Karlsruhe Institute of Technology

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

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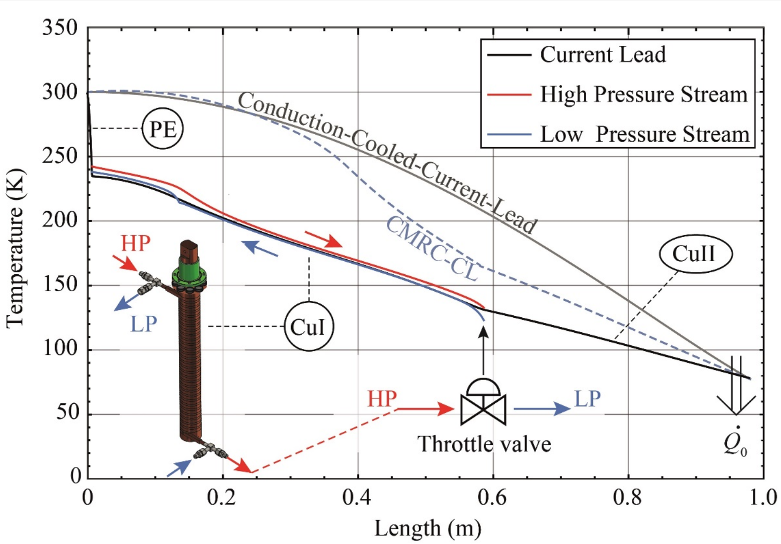
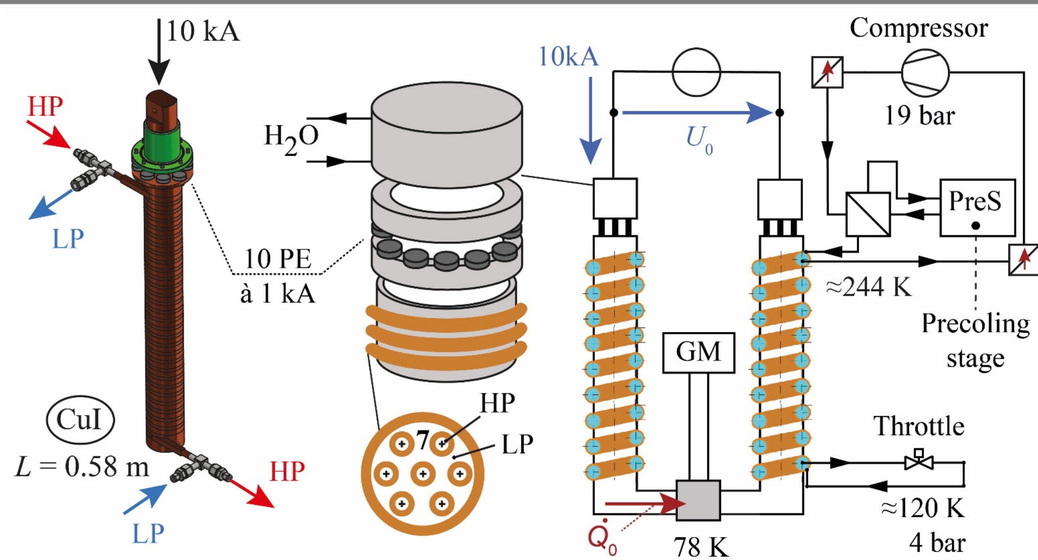
**CEC-ICM 2019**
**C1Or2B-07 – Superconducting RF Systems, Power Cables, and Leads I**

