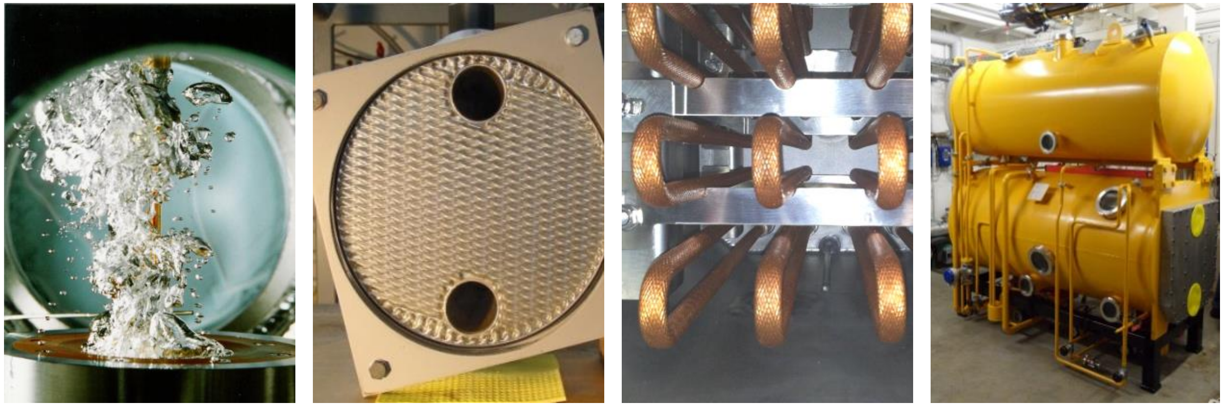

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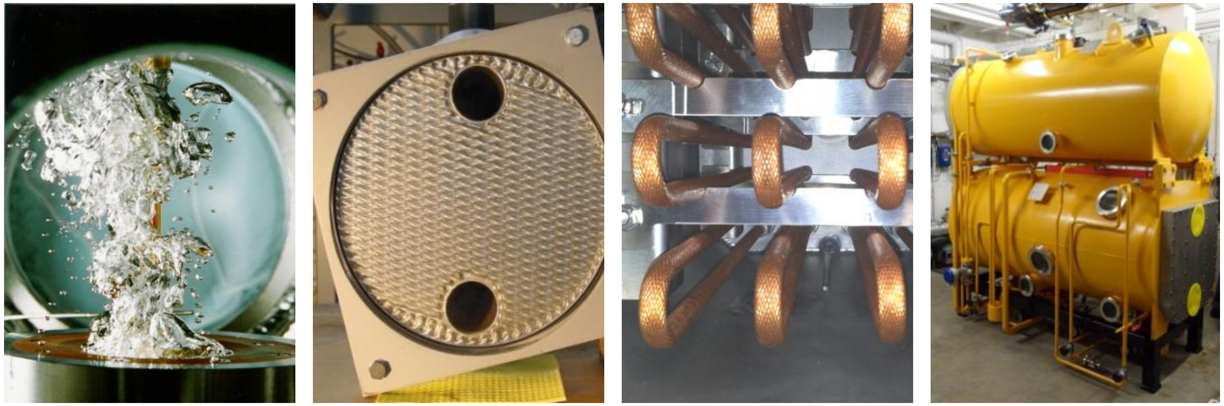
# Valorisation of Low-Grade Waste Heat

## Vision: No useful heat flow without use!

Felix Ziegler | Institut für Energietechnik

Innovationszentrum Energie



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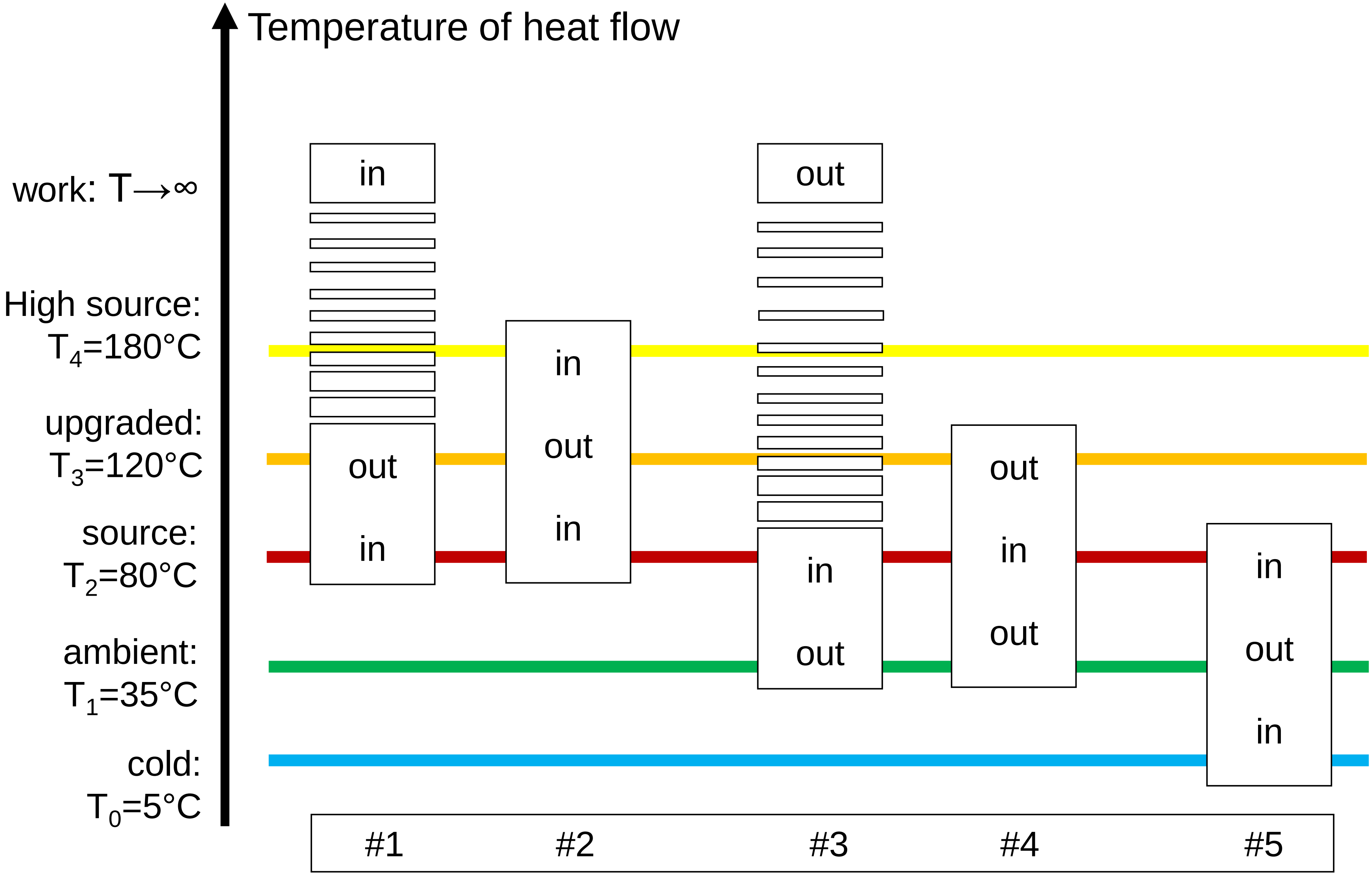
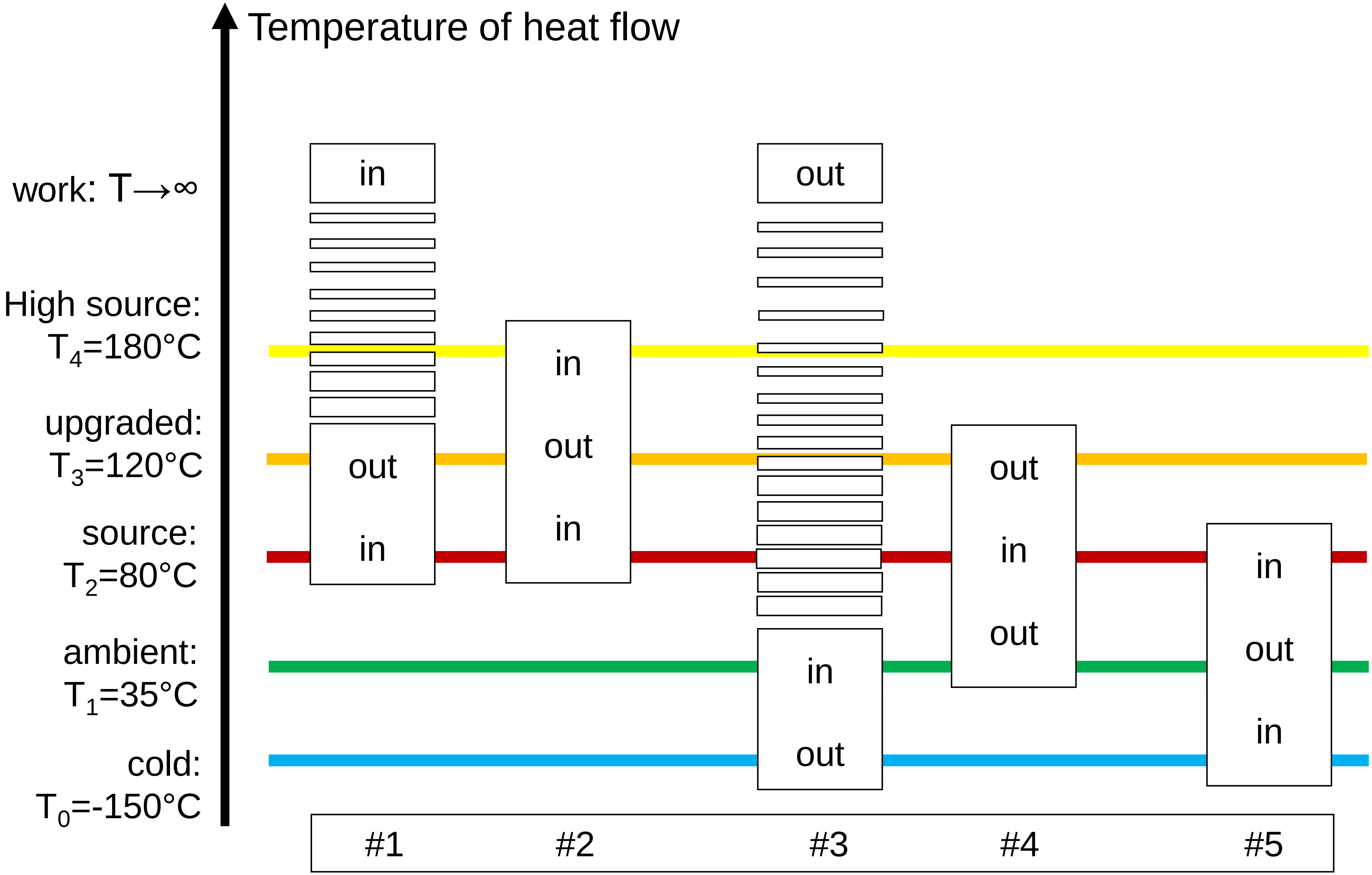
# Valorisation of Low-Grade Waste Heat

