Karlsruhe Institute of Technology

Investigation of Cryogenic Mixed-Refrigerant Cooled Current Leads in Combination with Peltier-Elements

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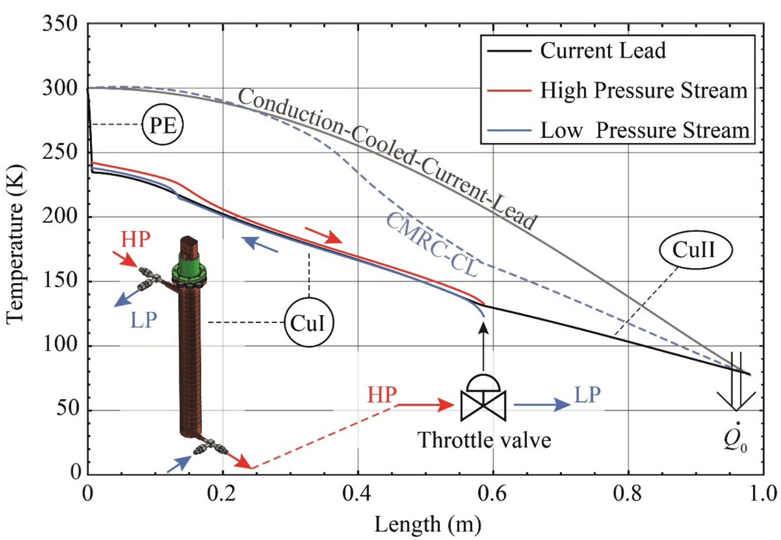
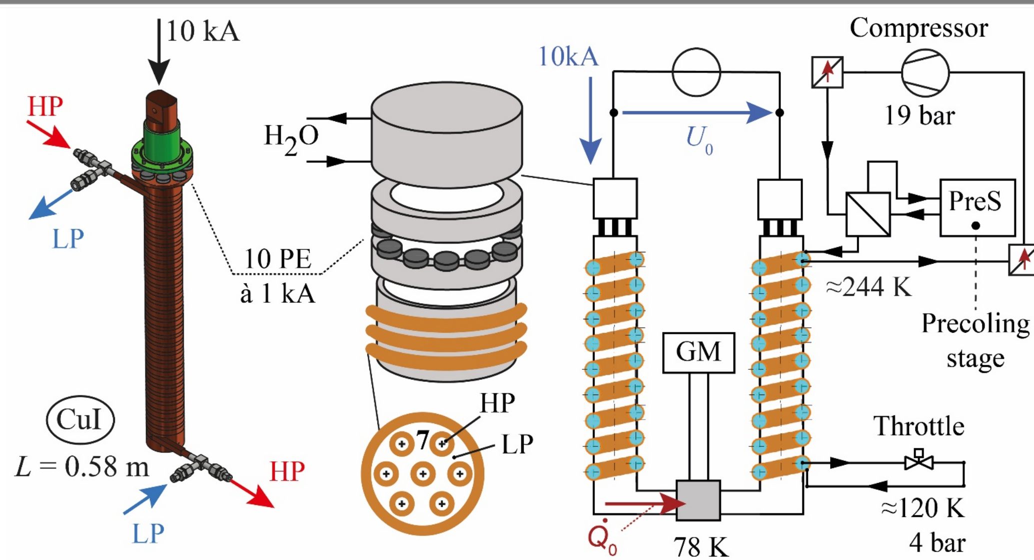
CEC-ICM 2019
C1Or2B-07 – Superconducting RF Systems, Power Cables, and Leads I

