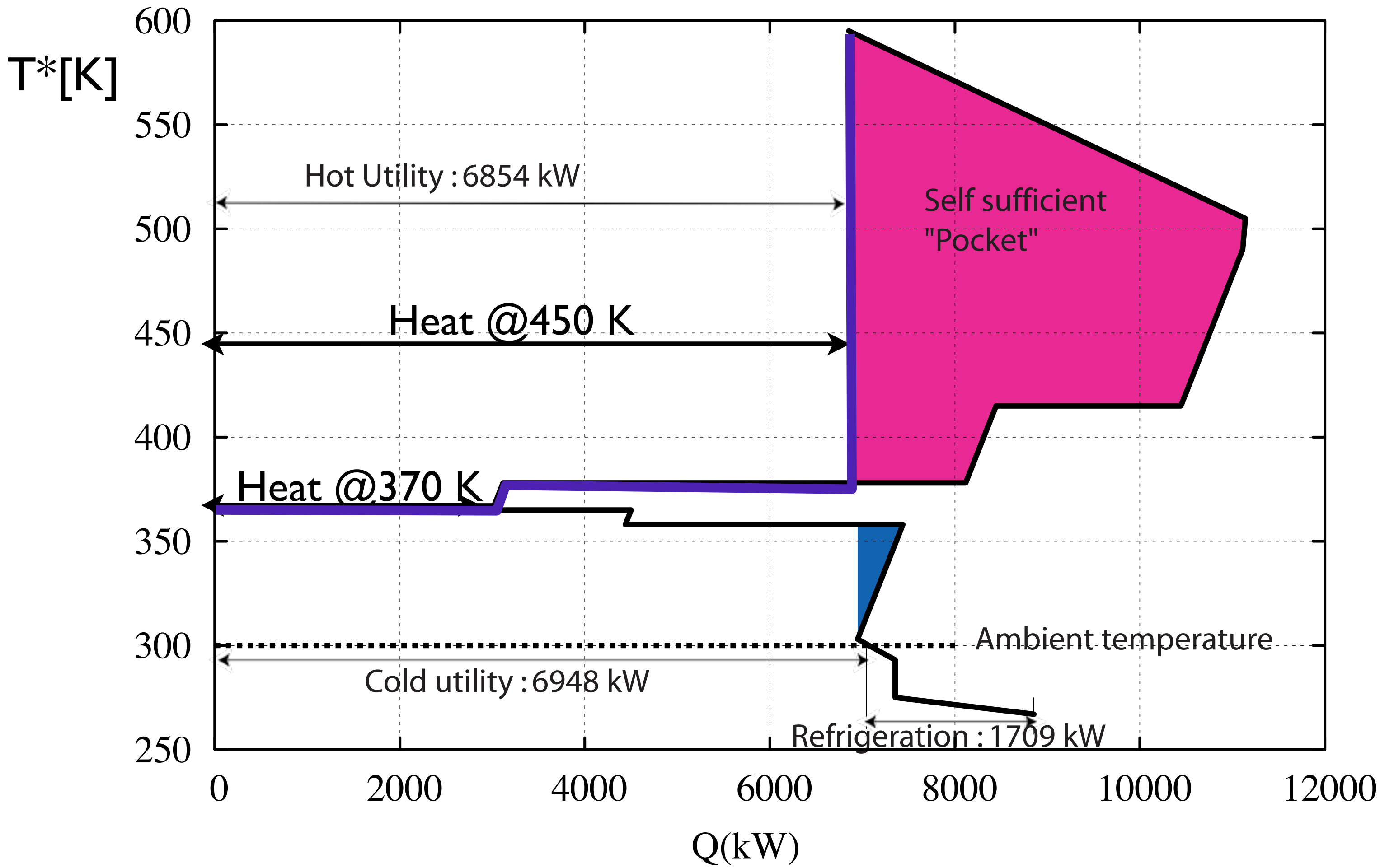
Suplying energy to the process

$$\dot{Q}^{(+)}_{r^{(+)}} = min((\min_r(R_r), \forall r = n_r + 1, ..., r^{(+)}), (\min_r(R_r), \forall r = r^{(-)}, ..., 1))$$



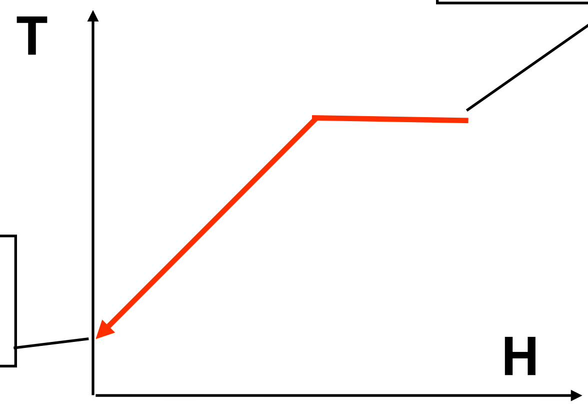
The heat requirement of the process appears as a cold stream to be heated by a hot utility stream whose Q-T* profile should be above the process Grand Composite

Self sufficient zones are eliminated

Utility stream definition

Type of utility (e.g. : Hot stream)

inlet conditions (T, P)
(fuel type, combustion , operation)