## Options
## Absorption cooling
## ~~Steam jet cycle~~
## Honigmann cycle
## Efficiency, and cost

Felix Ziegler | Institut für Energietechnik

ize Innovationszentrum Energie


Temperature of heat flow
work: T→∞
High source:
$T_4$=180°C
upgraded:
$T_3$=120°C
source:
$T_2$=80°C
ambient:
$T_1$=35°C
cold:
$T_0$=5°C
in
out
in
in
out
in
out
in
out
out
in
out
in
out
in
#1
#2
#3
#4
#5



Temperature of heat flow

work: $T\rightarrow\infty$

High source:
$T_4$=180°C

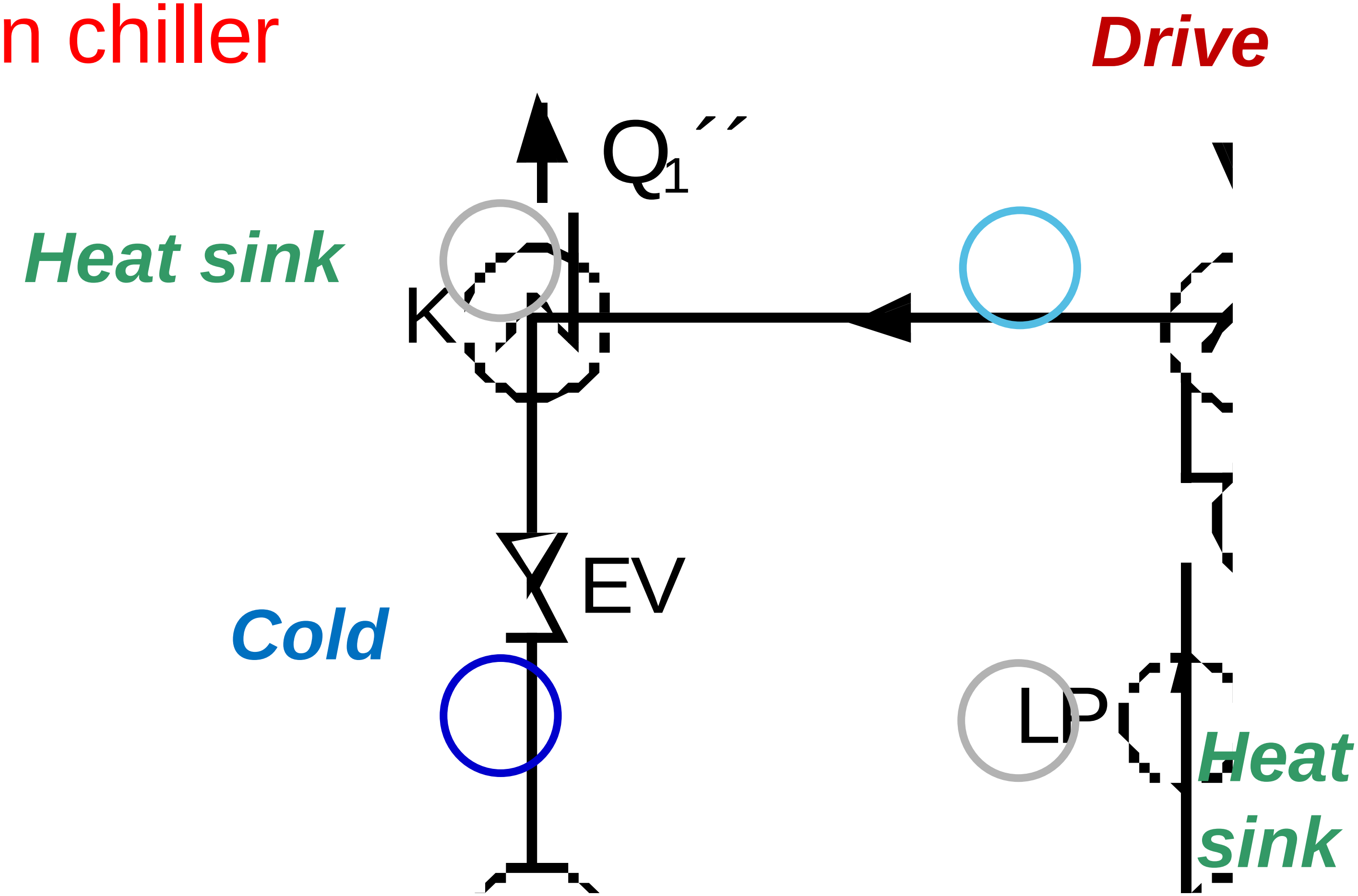
upgraded:
$T_3$=120°C

source:
$T_2$=80°C

ambient:
$T_1$=35°C

cold:
$T_0$=-150°C

# Single-effect absorption chiller

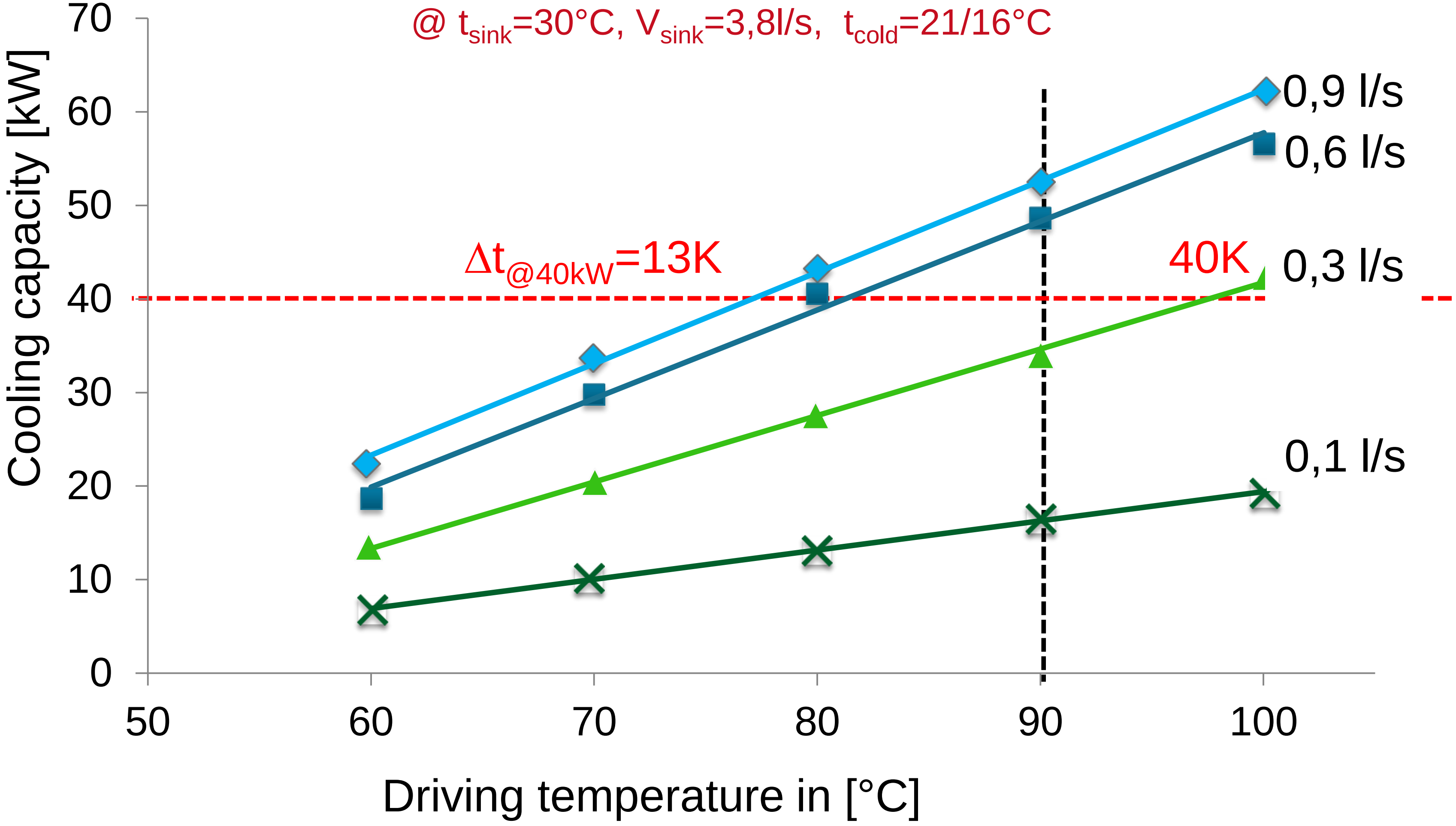


Cold is produced from heat

Nominal cooling capacity 50kW

# Variation of driving heat

@ $t_{sink}$=30°C, $V_{sink}$=3,8l/s, $t_{cold}$=21/16°C