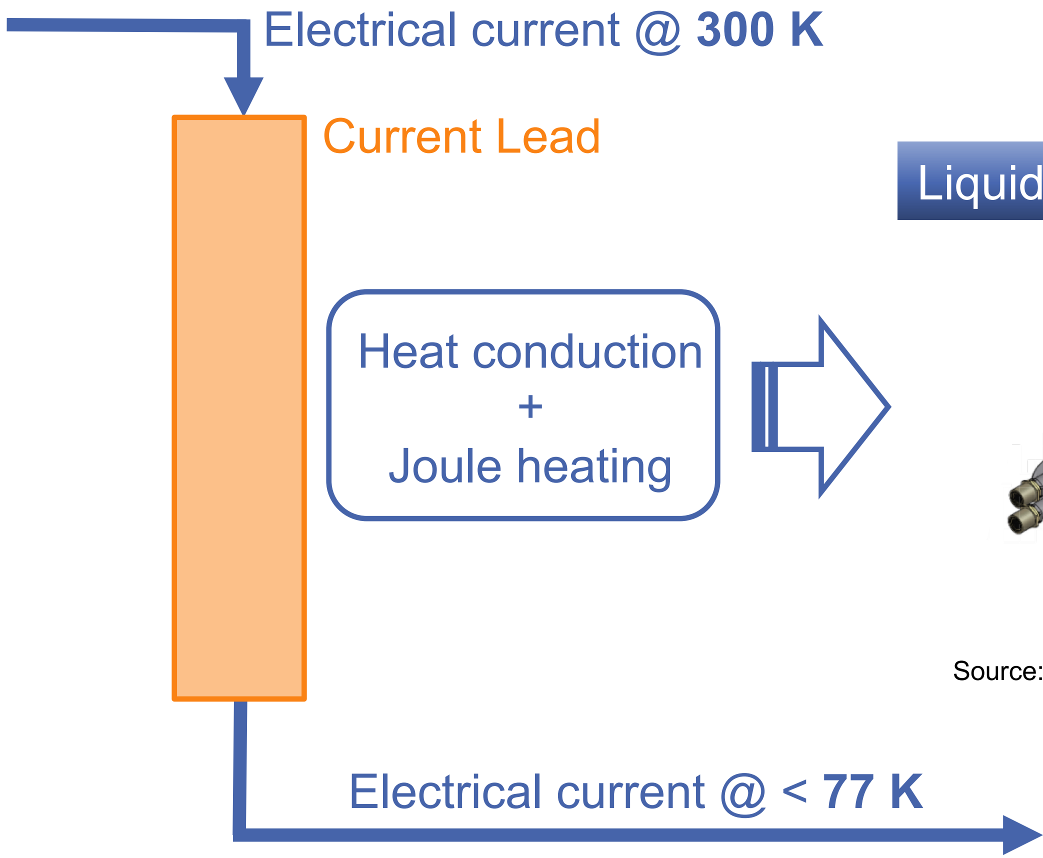
Institute for Technical Physics (ITEP)



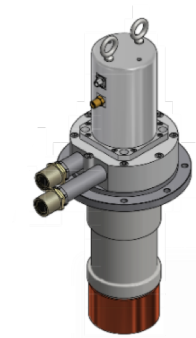


Motivation

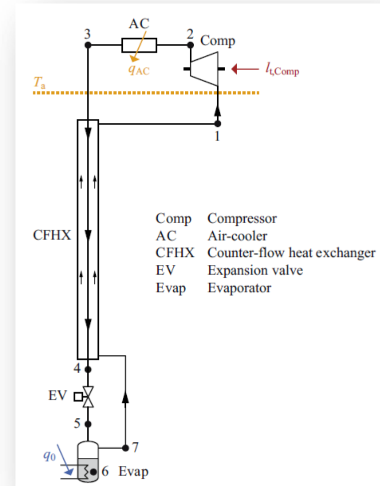
- **Efficient** transport of electrical current from room-temperature to a superconducting application at the cryogenic temperature

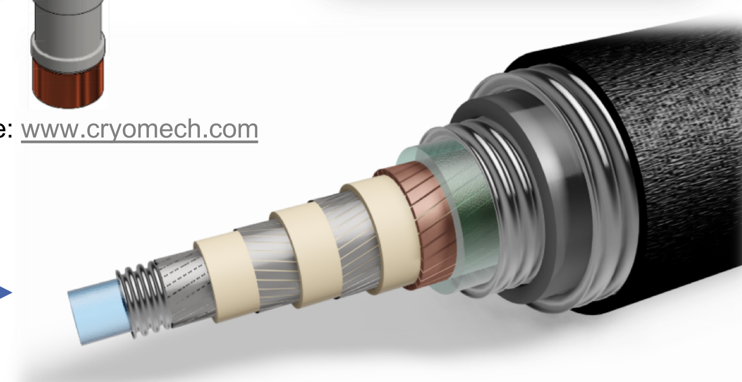


Liquid Nitrogen



Source: www.cryomech.com





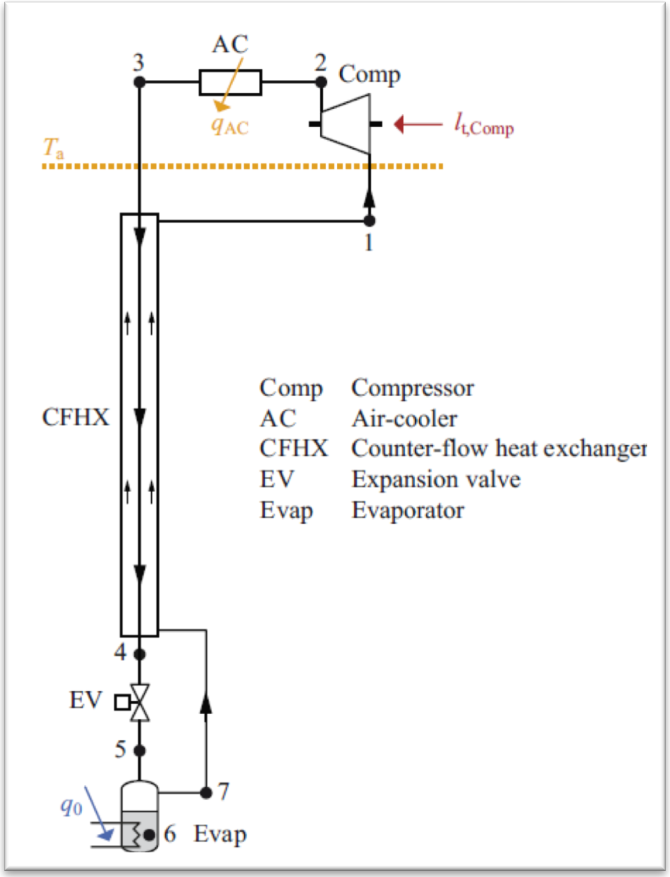
Current Lead Technologies (Overview)