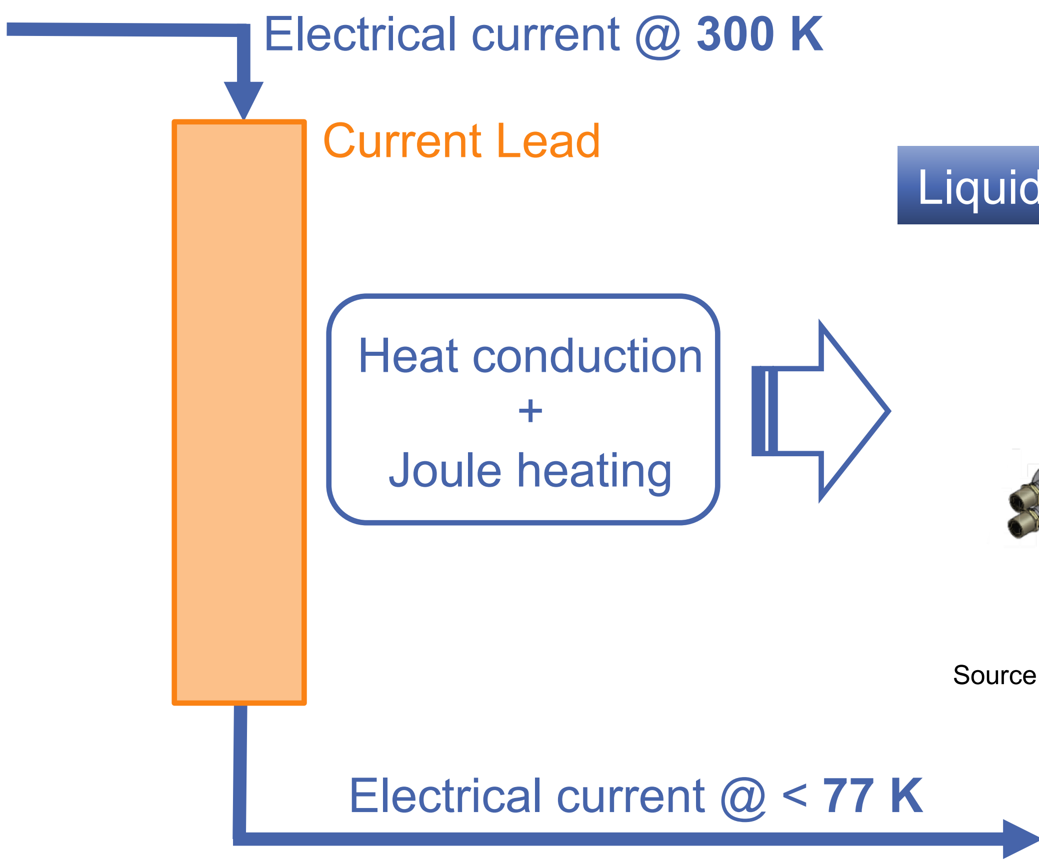
Institute for Technical Physics (ITEP)



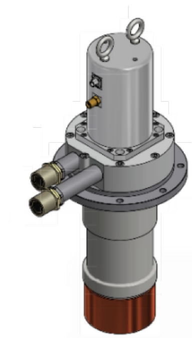



# Motivation

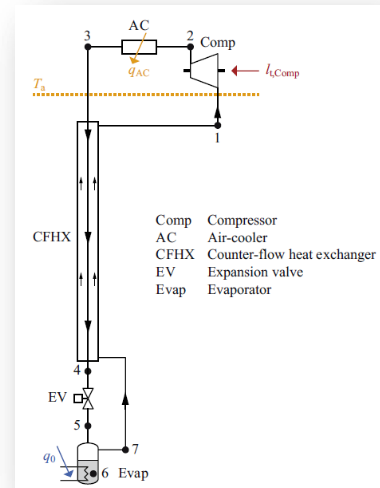
- **Efficient** transport of electrical current from room-temperature to a superconducting application at the cryogenic temperature