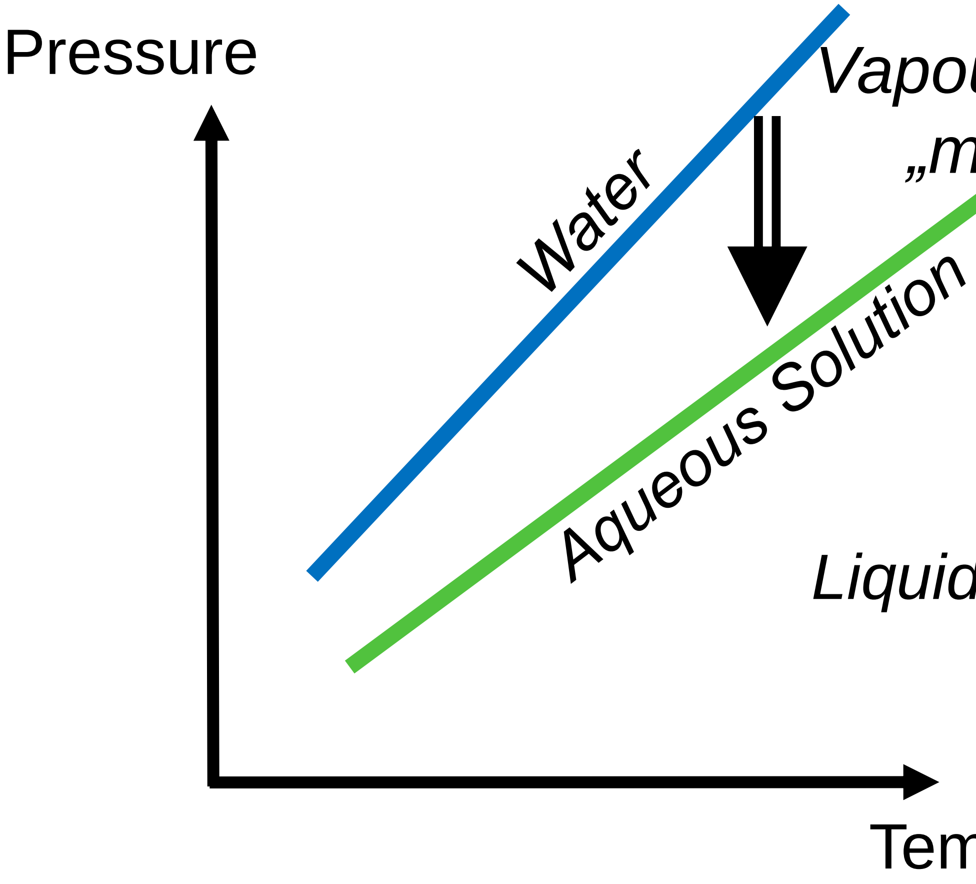
# Control: Minimisation of auxiliaries

Seasonal Energy Efficiency Ratio:

$$SEER_{el} = \frac{Q_{cold}}{\sum W} > 10$$

| **Control strategy** | **SEER$_{el}$** |
|---|---|
| **#1: Classic drive (Temperature)** | 13 |
| **#2: Heat sink (Temperature and flow rate)** | 19 |
| **#3: Drive (Temperature and flow rate)** | 14 |
| **#4: Combination (#2+#3)** | 22 |

# „Honigmann“ cycle: storage and conversion of low-grade heat



*Vapour pressure depression*
*„mechanical potential“*

*Liquid-Vapour-Equilibrium*

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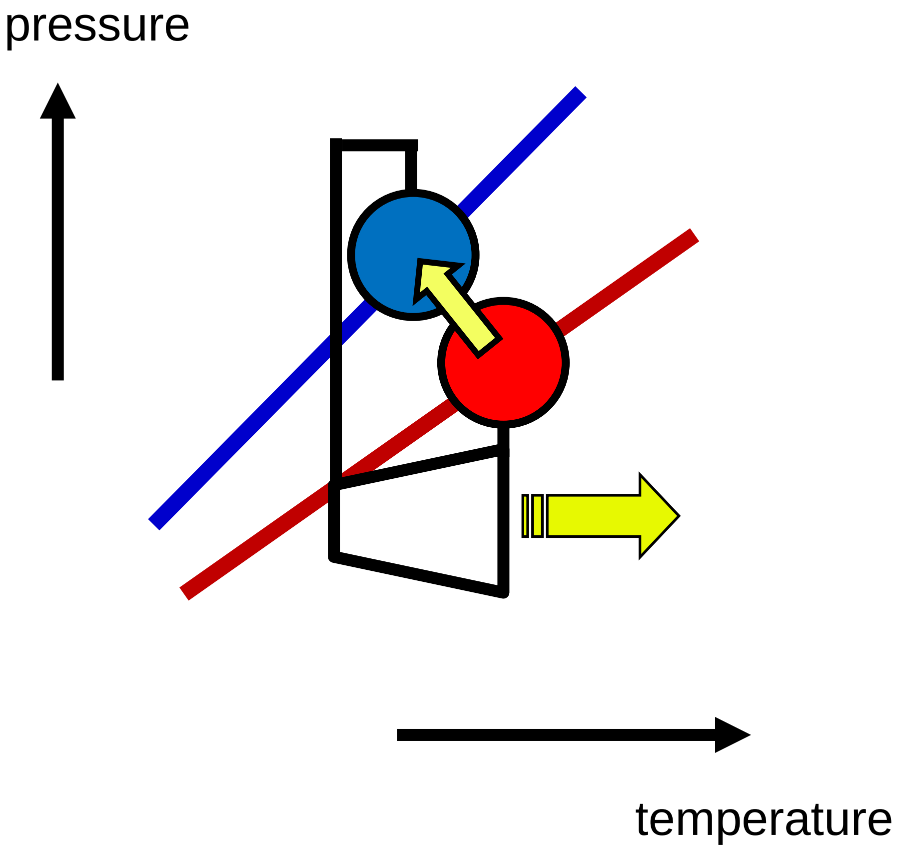
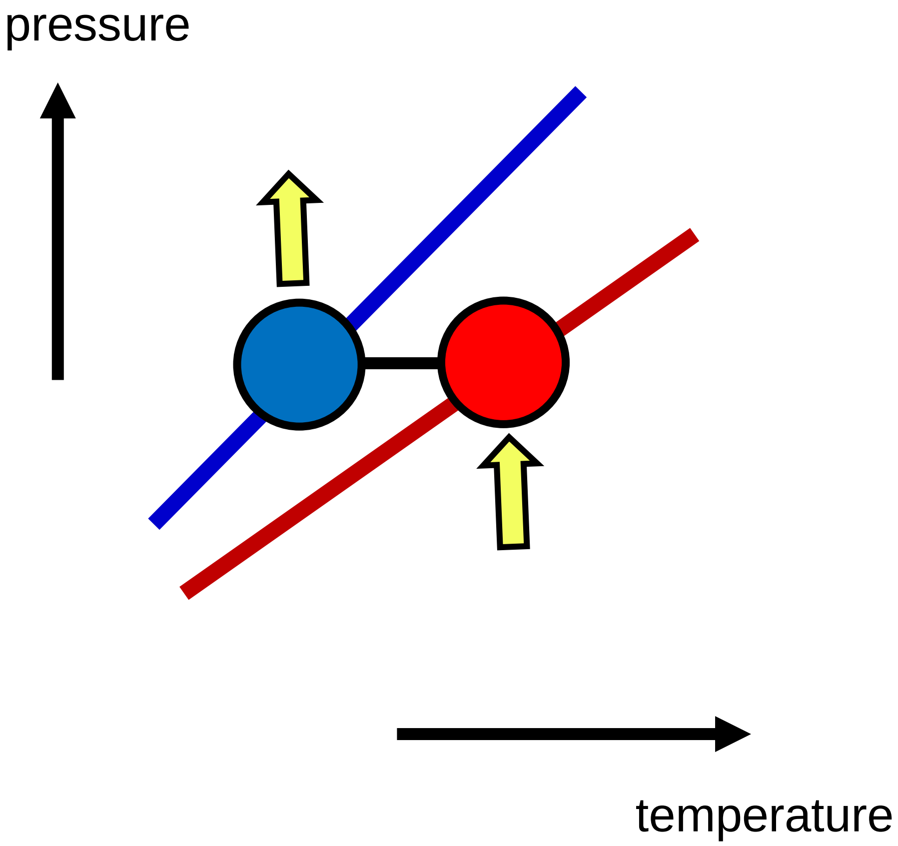
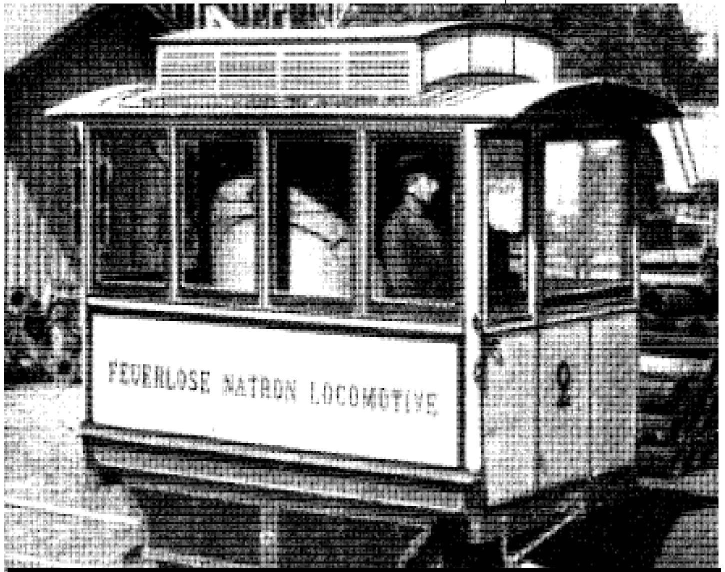