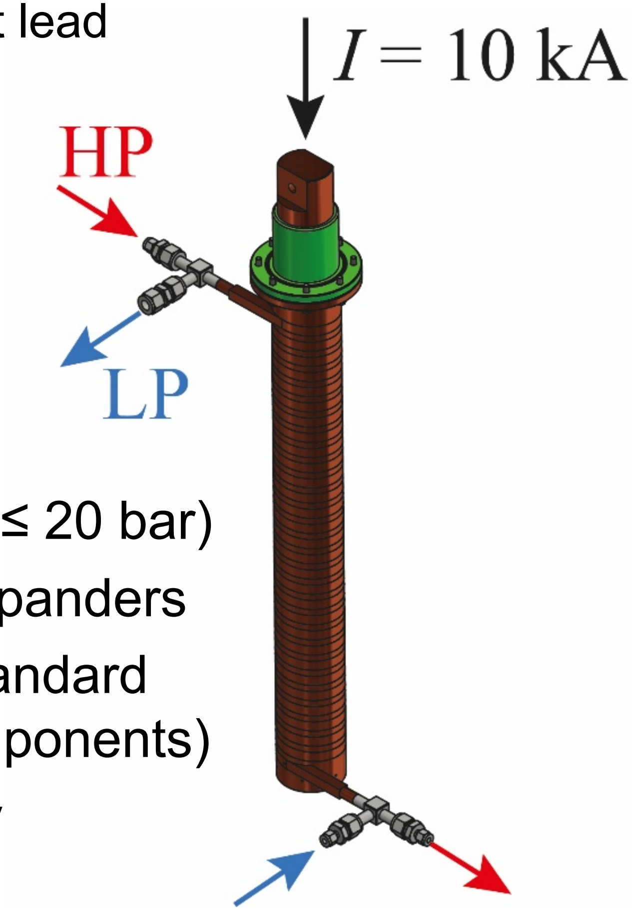
	Open cycle	Closed cycle	
	Evaporation of LN_2	1 Stage Cryocooler	Multistage
Principle	Gas-cooled (forced flow / self-sufficient)	Conduction cooled	Conduction cooled
Cooling power	Any @ 80K	Max~ 600 W @80K	Limited
Ampacity	Any	42,5 W/kA ► 14 kA (1 Cryocooler)	Limited (20 kA possible **[1]**)
Operation supplies	Electricity LN_2	Electricity Cooling water	Electricity Cooling water
Disadvantage	LN_2 supply	Cooling power limitation	Several refrigeration machines required

[1] Schreiner F, Gutheil B, Noe M et al. 2017 IEEE Trans. Appl. Supercond. 27 4802405; doi:10.1109/TASC.2017.2655108.