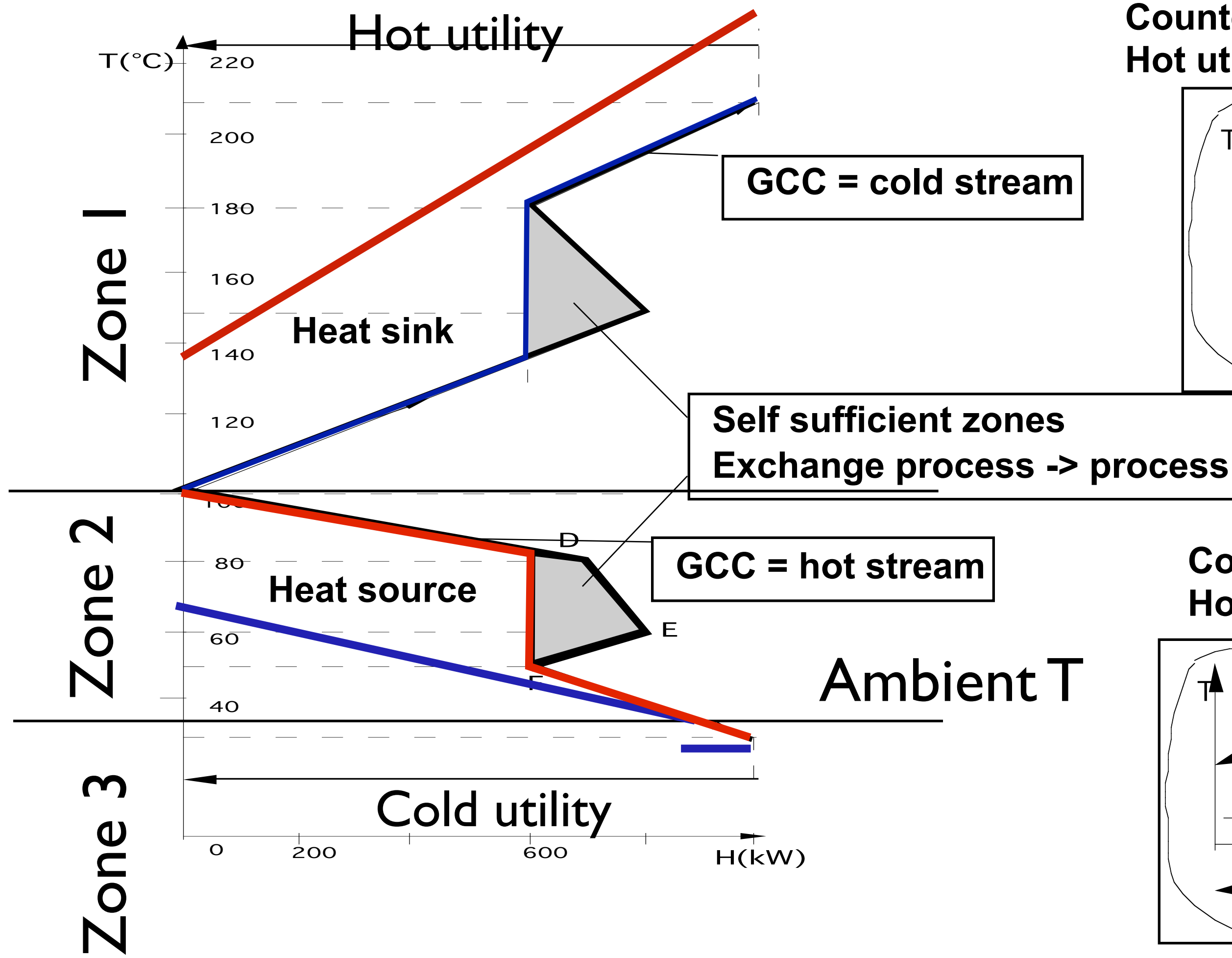


Outlet conditions (T,P)
(environment, operation)

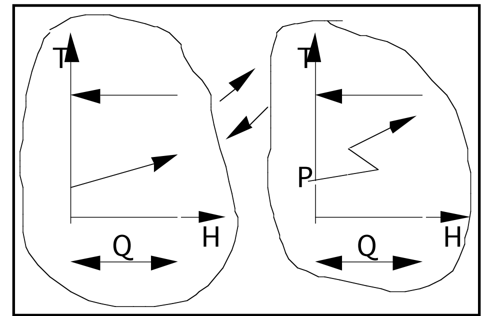
3 characteristics :

- **H-T diagram (from GCC analysis)**
- **Cost as a function of flowrate**
- **Flowrate : to be determined to satisfy the requirements at Minimum Costs.**

