Karlsruhe Institute of Technology

Institute for Technical Thermodynamics and Refrigeration
Institute for Beam Physics and Technology

Application of Cryogenic Mixed-Refrigerant Cycles in HTS Systems

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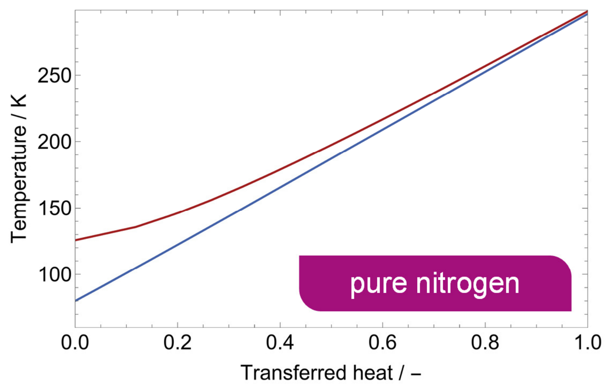
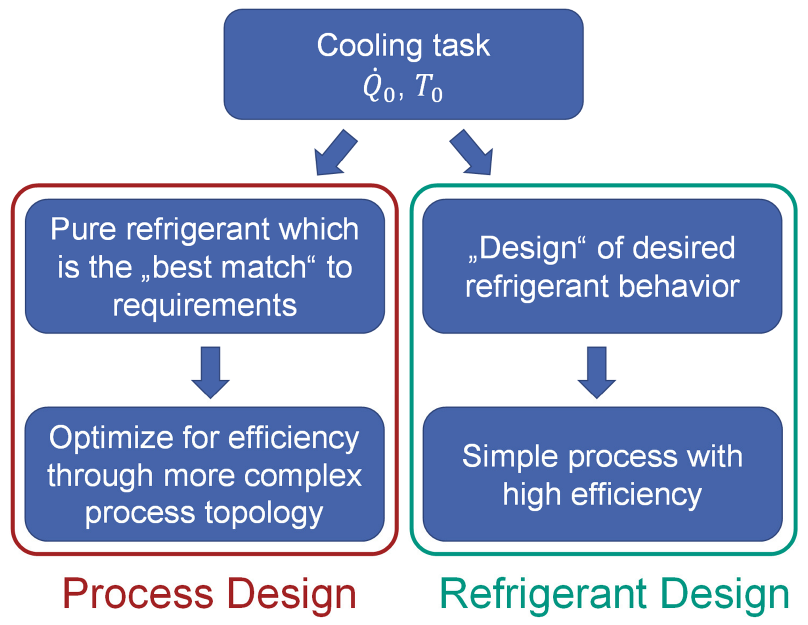
Cryogenic mixed-refrigerant cycles (CMRC)

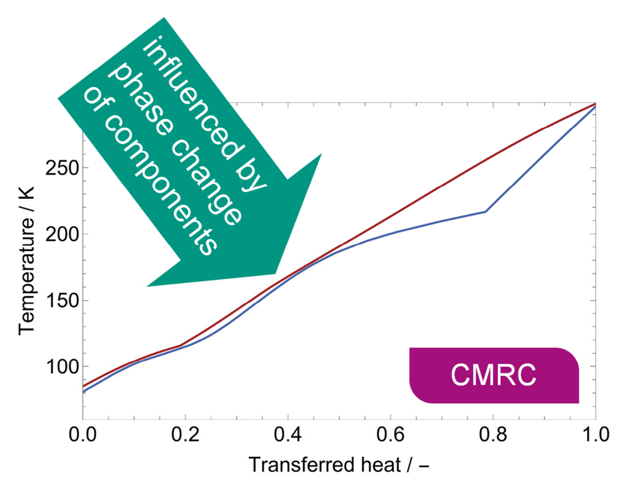
- Cooling systems are the main contributor to energy demand
  - 1st and 2nd law of thermodynamics → $P = \sum T_U \cdot \dot{S}_{i,irr}$

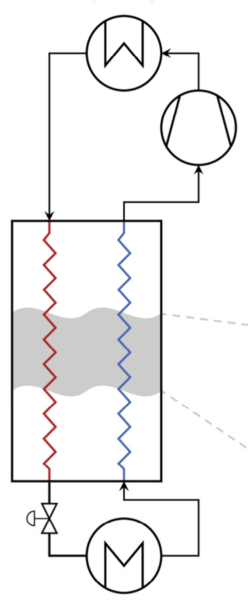
Δp: $\dot{S}_{i,irr} \propto -\frac{v}{T}\mathrm{d}p$ ΔT: $\dot{S}_{i,irr} \propto \frac{T_1 - T_2}{T_1 \cdot T_2}$





Key component of every cooling system is the refrigerant!