New Solution for HTS Power Application

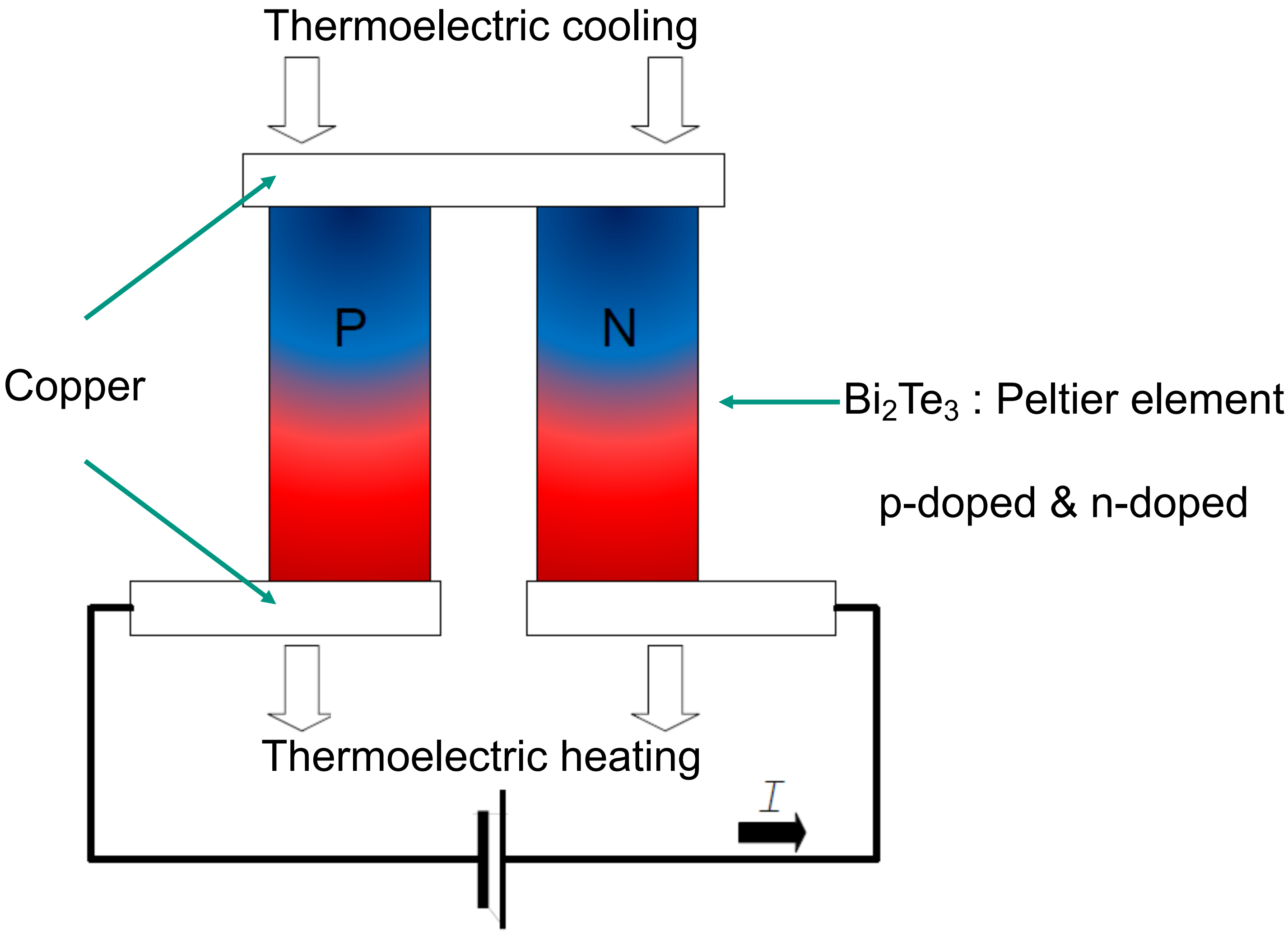
- **C**ryogenic **M**ixed **R**efrigerant **C**ycles (**CMRC**s) + **C**urrent **L**ead
  - Prototype of a 10 kA continuous cooled current lead





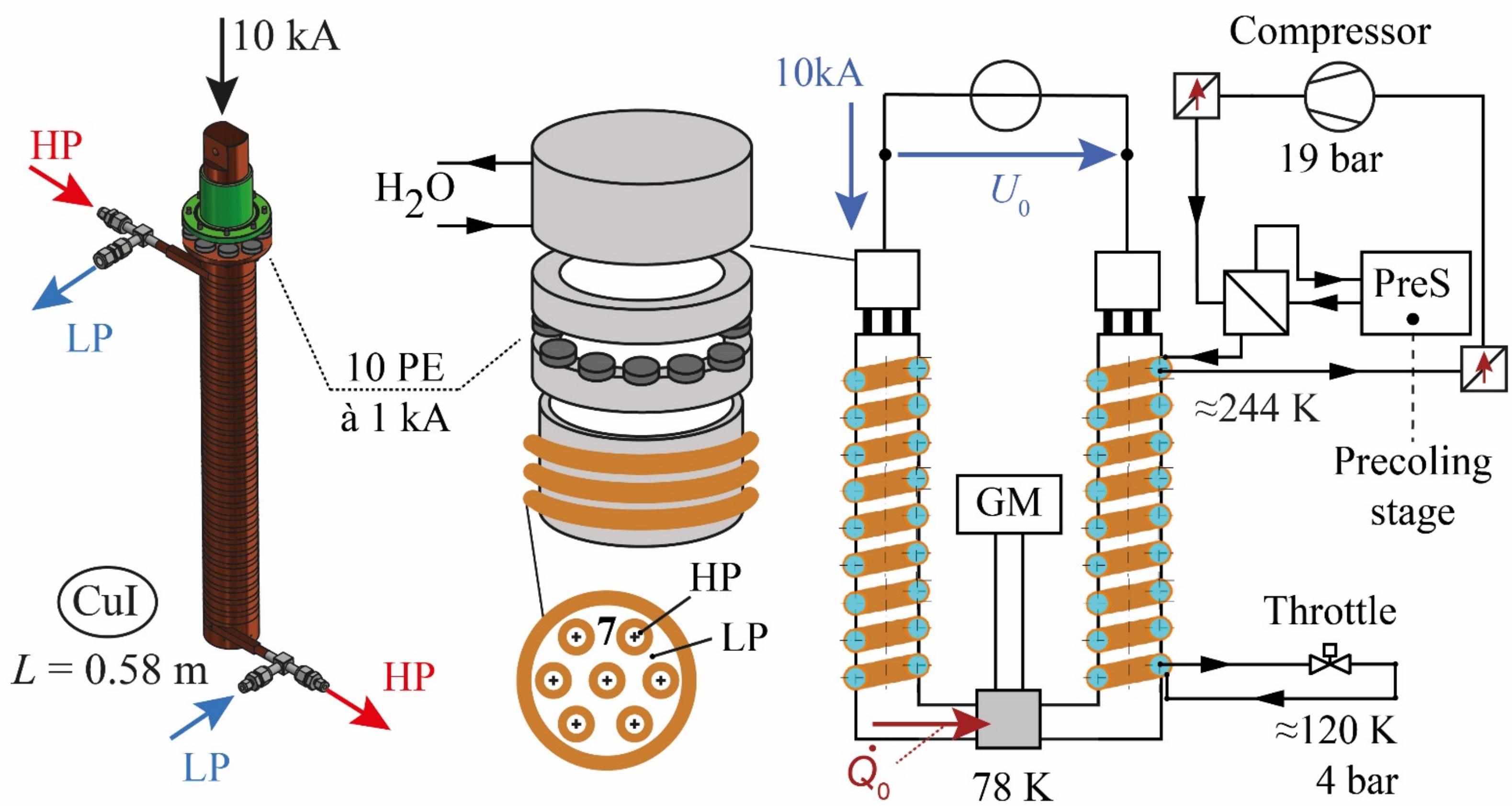
- Low pressure ($p \leq 20$ bar)
- No cold turbo-expanders
- **Inexpensive** (standard refrigeration components)
- **Good efficiency**
- **Scalable**