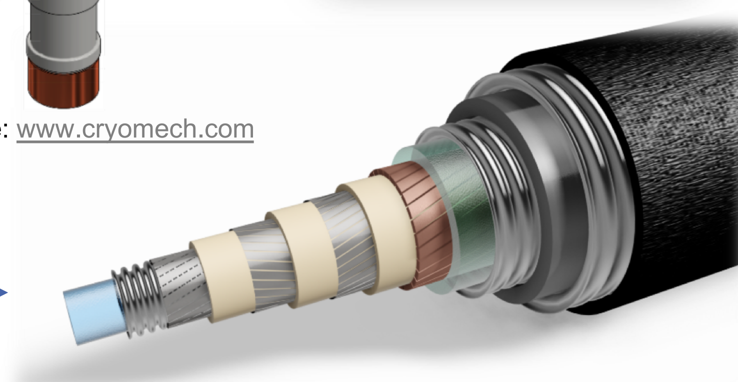



Liquid Nitrogen



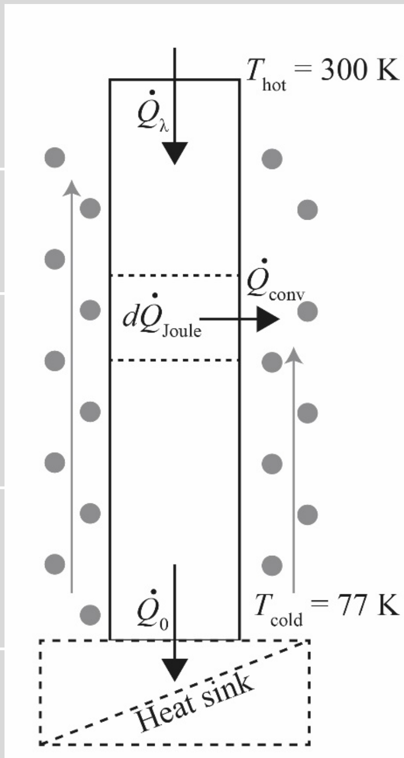
Source: www.cryomech.com

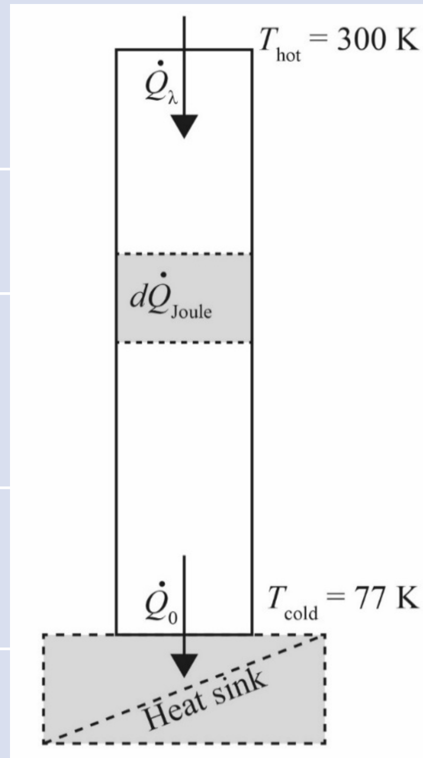


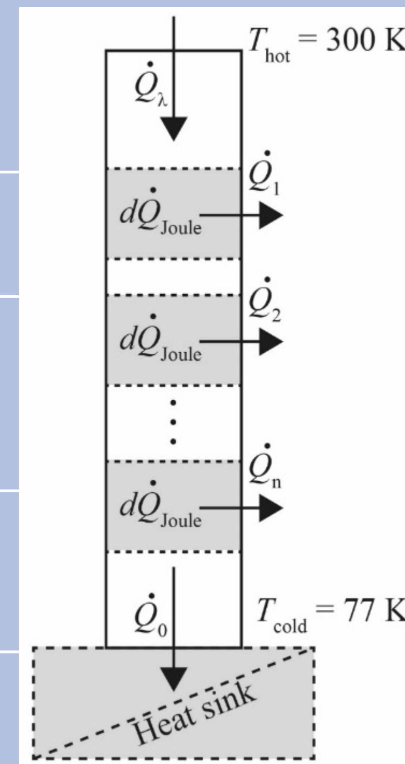



# Current Lead Technologies (Overview)

| | Open cycle | Closed cycle | |
|---|---|---|---|
| | Evaporation of $LN_2$ | 1 Stage Cryocooler | Multistage |



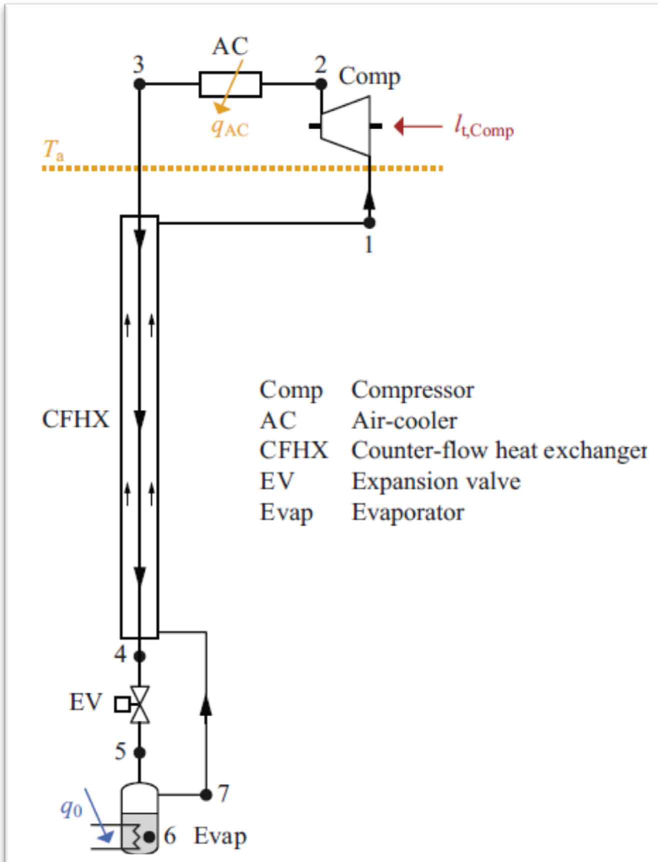
# Current Lead Technologies (Overview)

