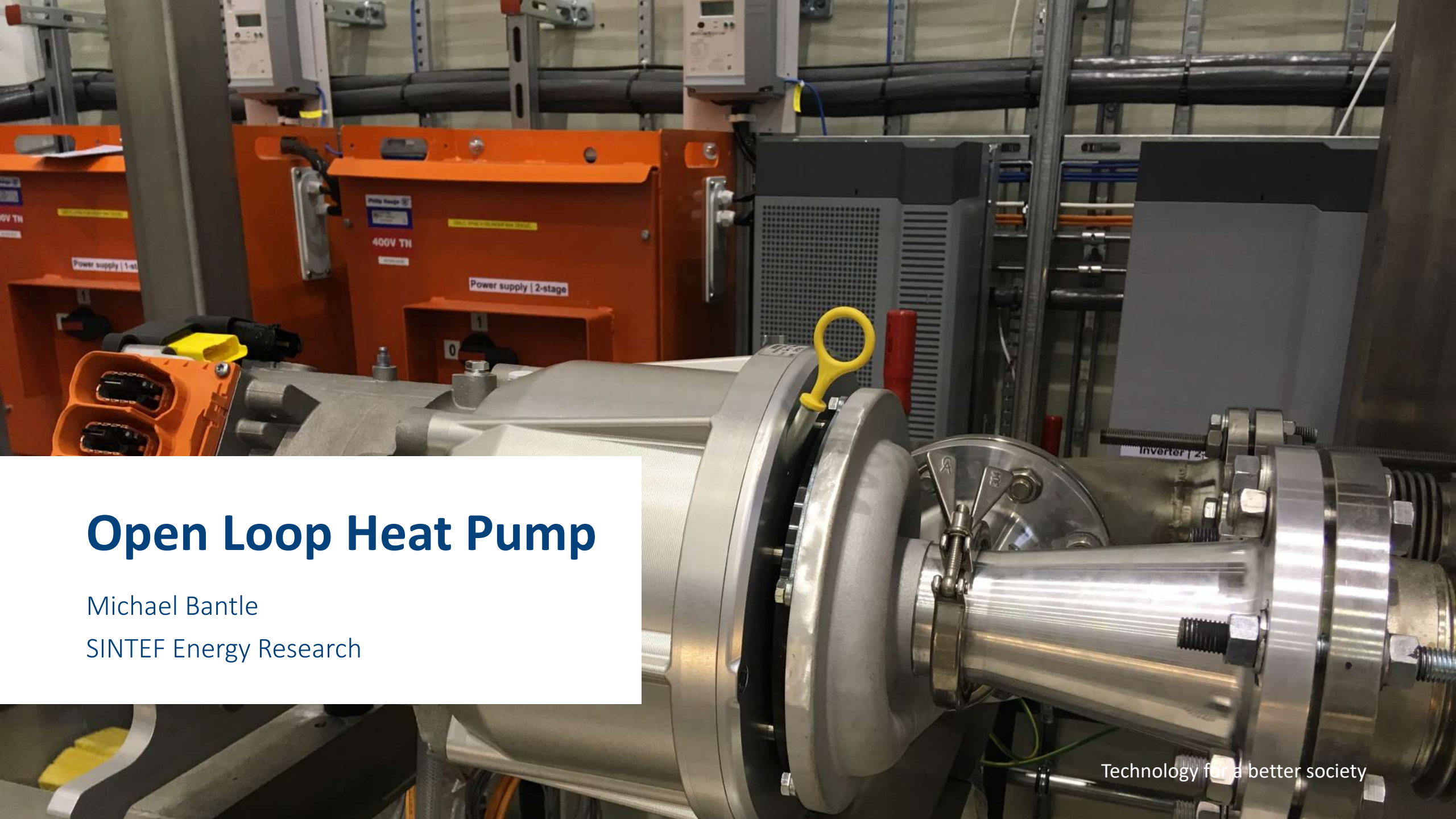