Thermoelectric effect (Peltier effect)

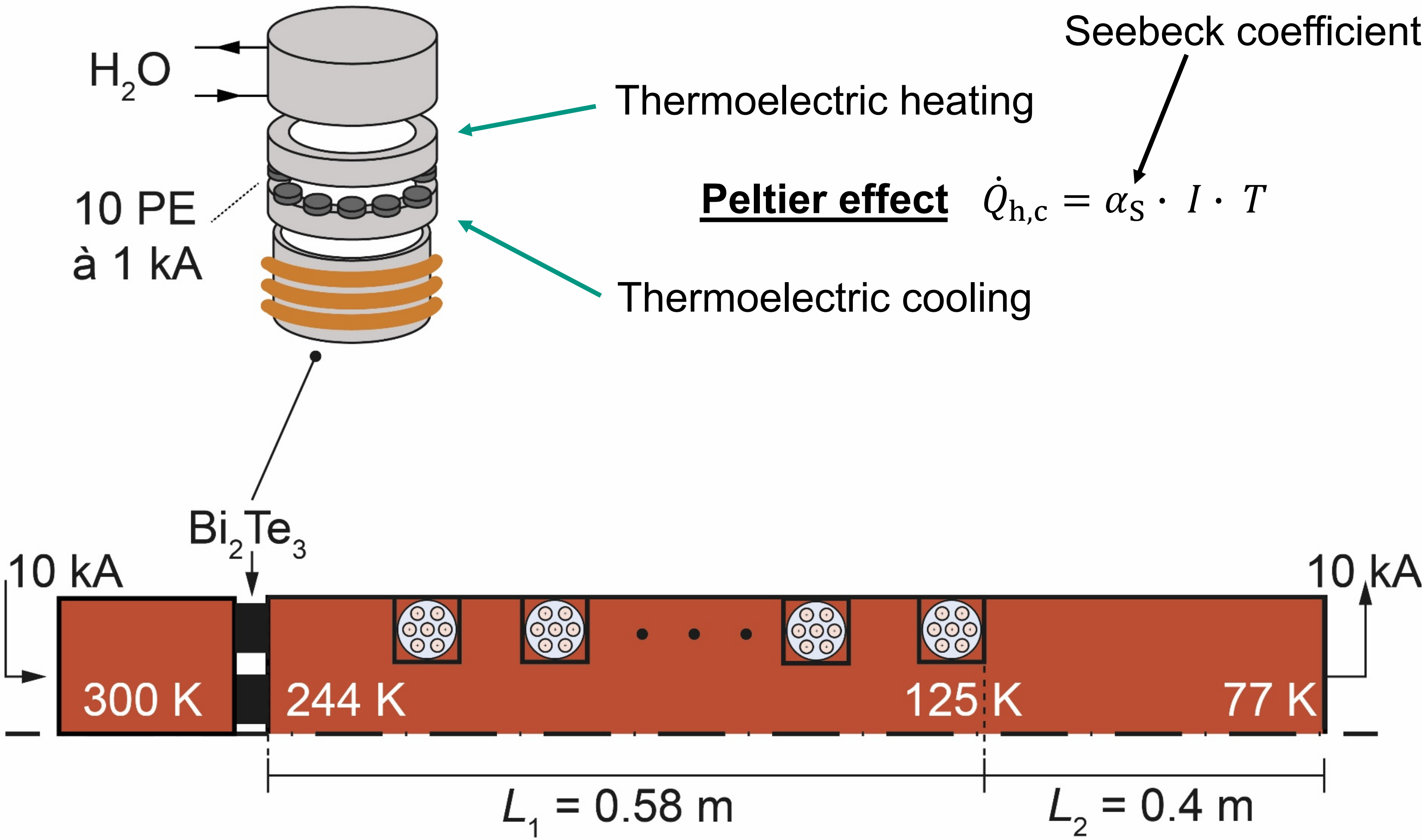


New Solution for HTS Power Application

- Concept of a **CMRC–CL** with **Peltier** elements (**Bi_2Te_3**)