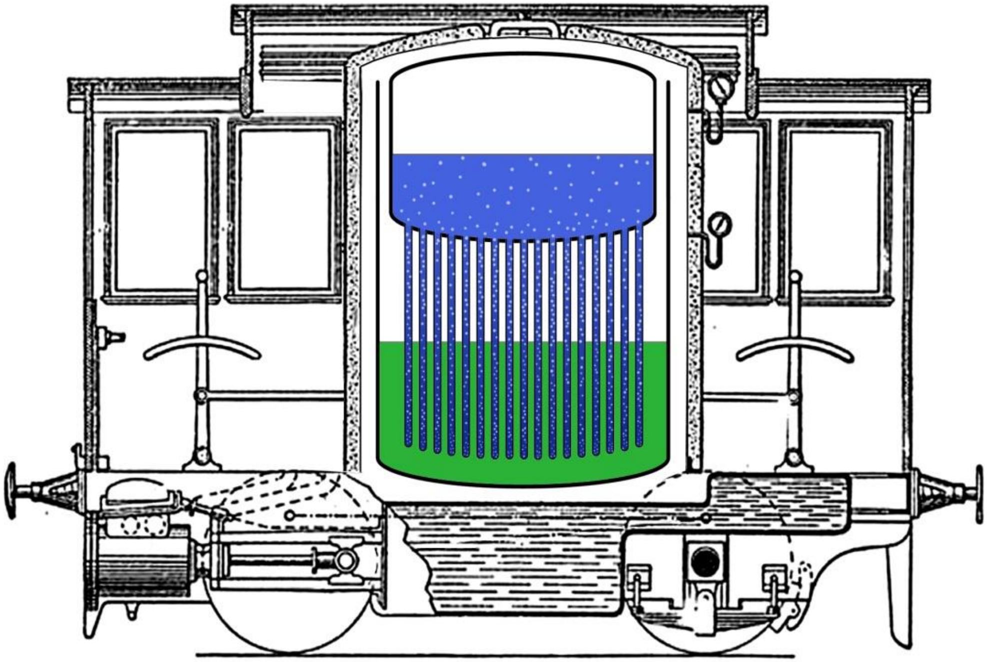
*Discharging (work!)*



*Charging (Heat!)*

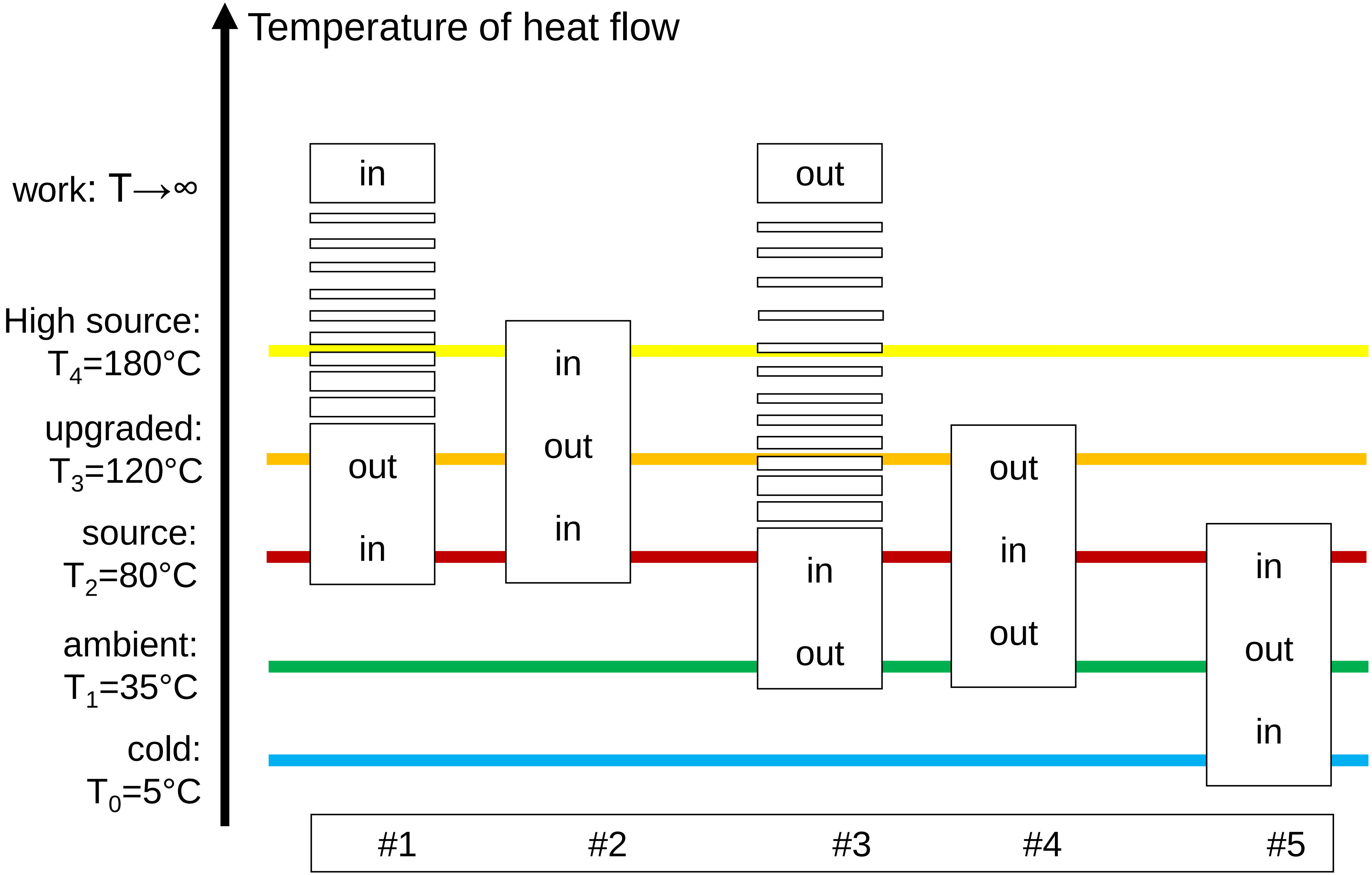


Quelle: Mähr, Vergessene Erfindungen



Honigmanns Natronlokomotive. Längsſchnitt.