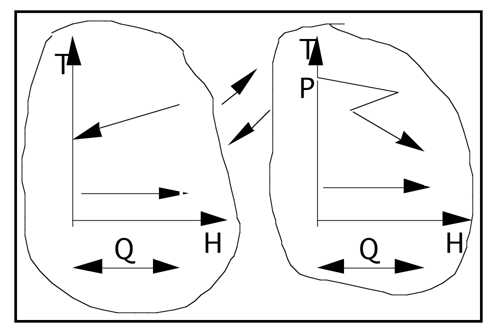
Utility integration principle



Counter current analogy
Hot utility - cold process

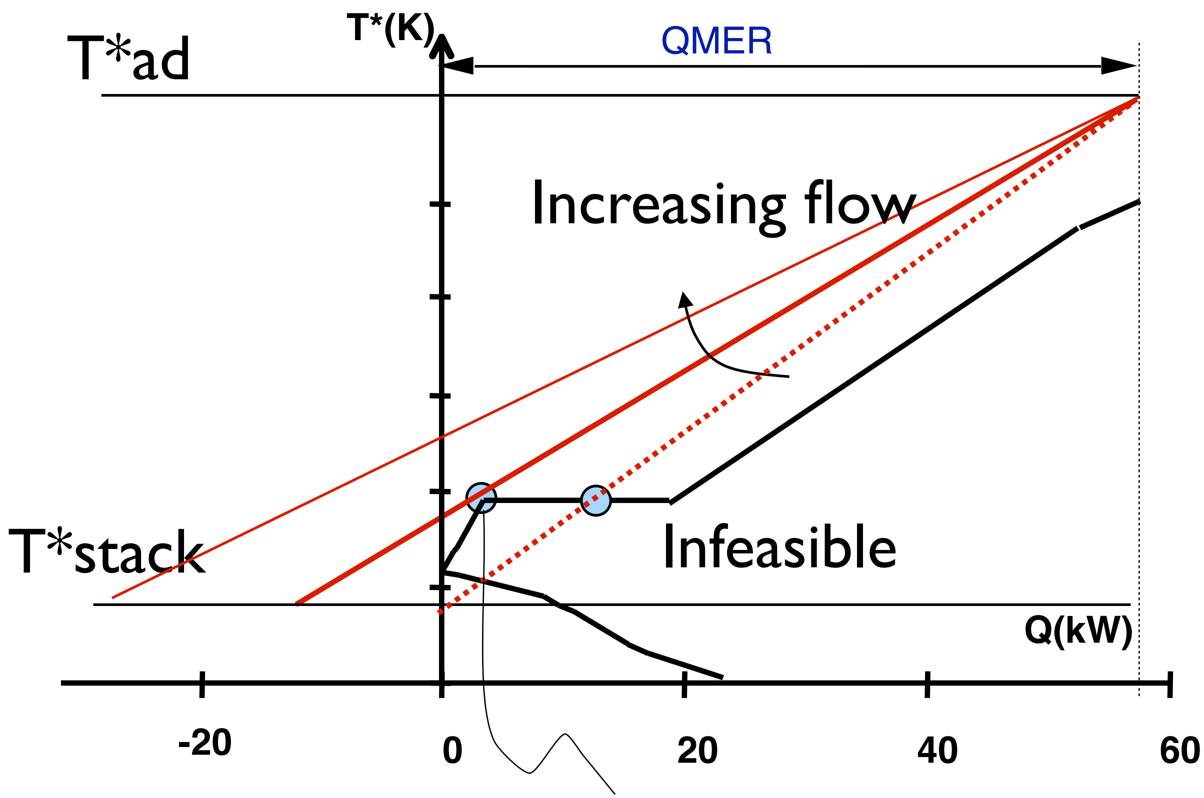


Counter current analogy
Hot process - cold utility



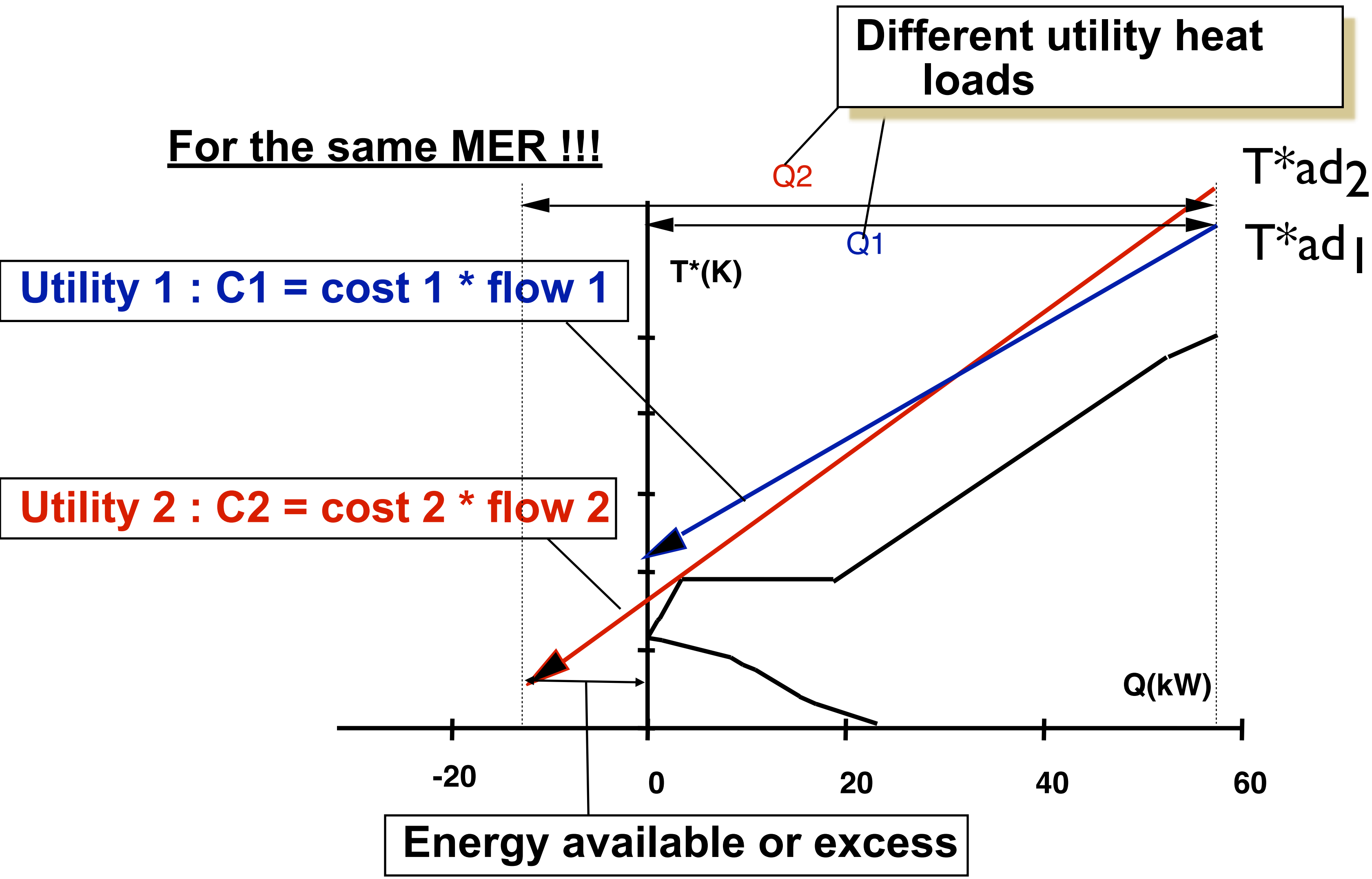
Utility flow definition

Utility cost : C(CHF/s) = cost(CHF/kg) * flow(kg/s)



DTmin = minimum flow

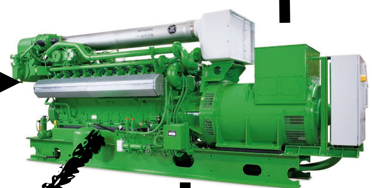
Different fuels



Cogeneration system : Energy Balance

$$\dot{E}^{-} = \eta_e \dot{M}_{fuel} LHV$$

$$\dot{M}_{fuel} LHV$$

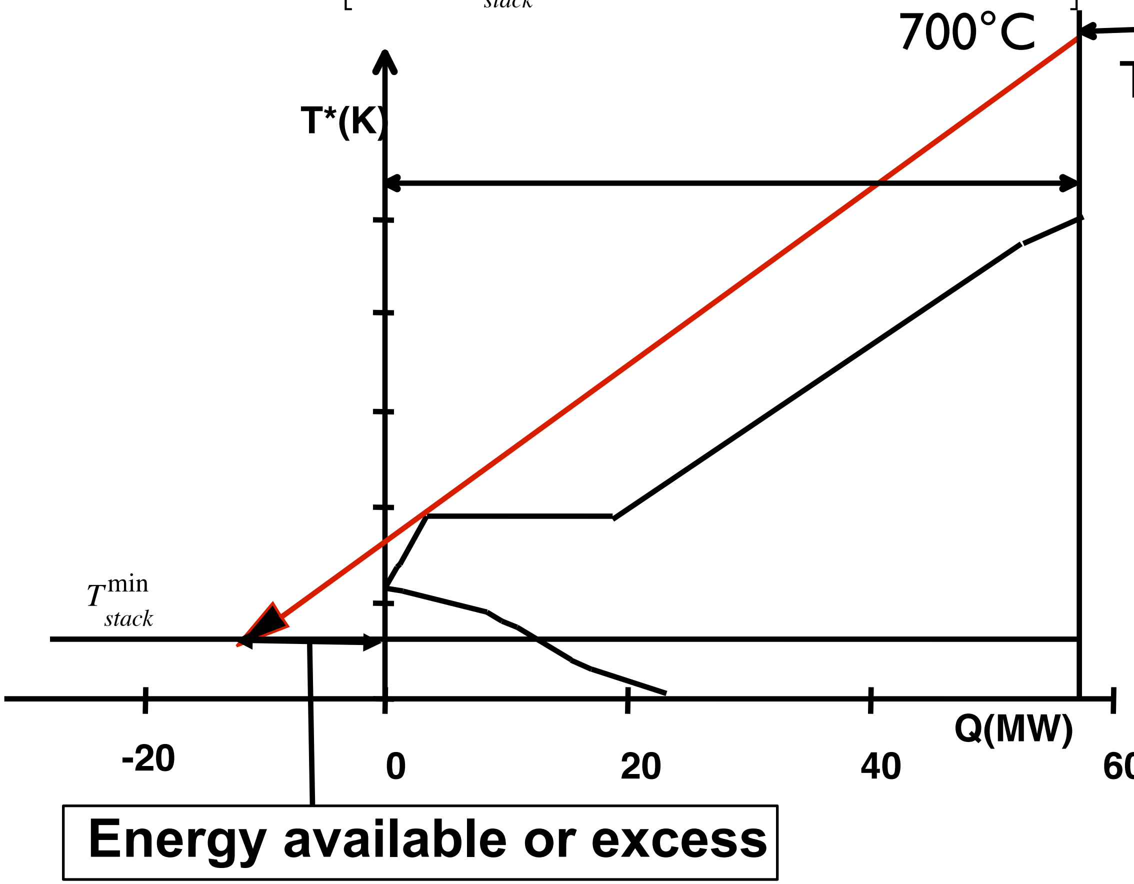


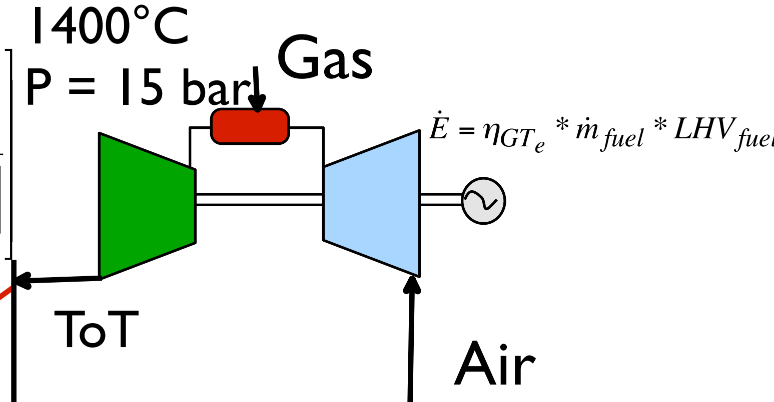
$$\dot{Q}^{-} = \eta_{th} \dot{M}_{fuel} LHV$$