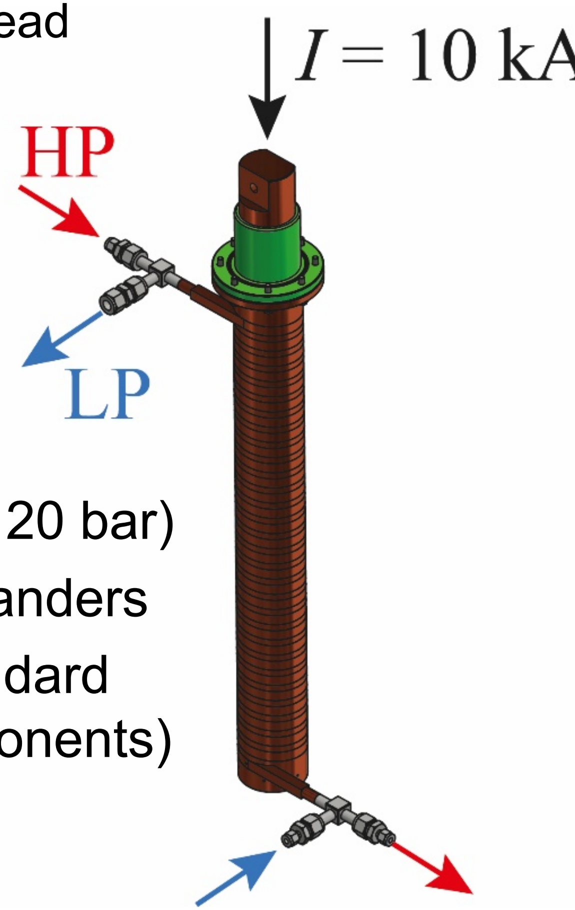
| | Open cycle | Closed cycle | |
|---|---|---|---|
| | Evaporation of $LN_2$ | 1 Stage Cryocooler | Multistage |
| Principle | Gas-cooled (forced flow / self-sufficient) | Conduction cooled | Conduction cooled |
| Cooling power | Any @ 80K | Max~ 600 W @80K | Limited |
| Ampacity | Any | 42,5 W/kA ► 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