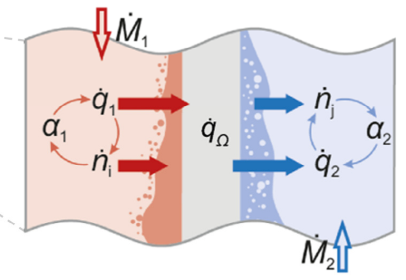




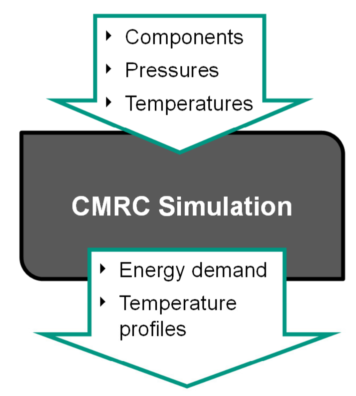
CMRC modeling and optimization tools

Numerical model for heat exchangers/current leads[1]

- Solution of conservation equations
- Empirical correlations for α, Δp and ε
- Heat source term for ohmic losses[2]

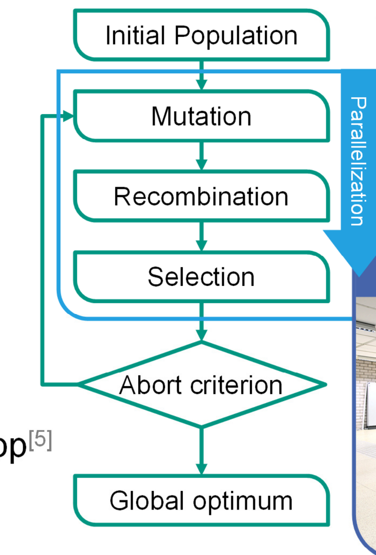


Process Modeling for CMRC[3]

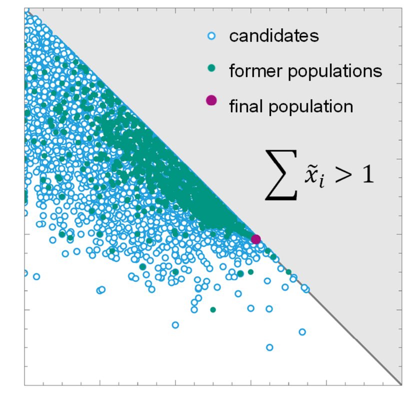


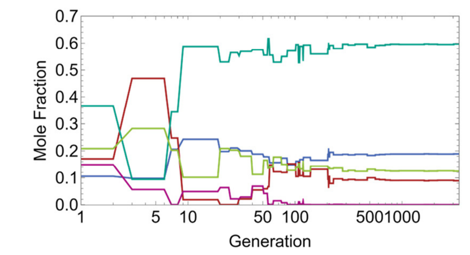
- Mathematica[4] with CoolProp[5]
- Steady-state calculation
- EoS: Peng-Robinson

Genetic Optimization Algorithm for global optimization[3]



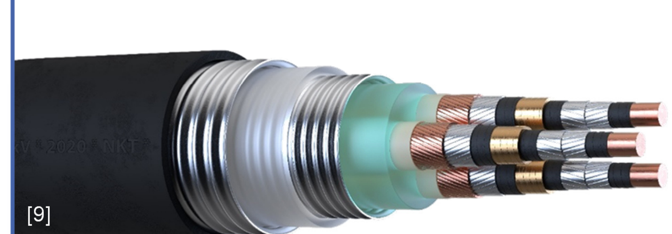
- Differential Evolution (DE) [6,7]
  - No derivatives needed
  - „Exploration & Exploitation"





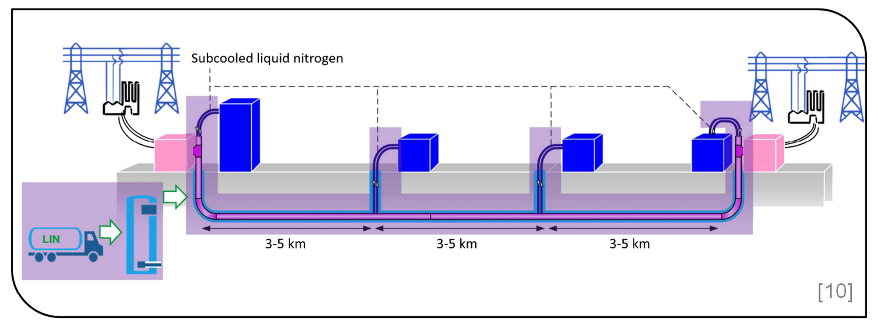
Applications

Cooling stations for SuperLink



SuperLink

- 15km, 110 kV, 500 MVA connection
- Lower space demand and higher transmission performance than conventional cables
- No electromagnetic emissions
- No joule heating