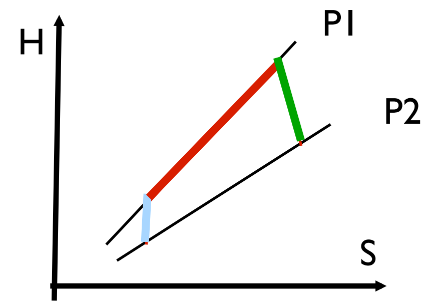
$$\dot{Q}^{-}_{losses} = (1 - \eta_e - \eta_{th}) \dot{M}_{fuel} LHV$$

Cogeneration : gas turbines

$$\dot{m}_{fuel} = \max_{k}\left[\frac{\dot{Q}_{mer_k}}{\frac{\eta_{GT_{th}} * LHV_{fuel}}{(T_{oT} - T^{\min}_{stack})} * \left[T_{oT} - \max\left(T^{\min}_{stack}, \left(T^*_k + \Delta T_{\min}/2_f\right)\right)\right]}\right]$$







$\eta_{GT_e} = 30 - 38\%$

$\eta_{GT_{t_{gc}}} = 55 - 47\%$

=> 120°C

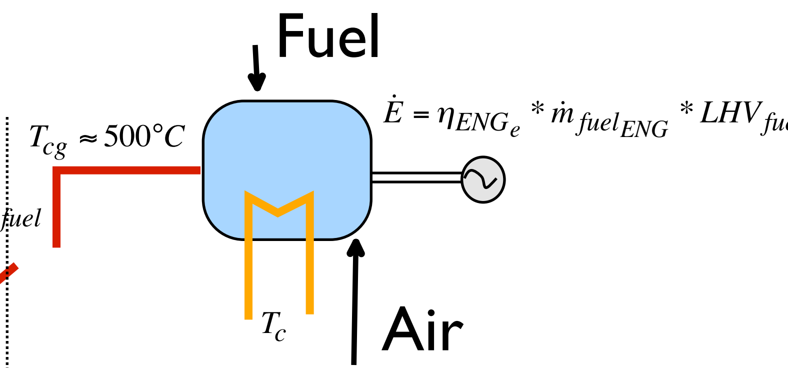
$\eta_{GT} = 85\%$

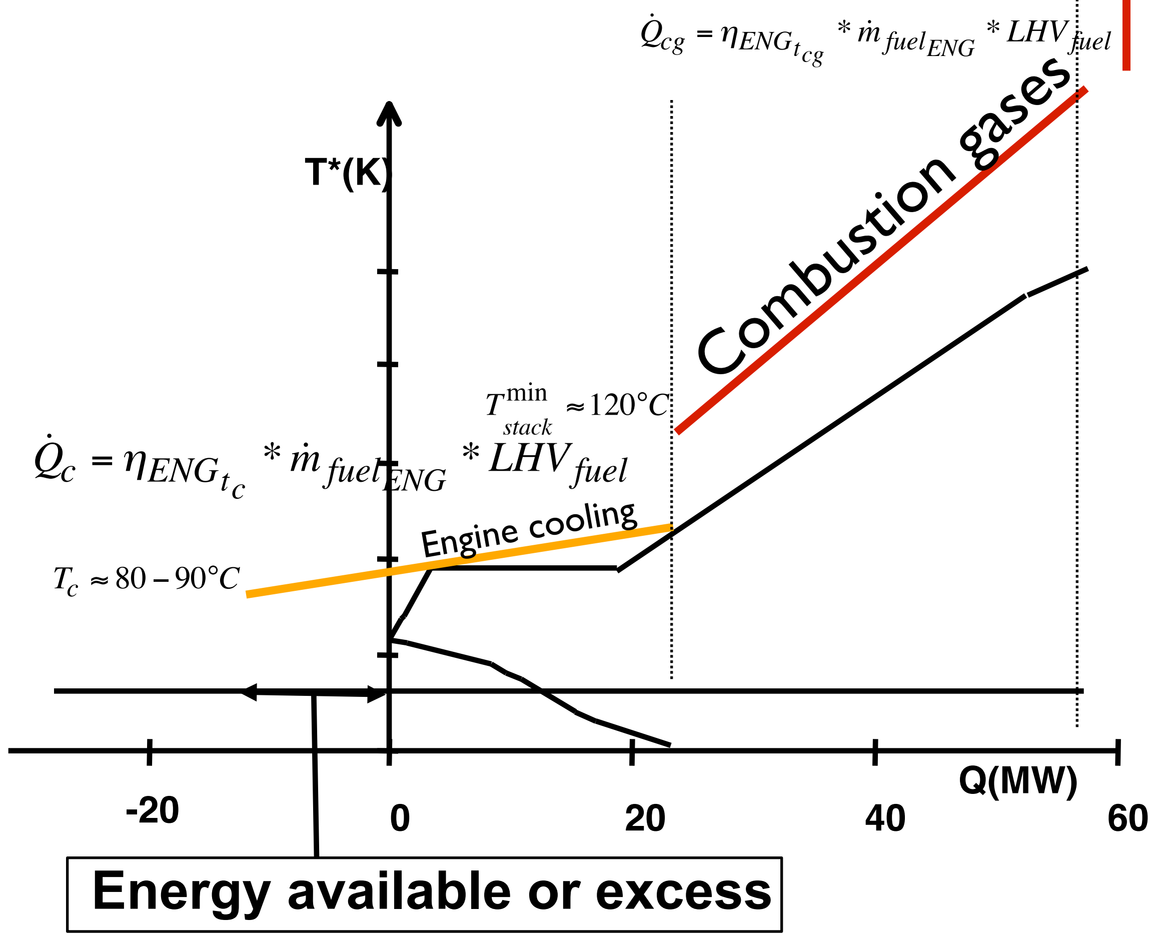
Inv = 1000 - 2500 CHF/kWe

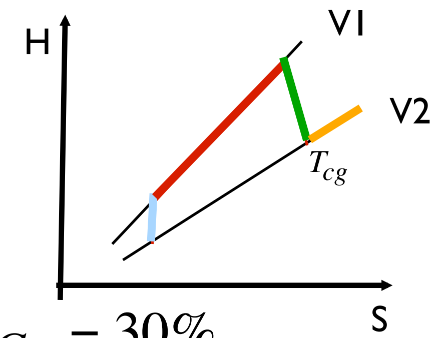
Size = 50000 - 1000 kWe

Cogeneration engines