# Honigmann fireless locomotive (1883)



Temperature of heat flow

work: T→∞

High source: $T_4$=180°C

upgraded: $T_3$=120°C

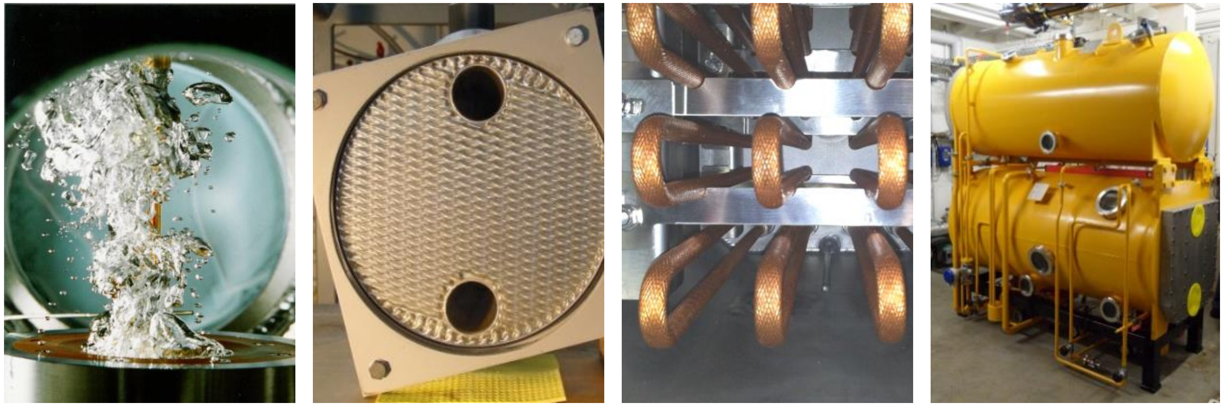
source: $T_2$=80°C

ambient: $T_1$=35°C

cold: $T_0$=5°C

|  |  | Efficiency | Example |
|---|---|---|---|
| #1 | Work-driven heat pump | $\mathrm{COP} = \frac{Q_3}{W} = g \ \frac{T_3}{T_3 - T_2}$ | $\mathrm{COP} = 4.9$ |
| #2 | Heat-driven heat pump | $\mathrm{COP} = \frac{Q_3}{Q_4} = g \ \frac{T_3}{T_4} \frac{T_4 - T_2}{T_3 - T_2}$ | $\mathrm{COP} = 1.1$ |
| #3 | Power cycle | $\eta = \frac{W}{Q_2} = g \ \frac{T_2 - T_1}{T_2}$ | $\eta = 0.06$ |
| #4 | Heat transformer | $\mathrm{COP} = \frac{Q_3}{Q_2} = g \ \frac{T_3}{T_2} \frac{T_2 - T_1}{T_3 - T_1}$ | $\mathrm{COP} = 0.29$ |
| #5 | Heat-driven refrigerator | $\mathrm{COP} = \frac{Q_0}{Q_2} = g \ \frac{T_0}{T_2} \frac{T_2 - T_1}{T_1 - T_0}$ | $\mathrm{COP} = 0.43$ |

| | | Relative heat turnover | Example (see Table 2) |
|---|---|---|---|
| #1 | Work-driven heat pump | $\sigma = \frac{\sum \lvert Q_i \rvert}{Q_3} = 2 - \frac{1}{COP}$ | 1.8 |
| #2 | Heat-driven heat pump | $\sigma = \frac{\sum \lvert Q_i \rvert}{Q_3} = 2$ | 2 |
| #3 | Power cycle | $\sigma = \frac{\sum \lvert Q_i \rvert}{W} = \frac{2}{\eta} - 1$ | 32 |
| #4 | Heat transformer | $\sigma = \frac{\sum \lvert Q_i \rvert}{Q_3} = \frac{2}{COP}$ | 6.9 |
| #5 | Heat-driven refrigerator | $\sigma = \frac{\sum \lvert Q_i \rvert}{Q_0} = 2 + \frac{2}{COP}$ | 6.7 |