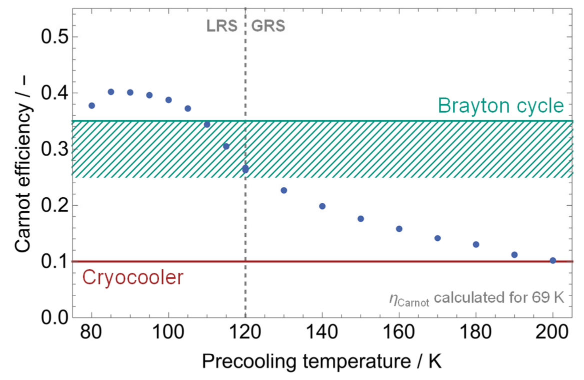


Boundary Conditions

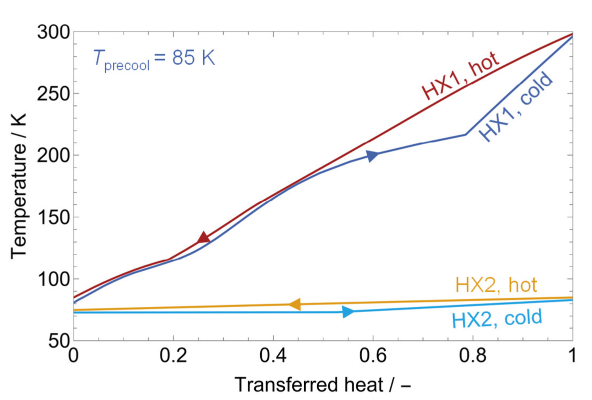
T_0	64 K – 74 K	ΔT_a	5 K	η_{is}	0.7
T_a	293.15 K	ΔT_{min}	2 K	p_{LP}	1 … 20 bar
$T_{precool}$	80 … 200 K	$\tilde{x}_i$	0 … 1	p_{HP}	10 … 60 bar

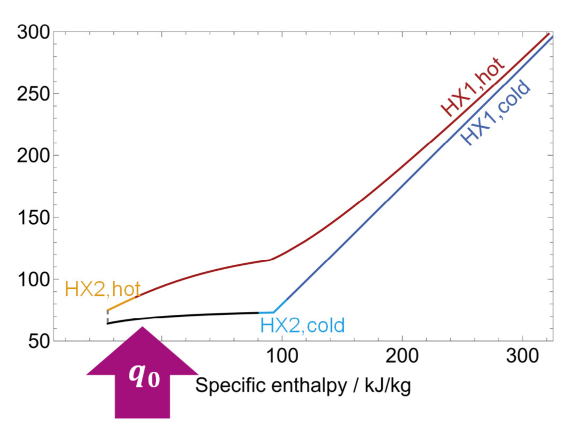
Optimization Results

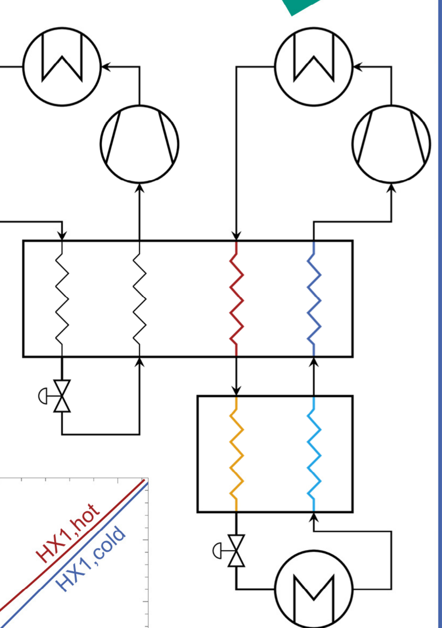
- Comparison of CMRC cascade with Brayton cycle for different temperatures → higher Carnot efficiency



- Temperature profiles and T-h plot for low temperature stage, $T_{precool}$ = 85 K



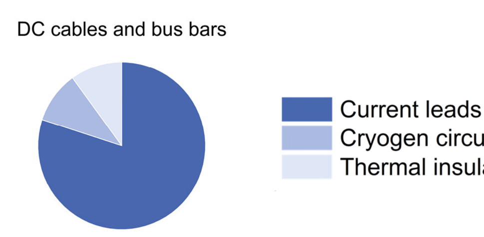




Prototype…?