Inv = 800 - 4000 CHF/kWe
Size = 10000 - 100 kWe







$\eta_{ENG_e} = 30\%$

$\eta_{ENG_{t_c}} = 30\%$

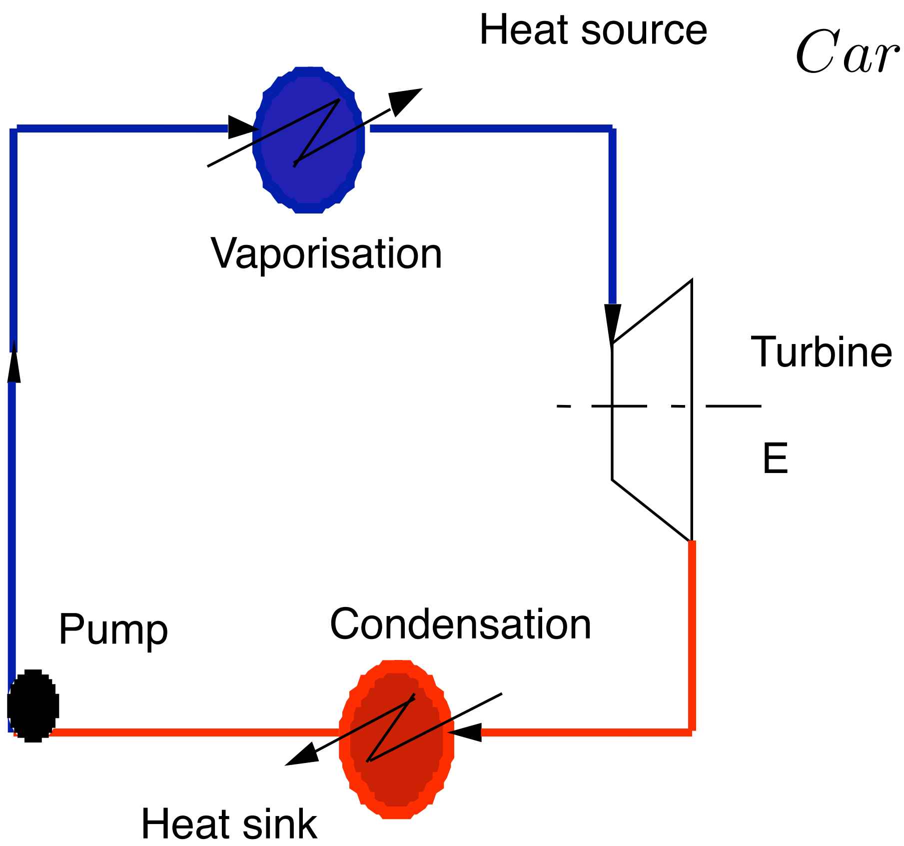
$\eta_{ENG_{t_{gc}}} = 25\%$ => 120°C

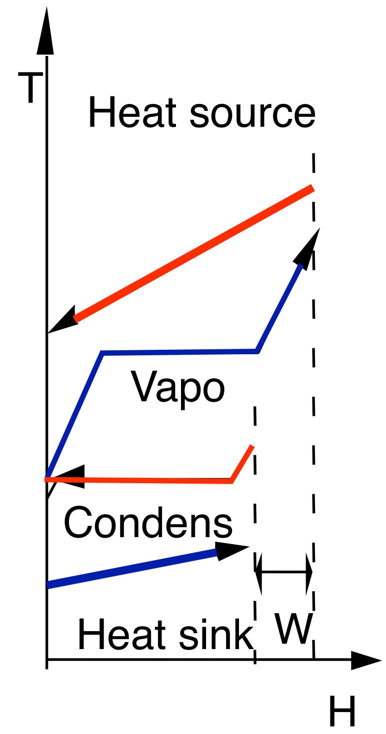
$\eta_{ENG_{total}} = 85-90\%$

Combined heat and power

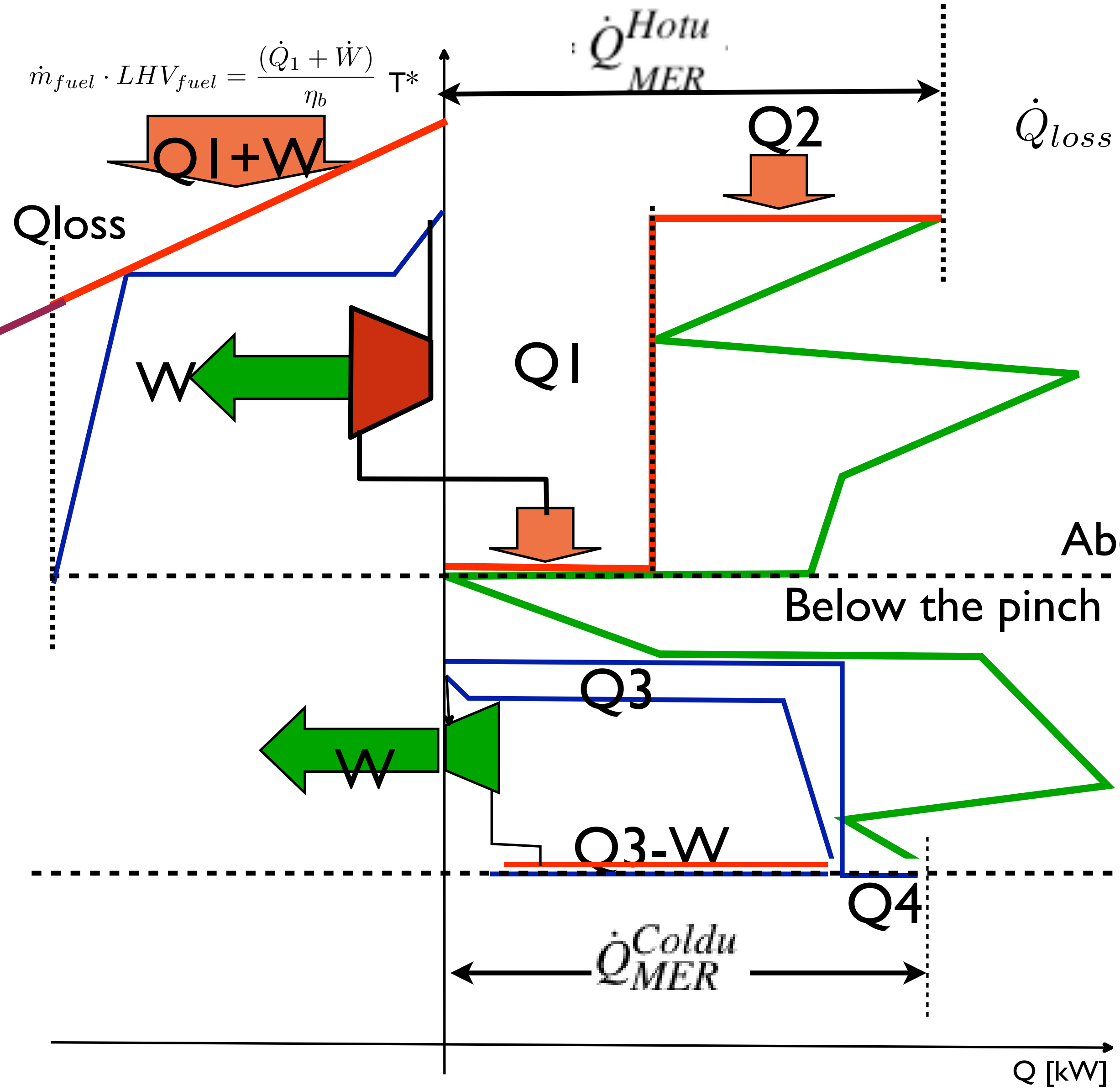
Example : Rankine cycle

$$Carnot : \dot{E}_{max} = \dot{Q} * (1 - \frac{T_{cond}}{T_{vap}})$$





Combined heat and power



New Hot Utility

$$\dot Q_{loss} + \dot Q_1 + \dot W + \dot Q_2 = \dot Q_{MER}^{Hotu} + \dot W$$

Marginal efficiency

$$\eta_e = \frac{\dot W}{\frac{\Delta \dot Q}{\eta_b}} = \frac{\dot W}{\frac{\dot W}{\eta_b}} = \eta_b$$