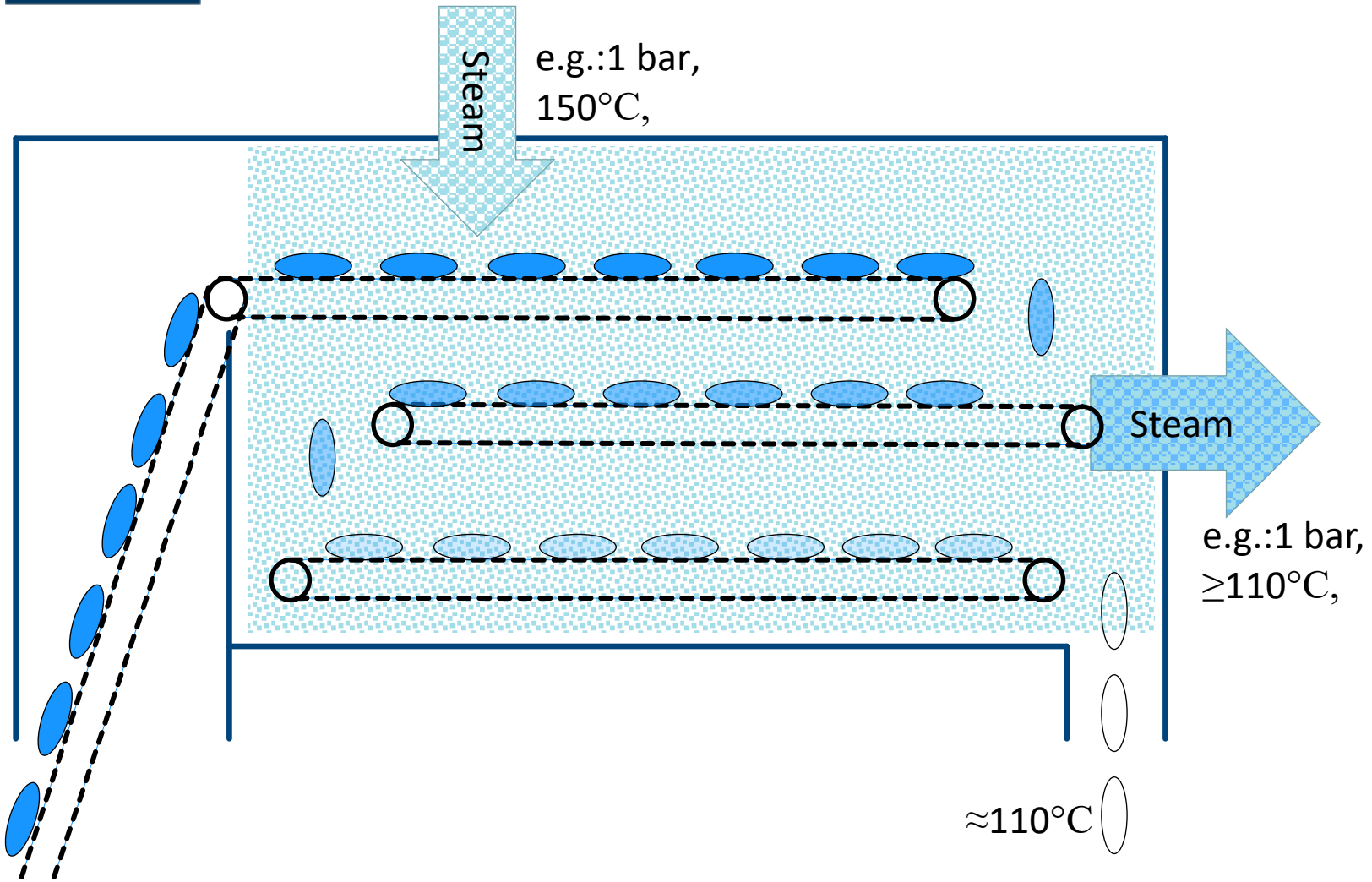