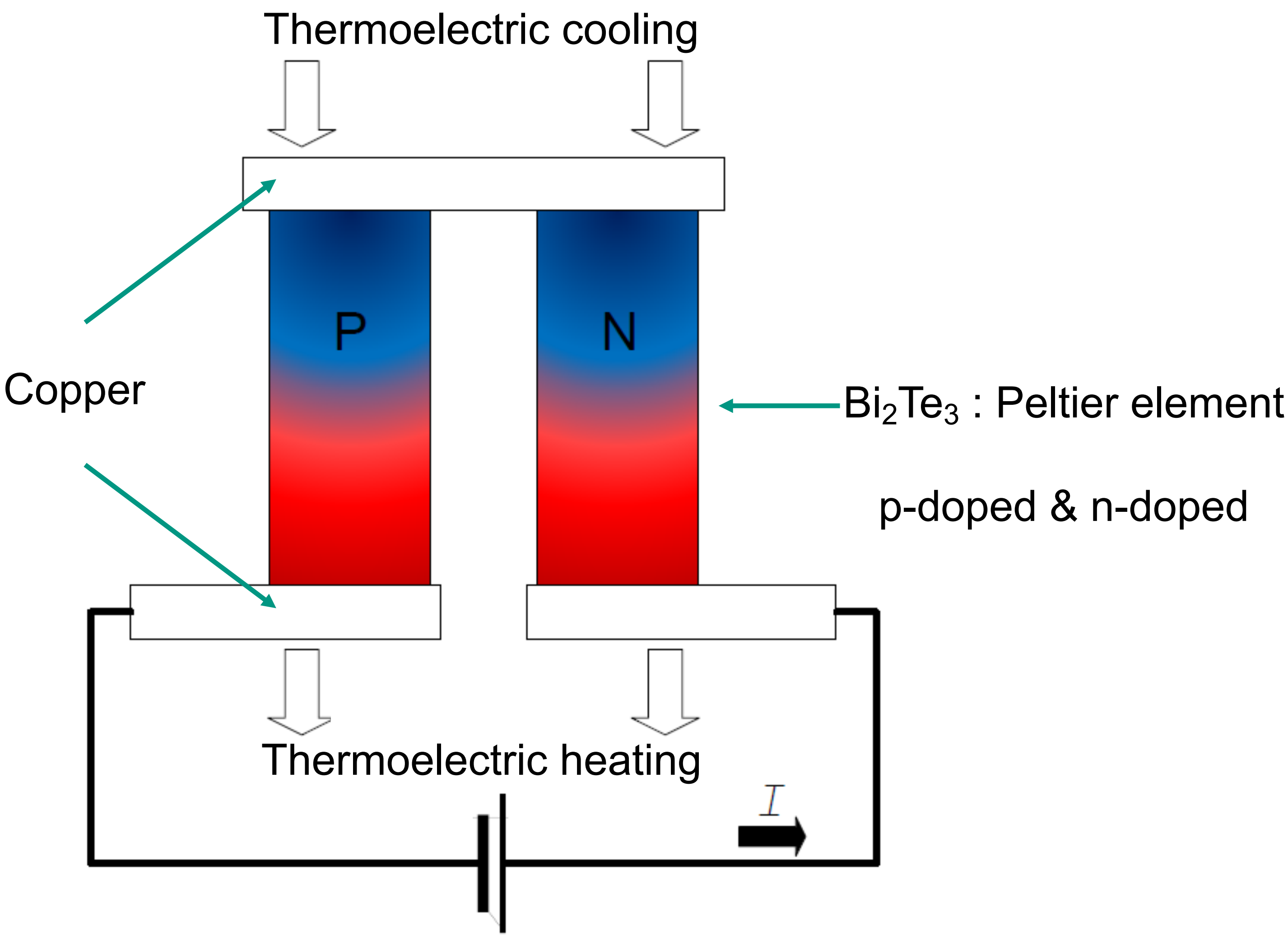
- **C**ryogenic **M**ixed **R**efrigerant **C**ycles (**CMRC**s) + **C**urrent **L**ead
  - Prototype of a 10 kA continuous cooled current lead