Above the pinch

Below the pinch

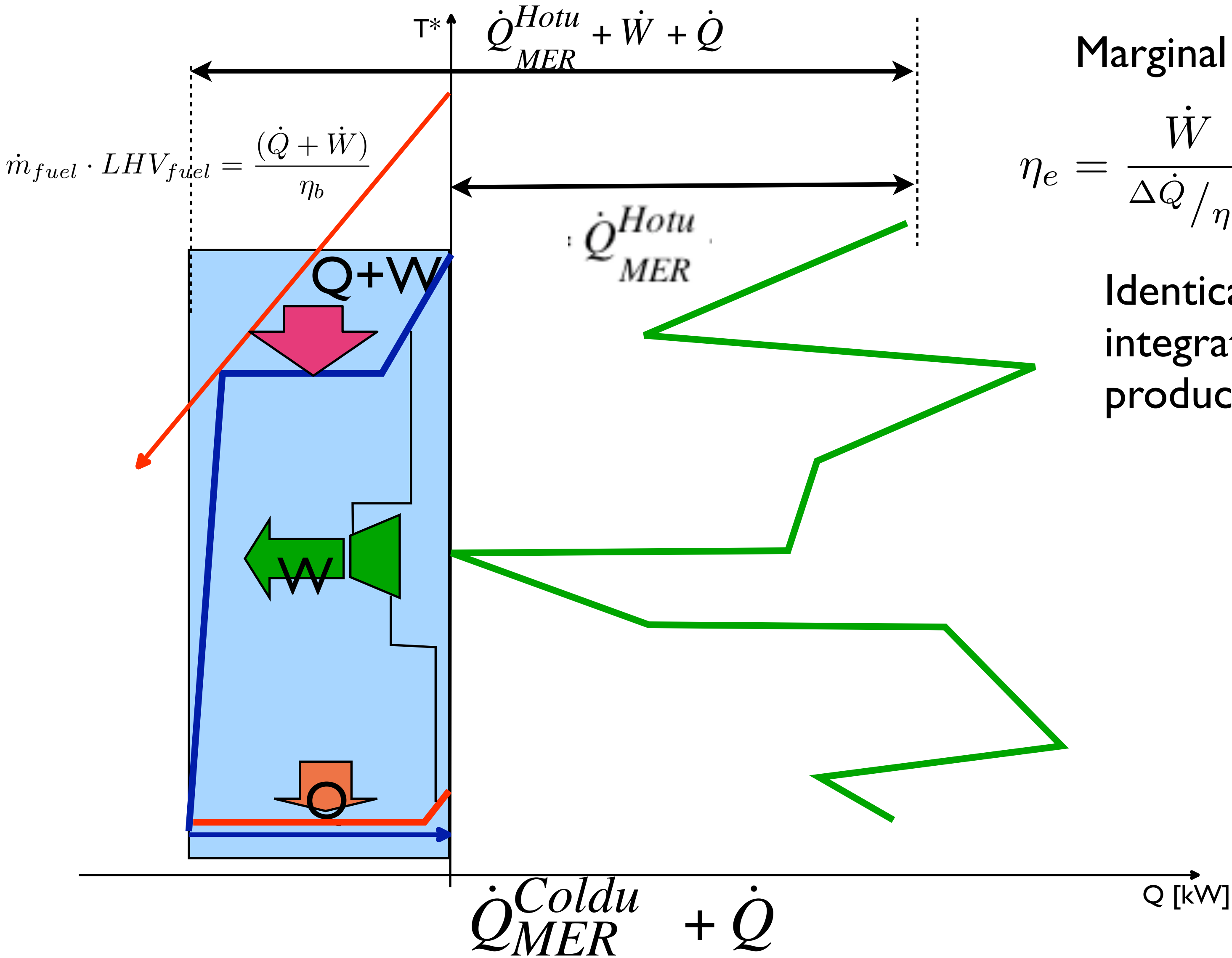
New Cold Utility

$$\dot Q_3 - W + \dot Q_4 = \dot Q_{MER}^{Coldu} - \dot W$$

$$\dot W(T) = \eta_{Carnot} \cdot \dot Q(T) \cdot (1 - \frac{T_0}{T})$$

Ambient temperature

Combined heat and power



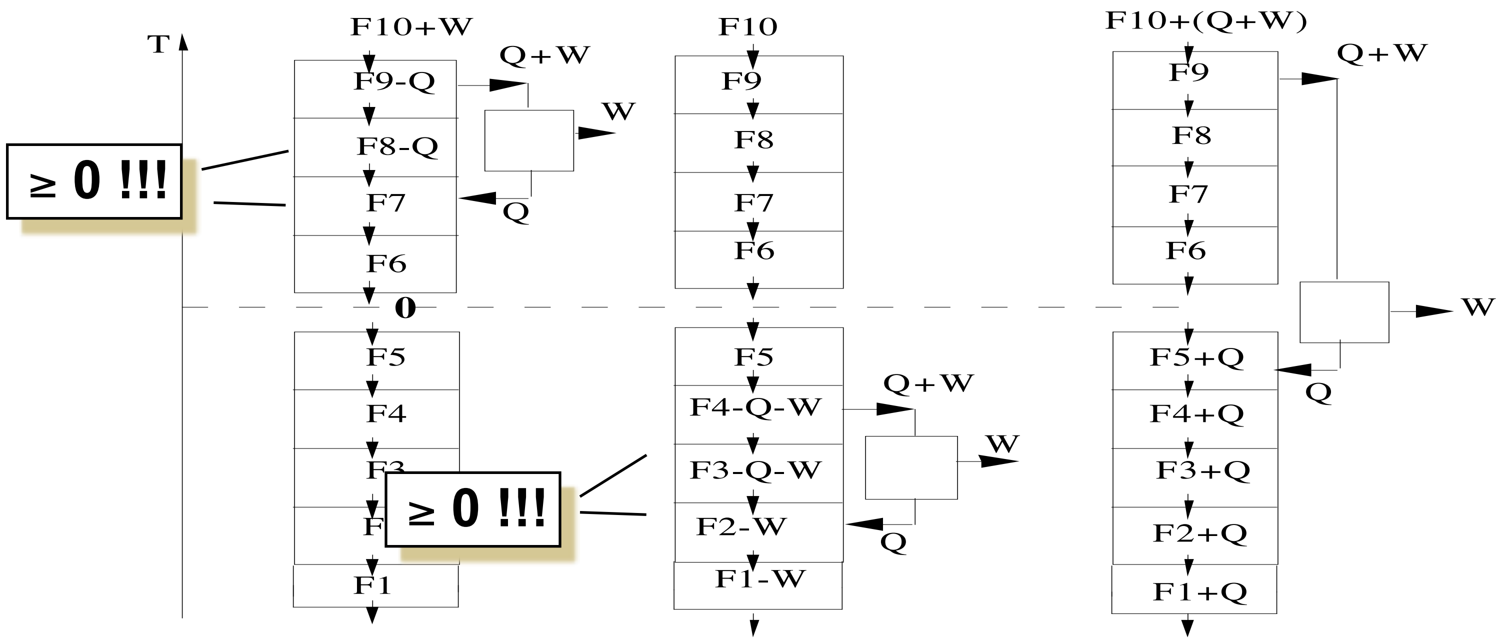
Marginal efficiency

$$\eta_e = \frac{\dot{W}}{\Delta\dot{Q}/\eta_b} = \frac{\dot{W}}{\frac{(\dot{Q}+\dot{W})}{\eta_b}}$$