Open Loop Heat Pump

Michael Bantle

SINTEF Energy Research

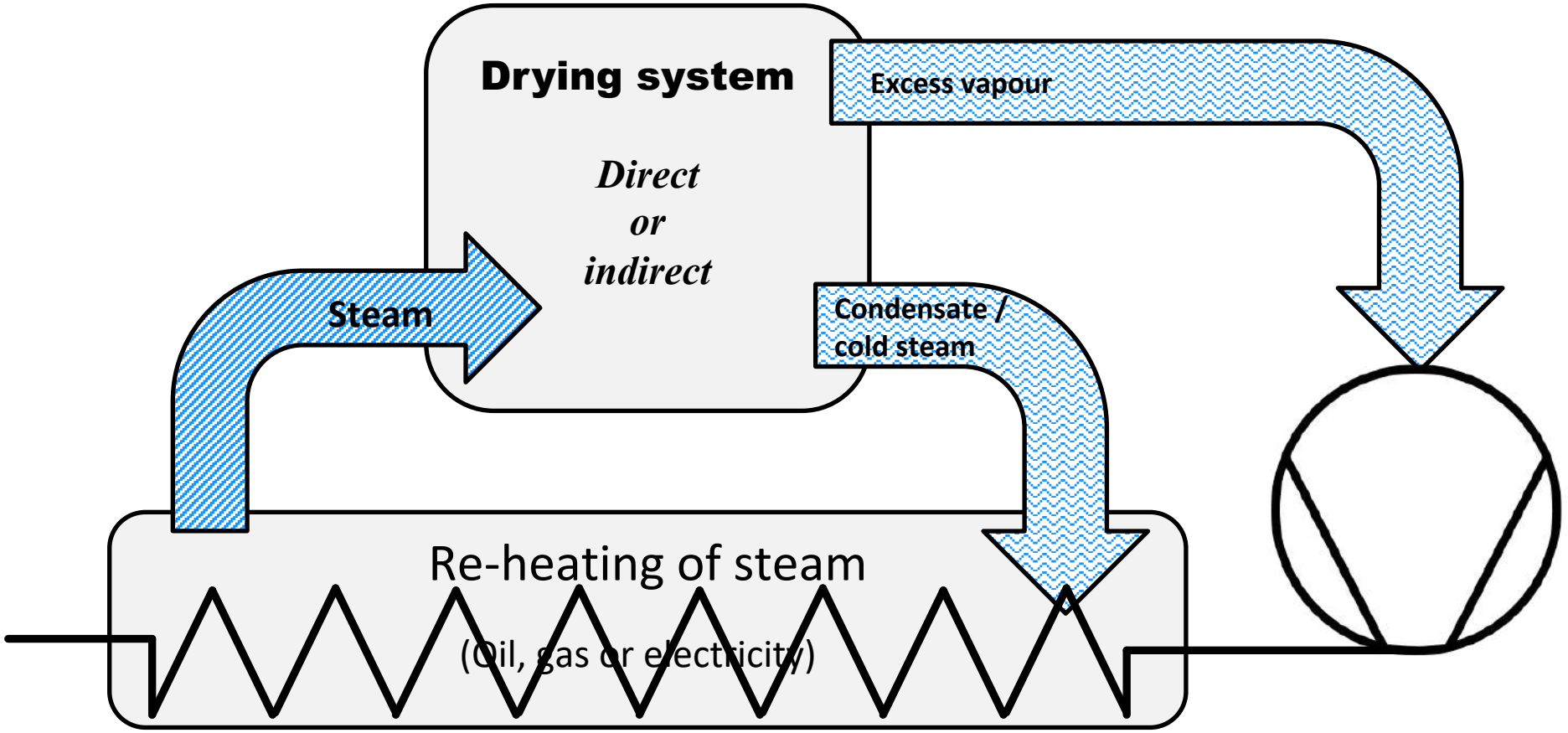
Superheated Steam Drying



Specific Energy Consumption:

- Dryer 0.8 kWh/kg
  - Ideal 0.63 kWh/kg
- Excess steam available
- Aim 0.2 kWh/h

Open Loop Heat Pump (Mechanical Vapor Recompression)



Why using Superheated Steam instead of Air as Drying medium?