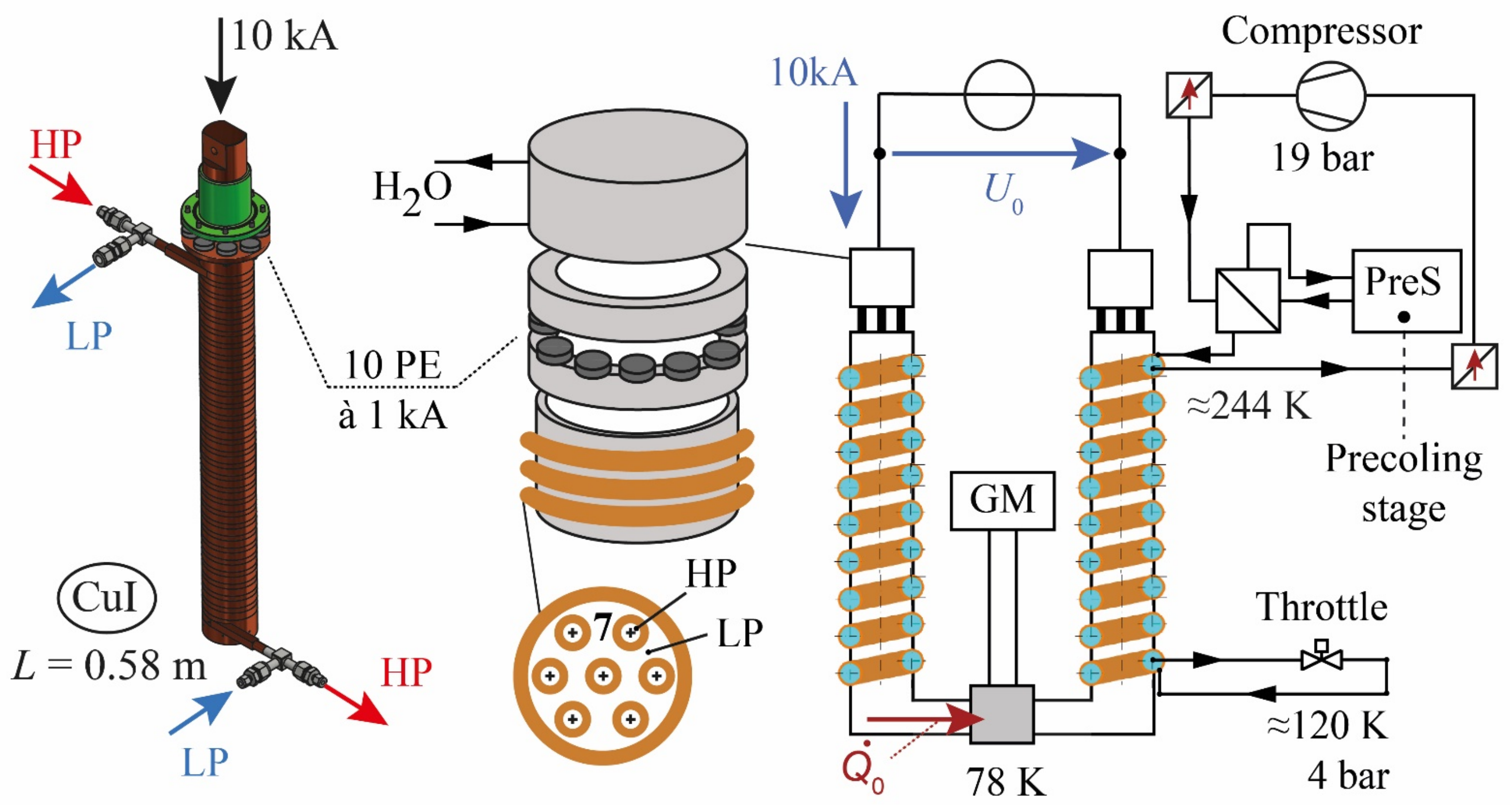

- Low pressure ($p \leq 20$ bar)
- No cold turbo-expanders
- **Inexpensive** (standard refrigeration components)
- **Good efficiency**
- **Scalable**

# Thermoelectric effect (Peltier effect)



# New Solution for HTS Power Application

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



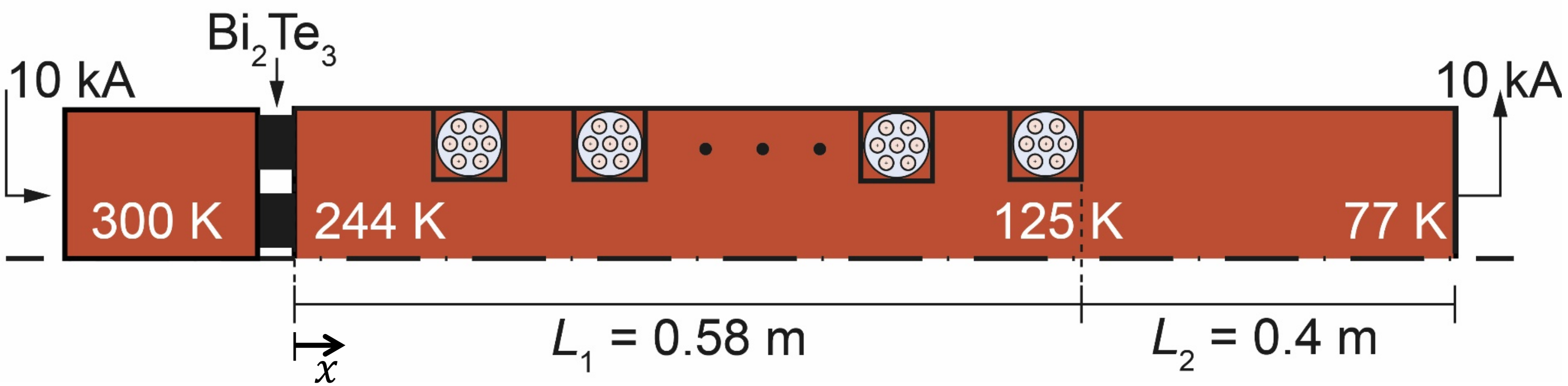
# Thermal & electric model design

- Temperature profile calculation

[2]

$$\frac{\partial}{\partial x}\cdot\left(\lambda_{\mathrm{i}}(T)\cdot A\cdot\frac{\partial T_i}{\partial x}\right)+I^2\cdot\frac{\rho_{\mathrm{i}}(T)}{A_i}-\left[k_{\mathrm{LP}}\cdot U\cdot(T-T_{\mathrm{LP}})\right]_{i=2}=0\,,\qquad i=1,2,3$$