Identical to non integrated power production

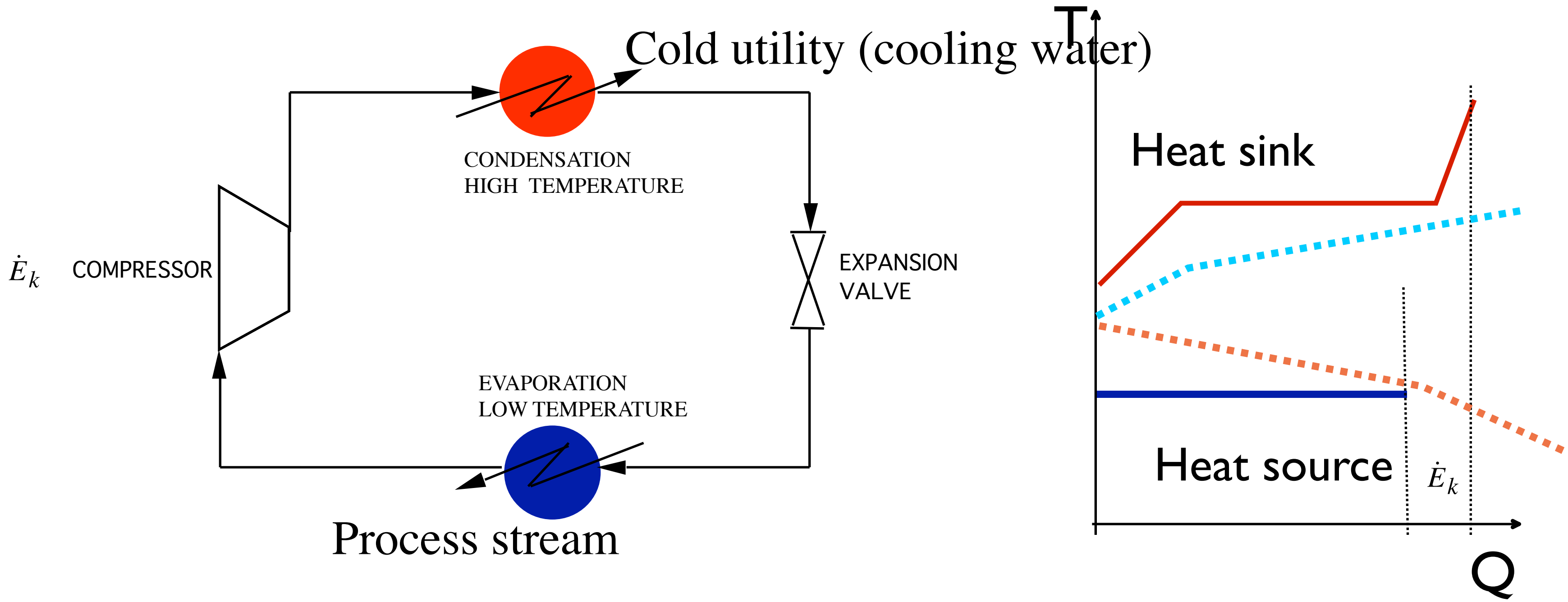
How to integrate mechanical power production ?

Above the pinch point : 1 thermal kW = 1mechanical kW	Below the pinch point : 1 cold utility kW = 1 mechanical kW	Across the pinch point: Separate production