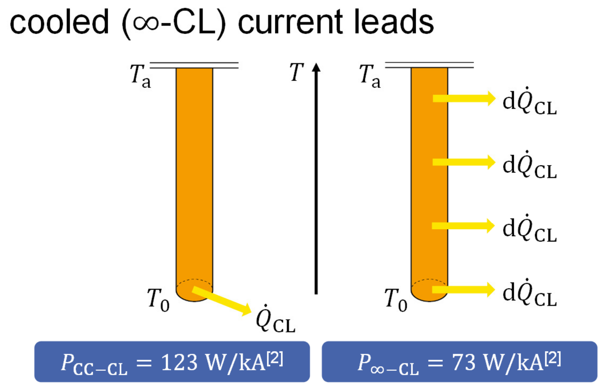
Micro-structured current leads

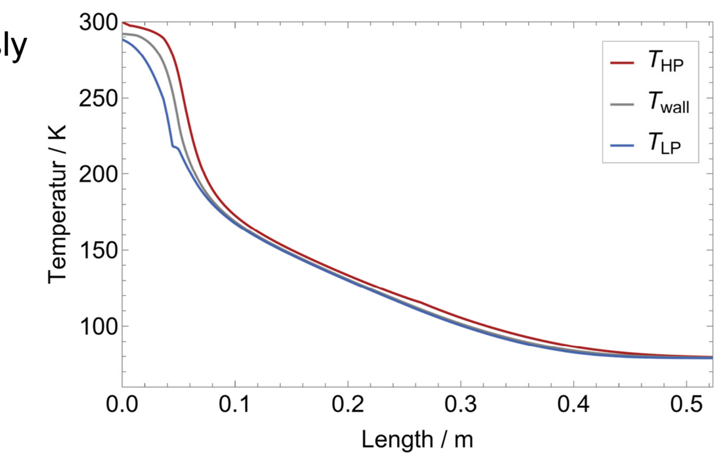
- Current leads (CL) impose heat load on cryogenic system
- Current leads are a main sources of power input for cooling[11]



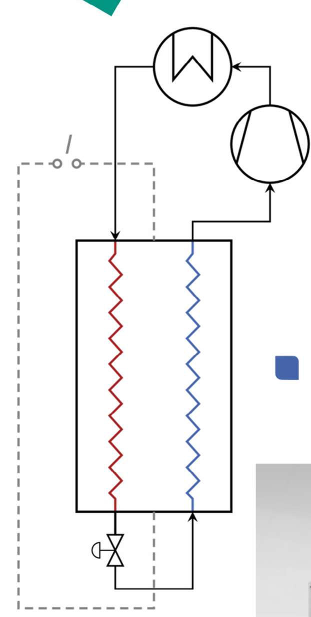
→ **Operating costs** can be **reduced** by about **50 %**

- Theoretical power demand for cooling of conduction cooled (CC-CL) and continuously cooled (∞-CL) current leads

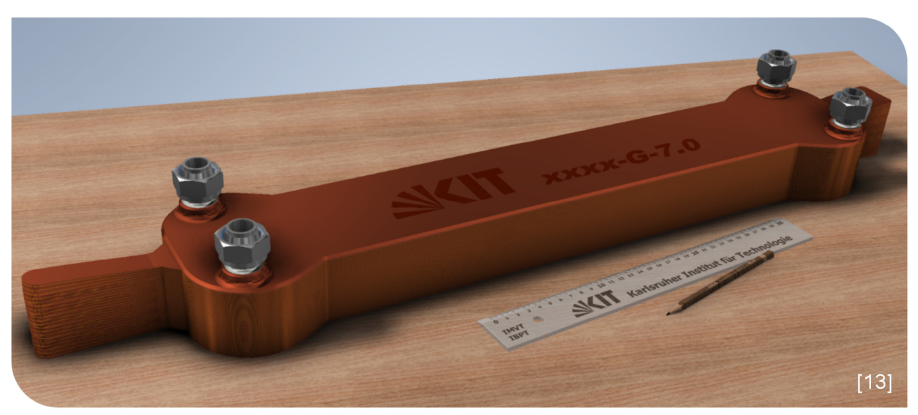




- **Compact Accelerator Systems** test stand (COMPASS)[12]




Key figures of CMRC-CL prototype			
Current capacity	10 kA	Dimensions (L x W x H)	564 x 90 x 56 mm
Pressure level	PN30	Total area for heat transfer	4.69 m^2



Parameter	CMRC-CL	CC-CL
Wall temperature at cold end	79.3 K	79.3 K
Current capacity	10 kA	10 kA
Mass flow mixed-refrigerant	17 g/s	-
Heat load due to ohmic losses	70.2 W	424 W
Power demand*	2.1 kW	8.1 kW
Carnot-Efficiency	35 %	15 %

*compared to Cryomech AI600 cryocooler

→ Reduction of **power demand** compared to CC-CL by **74 %**

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