$$H = m \cdot c \cdot \Delta T$$

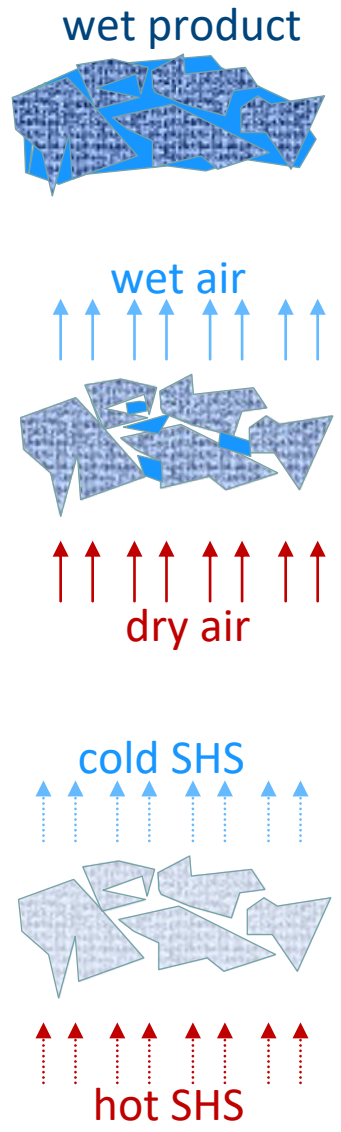
$$RE = \frac{w \cdot d_P \cdot \rho}{\eta \cdot (1-\varepsilon)}$$

Overall heat transfer coefficient c and viscosity η

	T [°C]	STEAM	AIR
c [kJ/(kg K)]	100	2.042	1.012
	150	1.980	1.018
η [10-6 kg/ms]	100	12.27	21.94
	150	14.18	24.07

As higher c value as higher drying rate

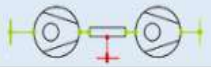
As lower η value as better pore diffusion



Refrigerant R718 (water)

- Abundance and Safety:
  - Most abundant elements on earth; low cost and nearly unlimited available
  - From environmental point of view: water is ideal refrigerant above 0°C
  - Non-toxicity, non flammable, 0 Ozone Depletion Potential, 0 Global Warming Potential
- Regulatory Relief:
  - Not subject to present or future environmental or safety regulations
- Efficiency:
  - High latent heat of evaporation (2270 kJ/kg); 4-5 times higher than hydrocarbons or CO2
  - Critical temperature: 380-386°C
  - General high COP

Multistage systems

	COP	COP (+Intercool)	$\dot{Q}_{ThermCap}$ $[kW]$	$\dot{Q}_{Intercool}$ $[kW]$	P_{Compr} $[kW]$	p_2 $[bar]$	T_2 [°C]
One Compressor 	12.79		247.3		19.3	2.03	187
Two Compressors 	6.57		255.4		38.9	3.67	270
Two Compr. + Intercooling 	6.12	6.46	240.6	12.8	39.3	4.13	213
Three Compressors 	4.50		263.7		58.6	6.12	351
Three Compr. + Intercooling 	4.00	4.38	237.3	22.6	59.3	7.84	255

Results of the Performance Analysis for Multi-Stage Compression for Compressor Speeds of n = 82 700 rpm, Inlet Pressure p = 1 bar, Inlet Temperature T = 105 °C and Mass Flow of $\dot{m} \approx$ 0.1 kg sec-1, Pcompr is required compression power, p2 the discharge pressure and T2 the discharge temperature after the last compression stage

Cost for Compressor

MVR-Compressor	screw compressor		steam fans/blowers		Turbocompressor	
stages	1 stage		5 stage		2 stage	
Inlet	110°C/1bar		110°C/1bar		110°C/1bar	
Outlet	150°C/5bar		150°C/5bar		150°C/5bar	
Investment	1 200 000 €		700 000 €		50 000 €	
Capacity	1300 kW		1300 kW		1300 kW	
steam flow	2000 kg/h		2000 kg/h		2000 kg / h	
COP (W/W)	4.25		4.25		4.25	
net savings	8.48 GWh		8.48 GWh		8.48 GWh	
Location	Germany	Norway	Germany	Norway	Germany	Norway
net savings**	52 275 €	482 885 €	52 275 €	482 885 €	52 275 €	482 885 €
ROI	**23 years**	**2.5 years**	**13.4 years**	**1.4 years**	**1 year**	**0.1 year**

**** based on: electricity 0.15€/kWh Germany, 0.07€/kWh Norway; gas 0.04€/kWh Germany 0.06 €/kWh Norway**

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