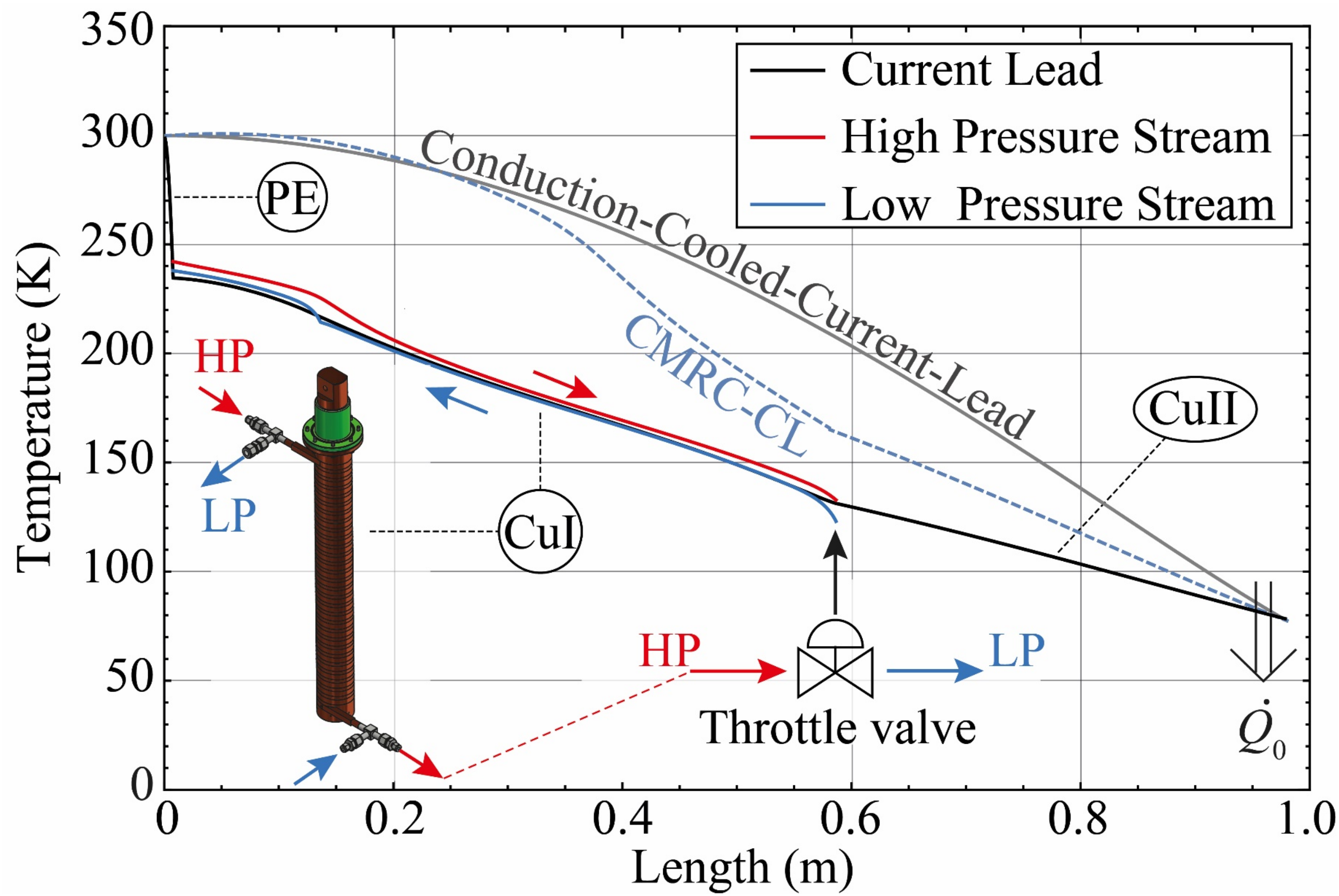
Thermal & electric model design



Peltier effect $\dot{Q}_{\mathrm{h,c}} = \alpha_{\mathrm{S}} \cdot I \cdot T$

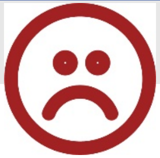
[2] Gomse D, Kochenburger T M, and Grohmann S 2018 *Journal of Heat Transfer* **140** 051801; doi: 10.1115/1.4038852

Temperature Profiles



Investigation of energy consumption

- **PE-CMRC-CL**: 35.9 mole % N_2, 31.9 % CH_4, 18.2 % C_2H_6, 14 % C_3H_8
- **CMRC-CL**: 30 mole % N_2, 20 % CH_4, 20 % C_2H_6, 30 % C_3H_8

I = 10 kA	P_{el} (W)	Q_0 @80K (W)	P_{CMRC} (W)	P_{GM} (W)	P_{total} (W)	P_{total} / P_{CCCL}
CCCL	425	425	0	11500	**11925**	100 %
		51 % reduction				
CMRC-CL	525	310	740	7500		**73.5 %**
PE-CMRC-CL	704	**204**	854+500	7500		80.2 %

P_{CMRC} = compressor rating

- **GM 1**: 600 W @ 80 K ► **11.5 kW**
- **GM 2**: 320 W @ 80 K ► **7.5 kW**

Strong motivation for a **second** CMRC stage down to 77.4 K!