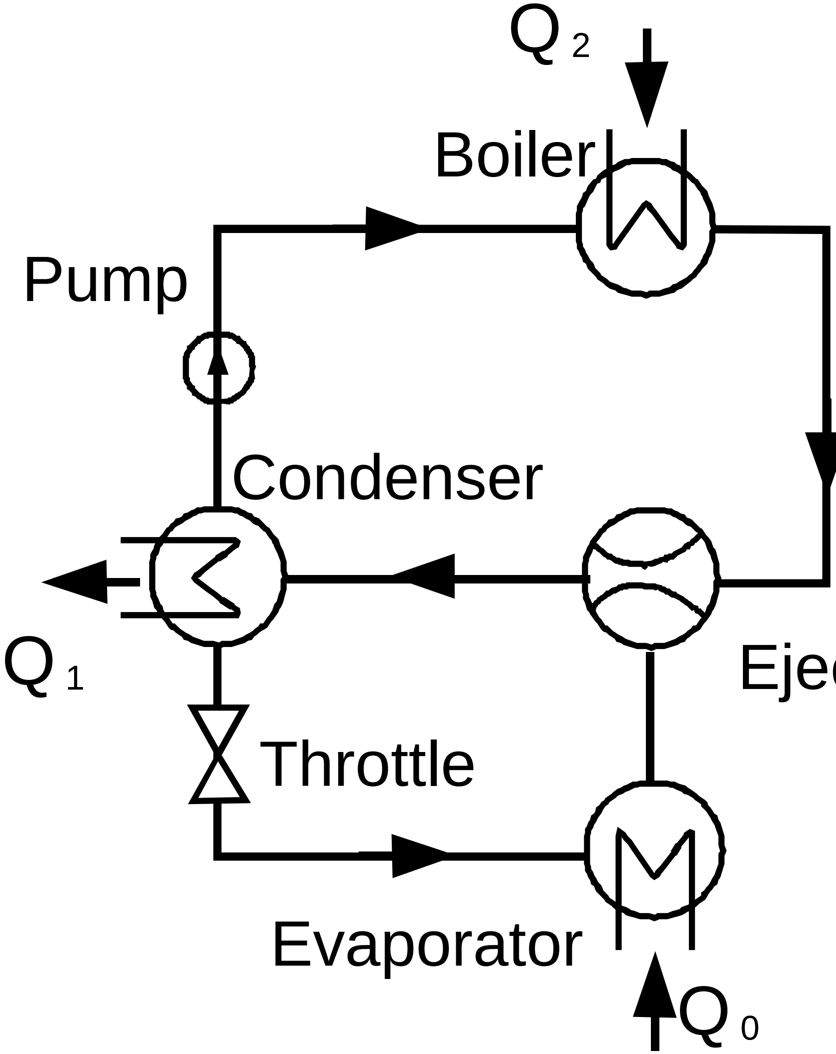


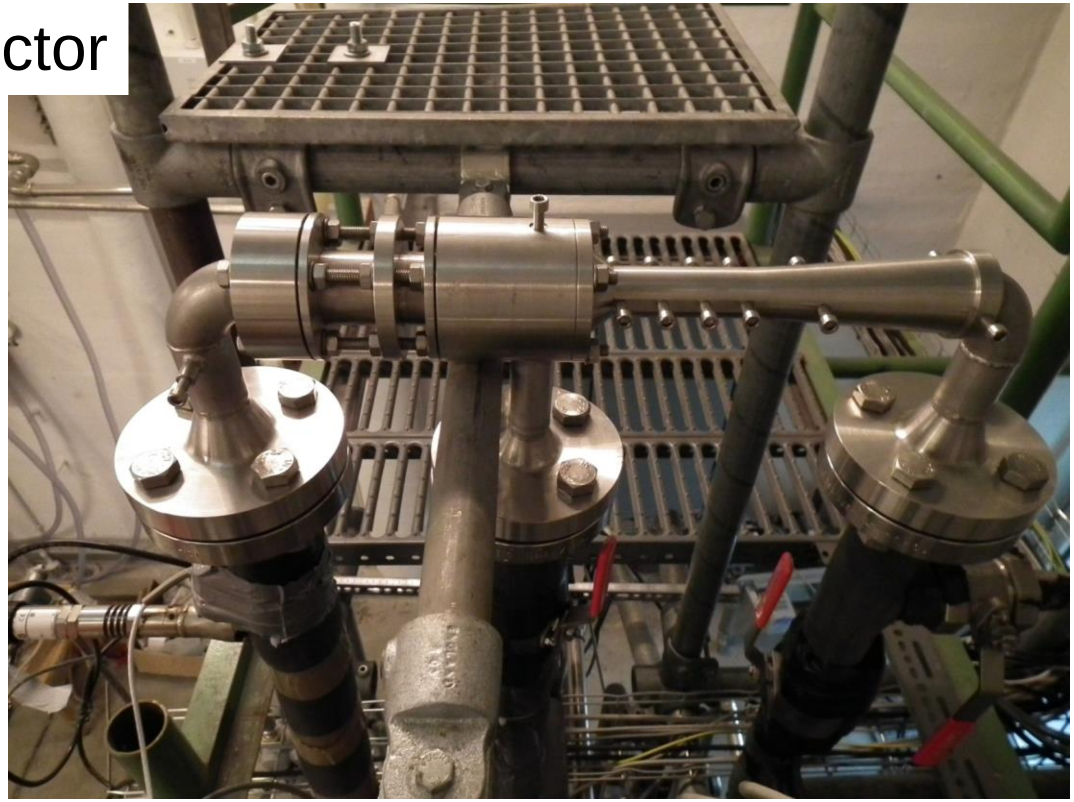
# Valorisation of Low-Grade Waste Heat

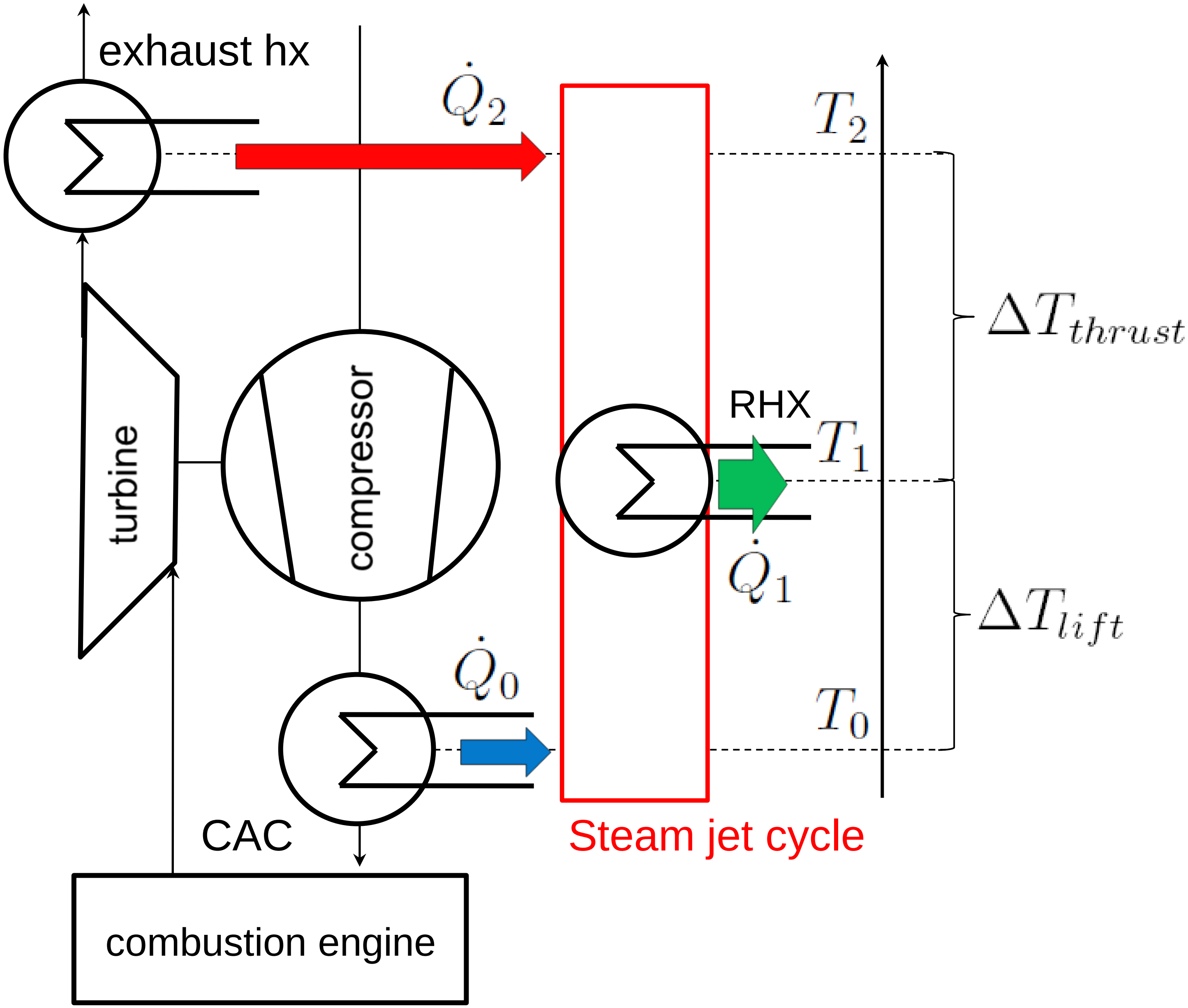
There are many challenging / promising options

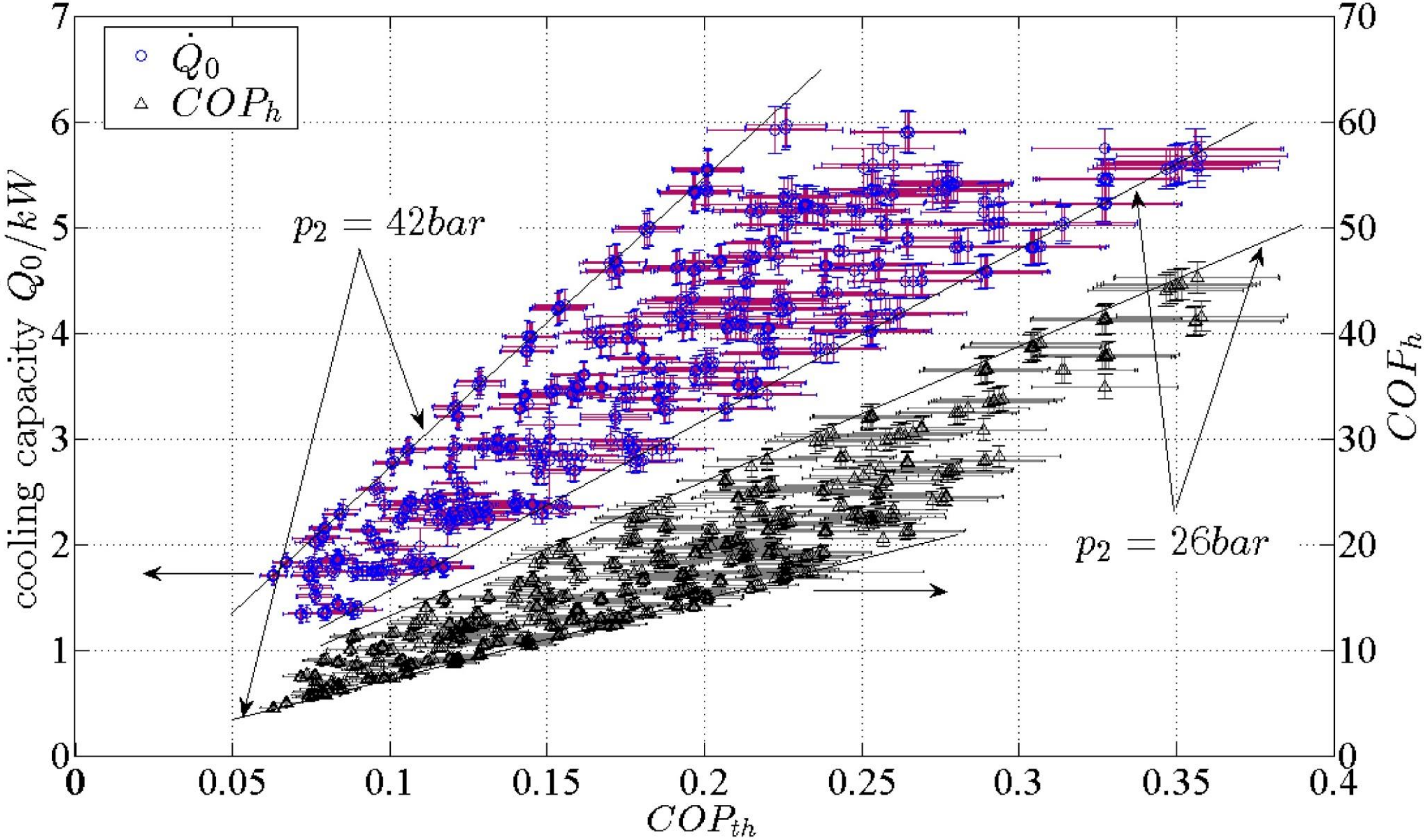
Efficient heat transfer is key to implementation