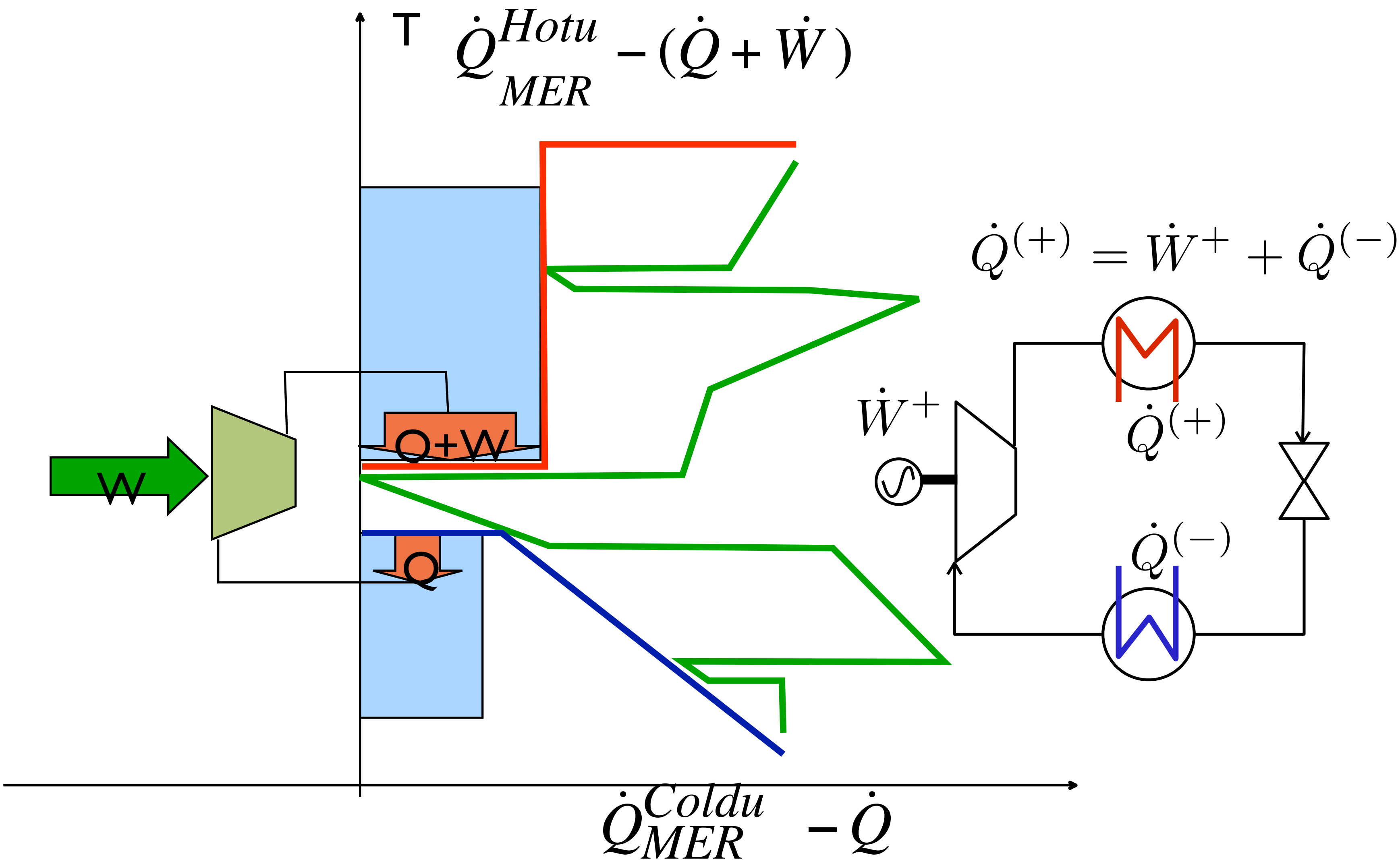


The pinch constraints limit the CHP production

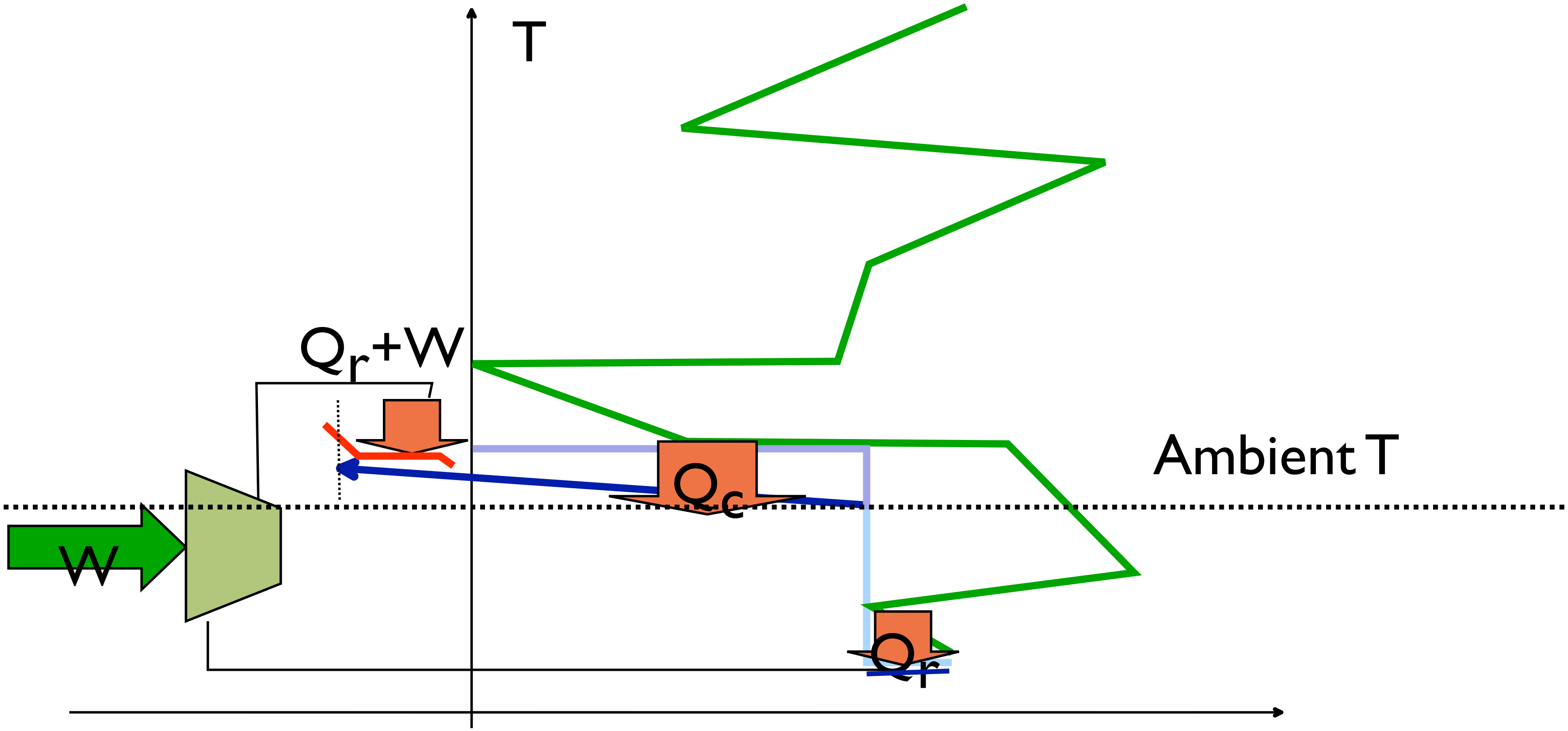
Heat pump and refrigeration



Heat pumping from below to above the pinch



Refrigeration

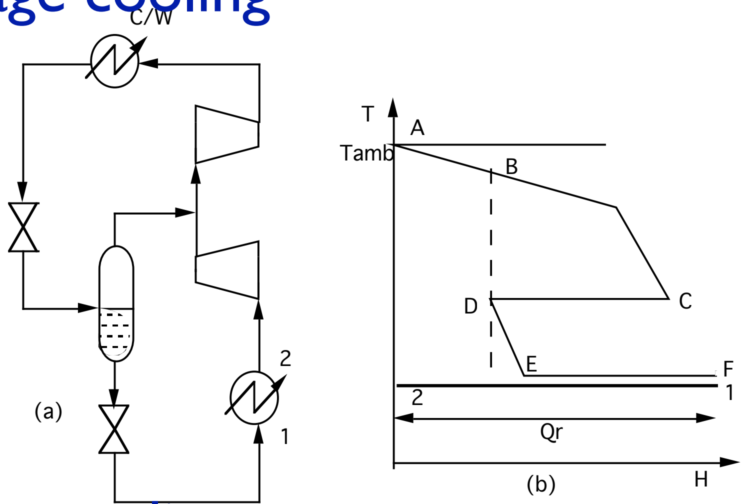


$$\dot{Q}_c + \dot{Q}_r + \dot{W} = \dot{Q}_{MER}^{Coldu} + \dot{W}$$

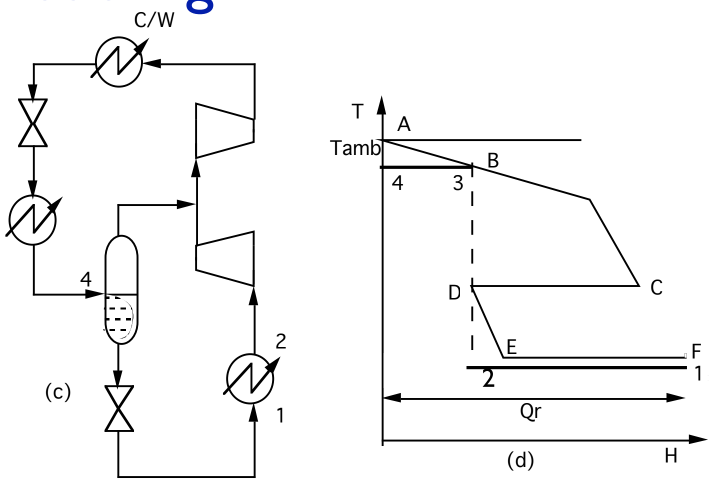
Increasing the flow of the cold water

Refrigeration cycle integration

Single stage cooling



Two stages cooling



Three stages cooling
+ condensation