Source: www.cryomech.com

Summary

- **Combination** of **Peltier elements** and a **CMRC-CL** is possible
  - State-of-the-art solutions require **multiple** stages
  - Numeric **coupling** of **electric model** and **thermal modeling framework** for integrated optimization
    - Heat exchanger = current lead
  - **Reduction** of **thermal load** at cold end **by 51 %** compared to conventional conduction-cooled current leads
  - **Still high** energy consumption for a current lead
    - GM Cryocooler

Aim:

Development of a **second CMRC stage** down to **77.4 K**

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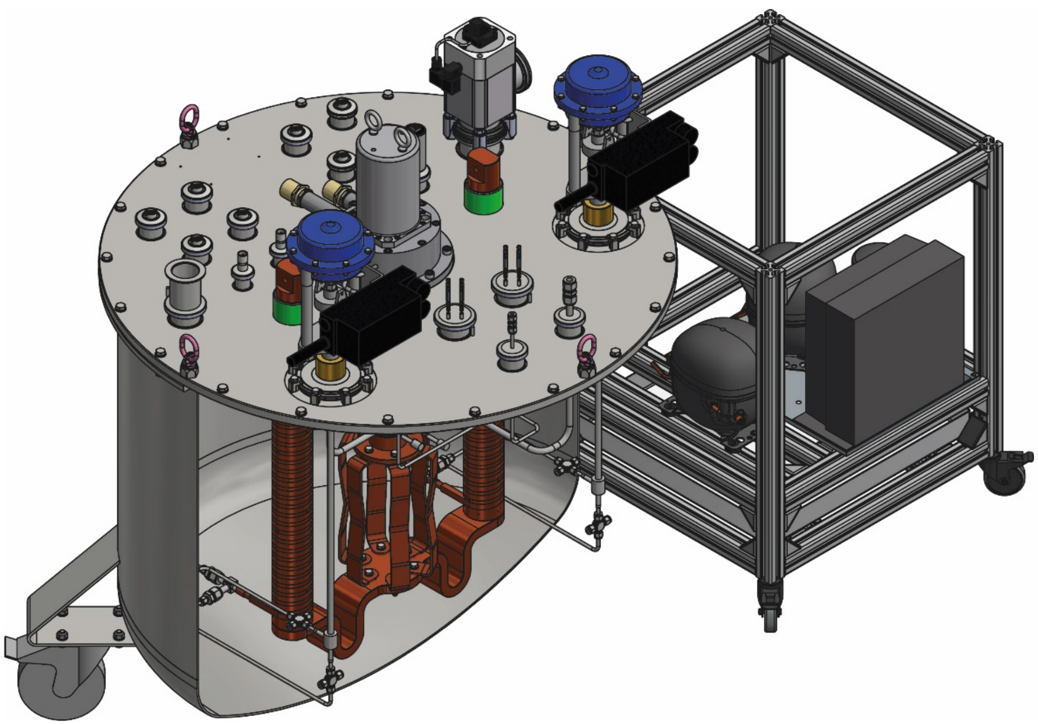
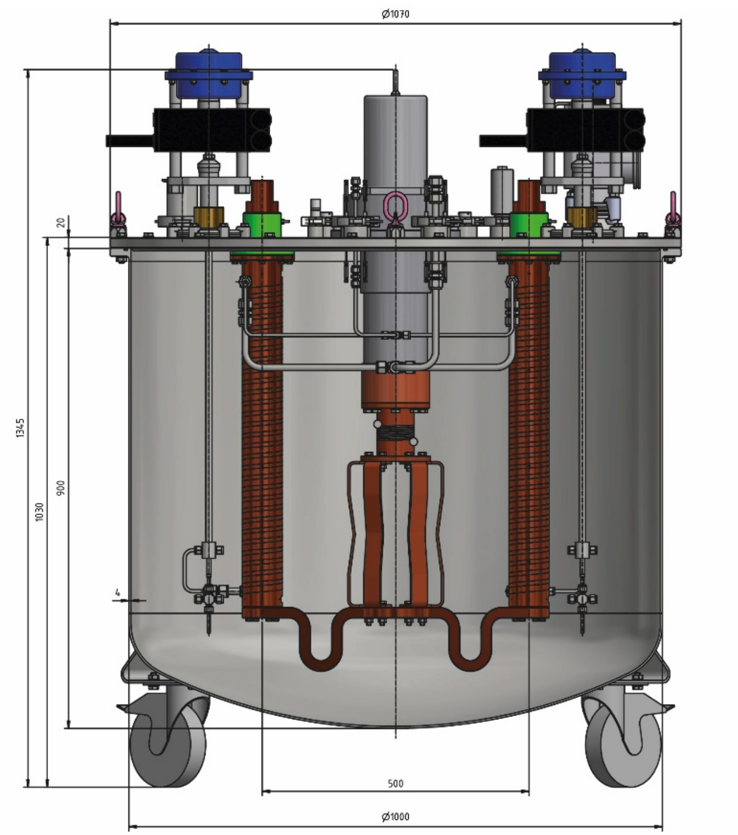
Thank you for your attention !