# Steam ejector cycle



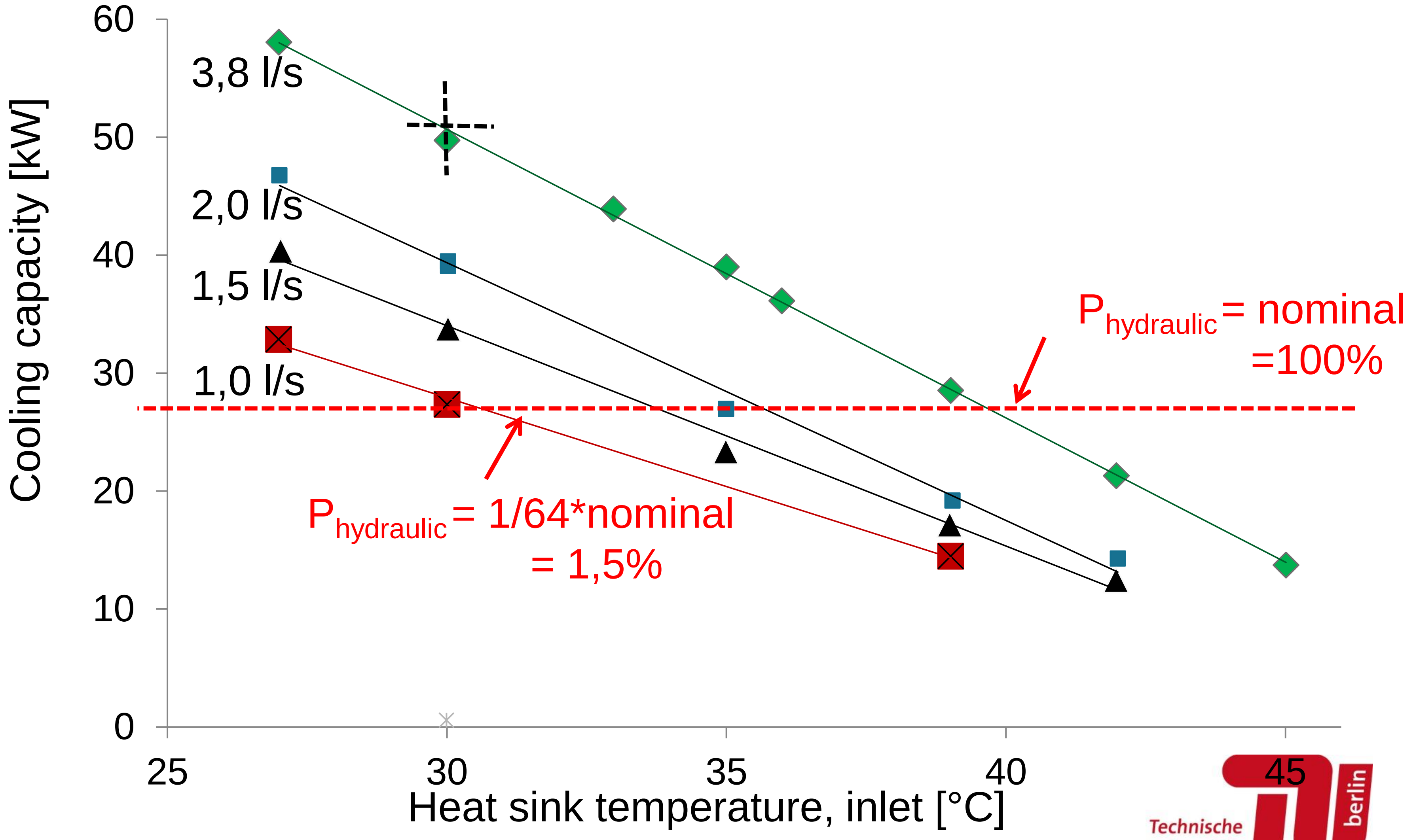


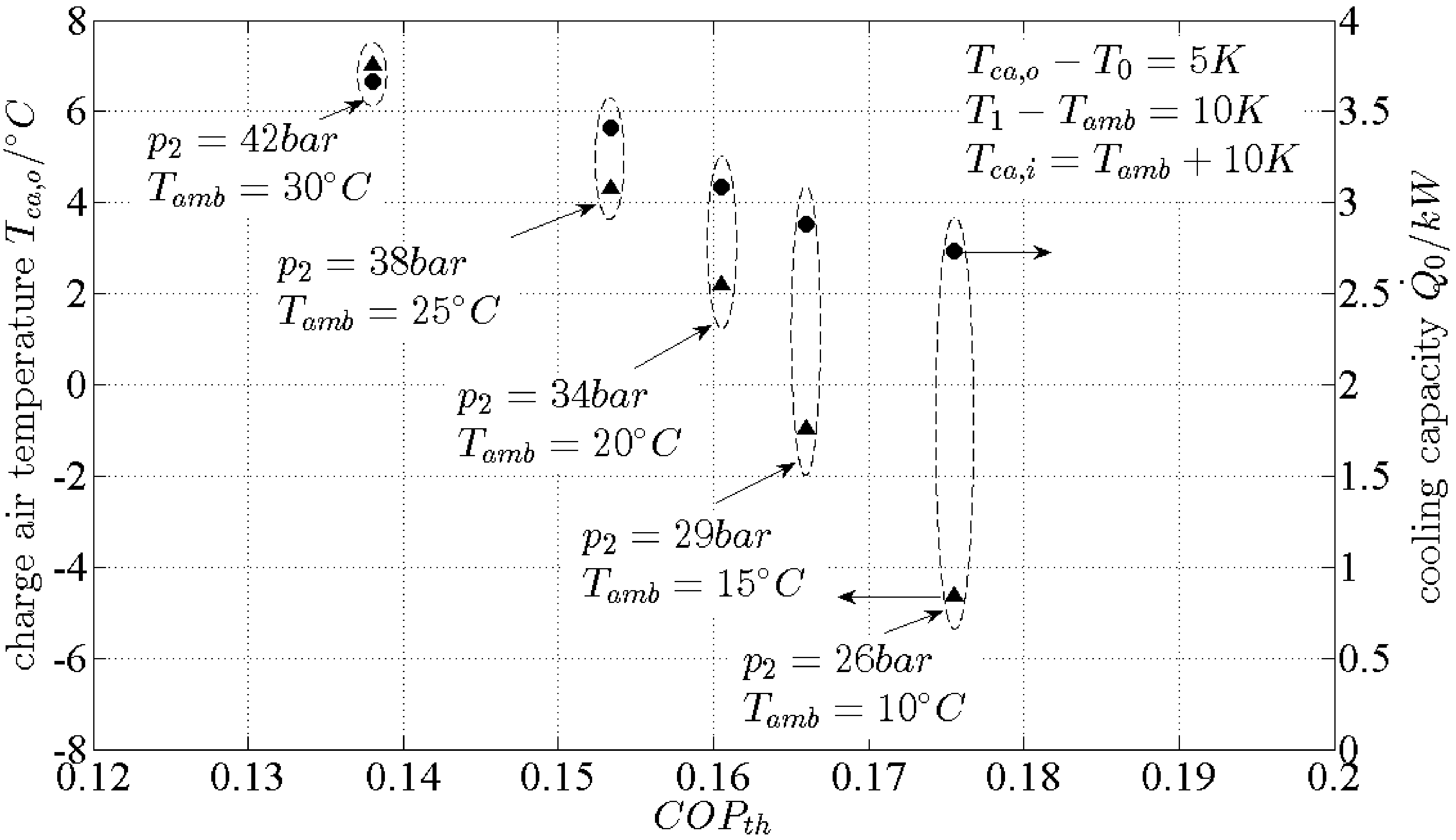

exhaust hx
$\dot{Q}_2$
$T_2$
$\Delta T_{thrust}$
turbine
compressor
RHX
$T_1$
$\dot{Q}_1$
$\Delta T_{lift}$
$\dot{Q}_0$
$T_0$
CAC
Steam jet cycle
combustion engine


$\dot{Q}_0$
$COP_h$
$p_2 = 42bar$
$p_2 = 26bar$
cooling capacity $\dot{Q}_0/kW$
$COP_h$
$COP_{th}$
0
1
2
3
4
5
6
7
10
20
30
40
50
60
70
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4