New Solution for HTS Power Application

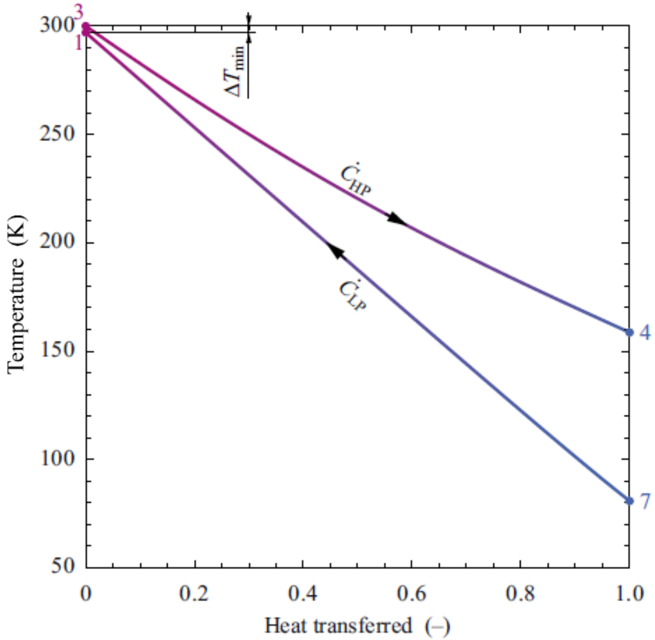
- Development of a pair of **10 kA current leads** cooled with a cryogenic mixed refrigerant cycle (CMRC)



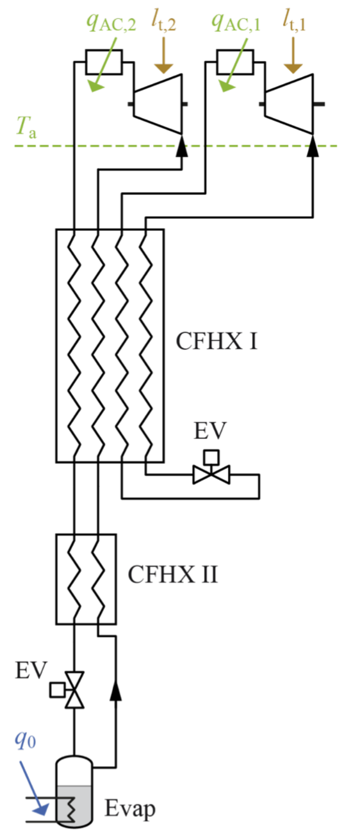


Pure- vs. mixed-refrigerant cooling

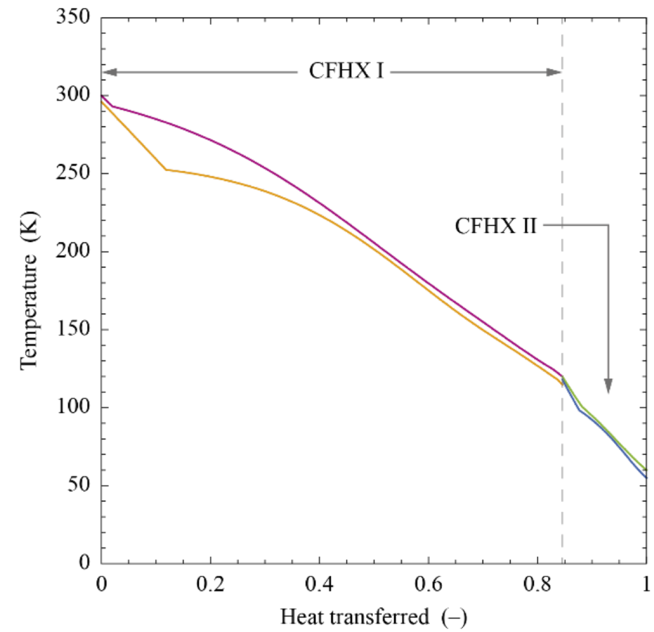
- Pure-refrigerant cooling



- High ΔT → Poor efficiency
- High pressure (200 bar)
- **Expensive** compressor



- Mixed-refrigerant cooling



- Low ΔT → Good efficiency
- Low pressure (20 bar)
- **Inexpensive**
- **Scalable**