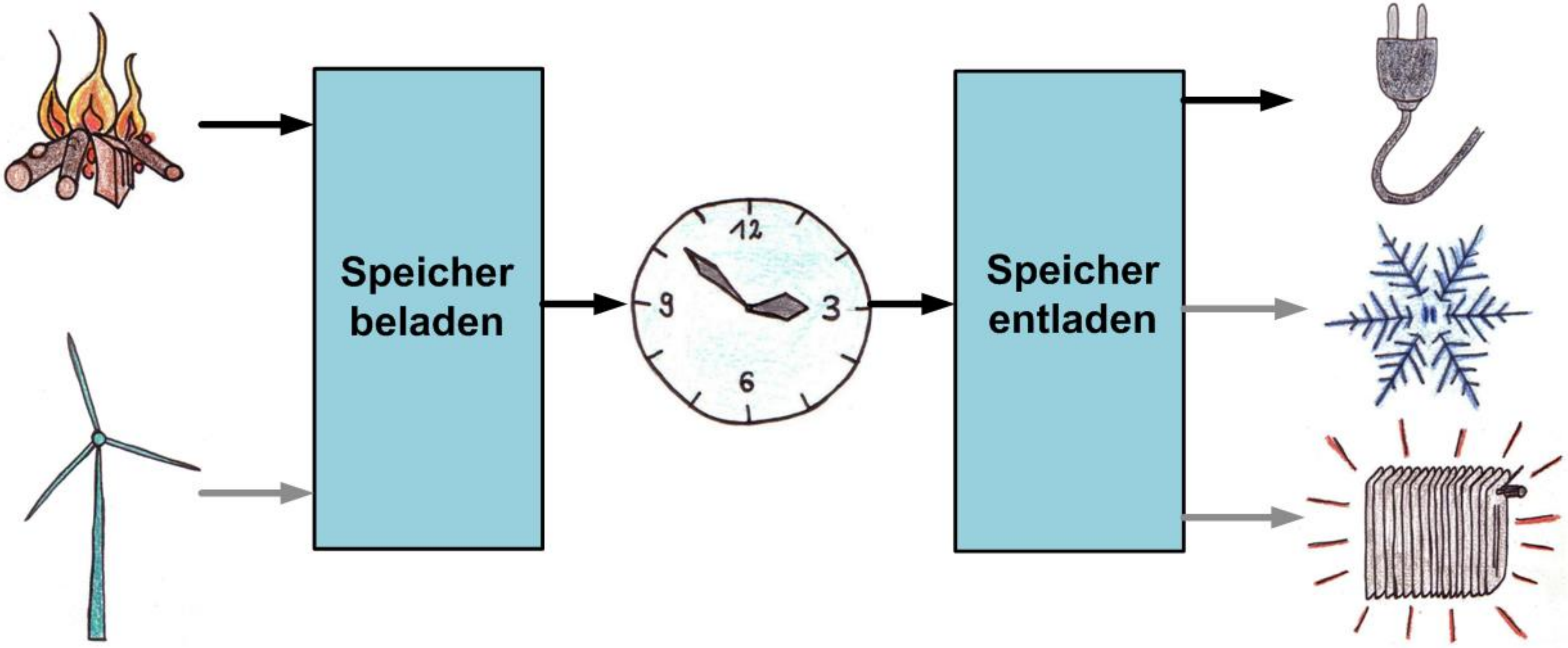
# Rückkühlvariationen (Biene)

@ t_FW=90°C, m_FW=0,9kg/s, t_KW=21/16°C




$T_{ca,o} - T_0 = 5K$
$T_1 - T_{amb} = 10K$
$T_{ca,i} = T_{amb} + 10K$
$p_2 = 42bar$
$T_{amb} = 30°C$
$p_2 = 38bar$
$T_{amb} = 25°C$
$p_2 = 34bar$
$T_{amb} = 20°C$
$p_2 = 29bar$
$T_{amb} = 15°C$
$p_2 = 26bar$
$T_{amb} = 10°C$
charge air temperature $T_{ca,o}/°C$
8
6
4
2
0
-2
-4
-6
-8
cooling capacity $\dot{Q}_0/kW$
4
3.5
3
2.5
2
1.5
1
0.5
0
0.12
0.13
0.14
0.15
0.16
0.17
0.18
0.19
0.2
$COP_{th}$

# Vorteile des Prozesses



**Speicher beladen**

**Speicher entladen**

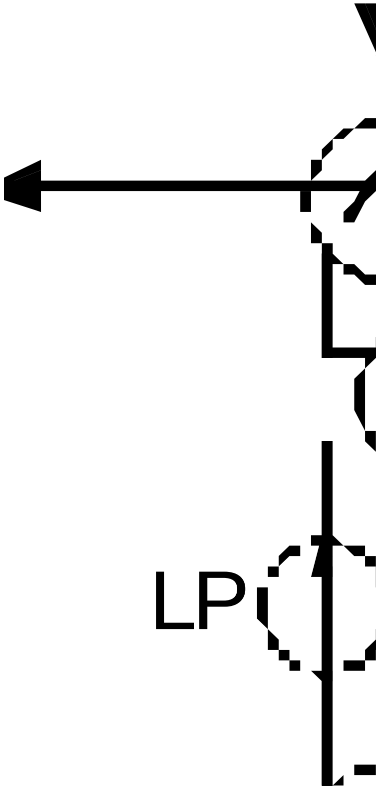
- Flexible Be- und Entladung
- Nutzung von Abfallwärme
- Keine Selbstentladung

In the Regenerator G it is regenerated,
consuming the driving heat.

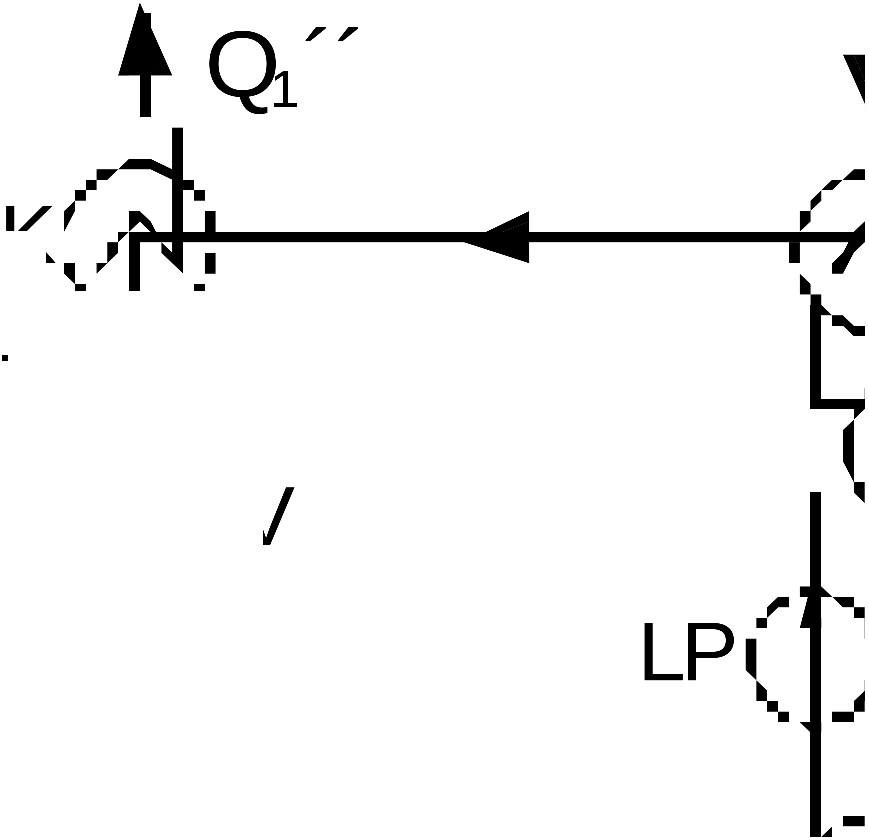
The absorbed refrigerant is
vaporised again.

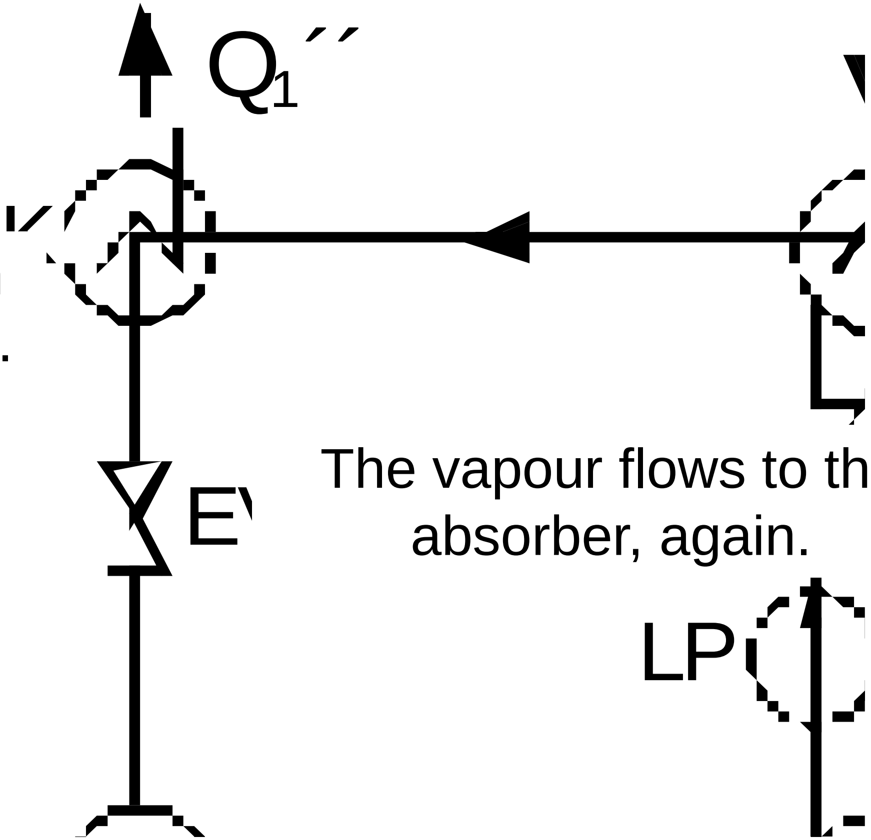
A solution circulates between
absorber A and regenerator G.

In the absorber it absorbs
refrigerant vapour, rejecting heat.



The refrigerant is liquefied in the absorber, rejecting heat...





The refrigerant is liquefied in the absorber, rejecting heat...

The vapour flows to the absorber, again.

...and is vapourised again in the evaporator, consuming heat (producing cold).