Heat conduction — Joule heating — Forced convection




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

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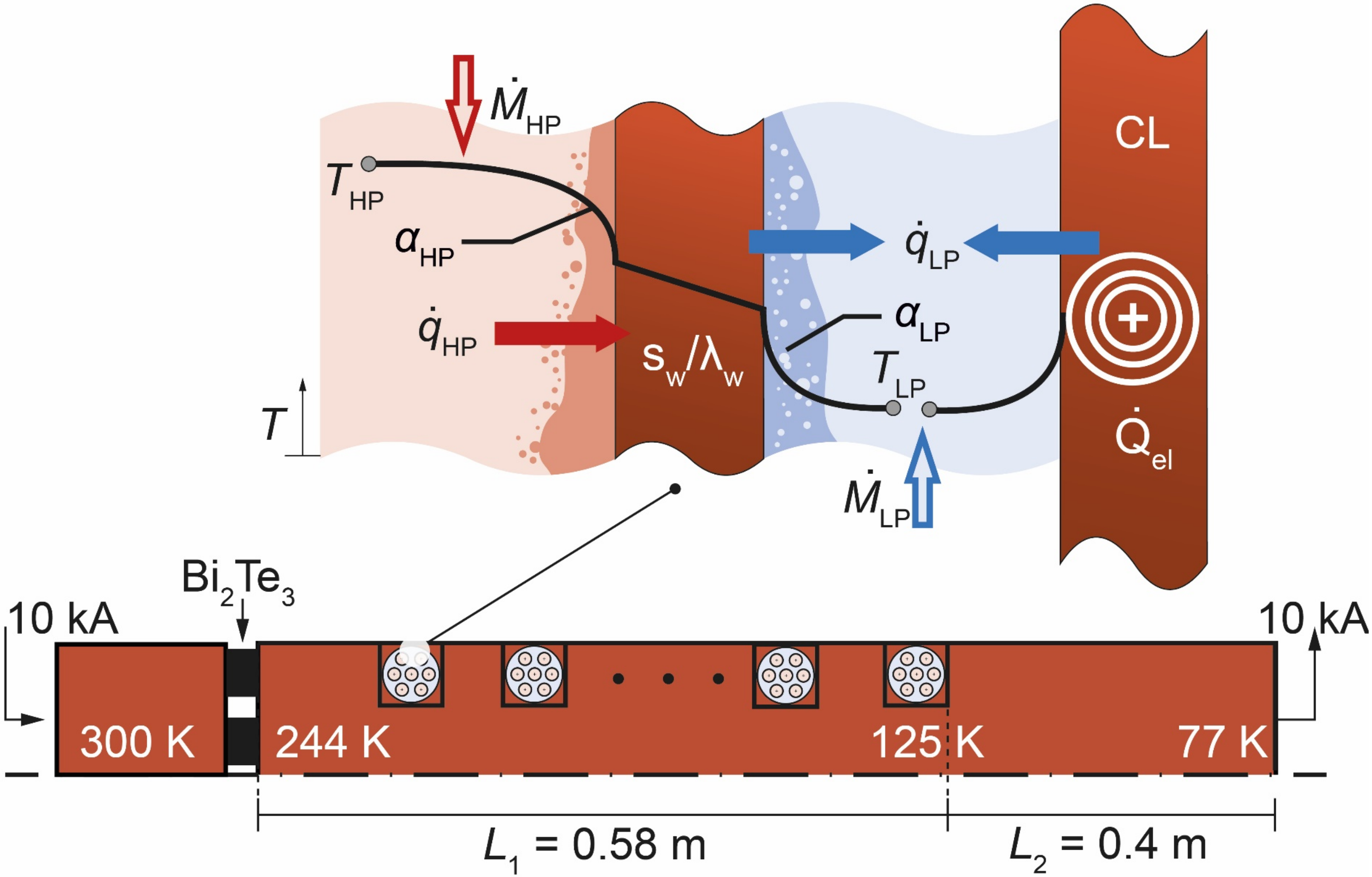



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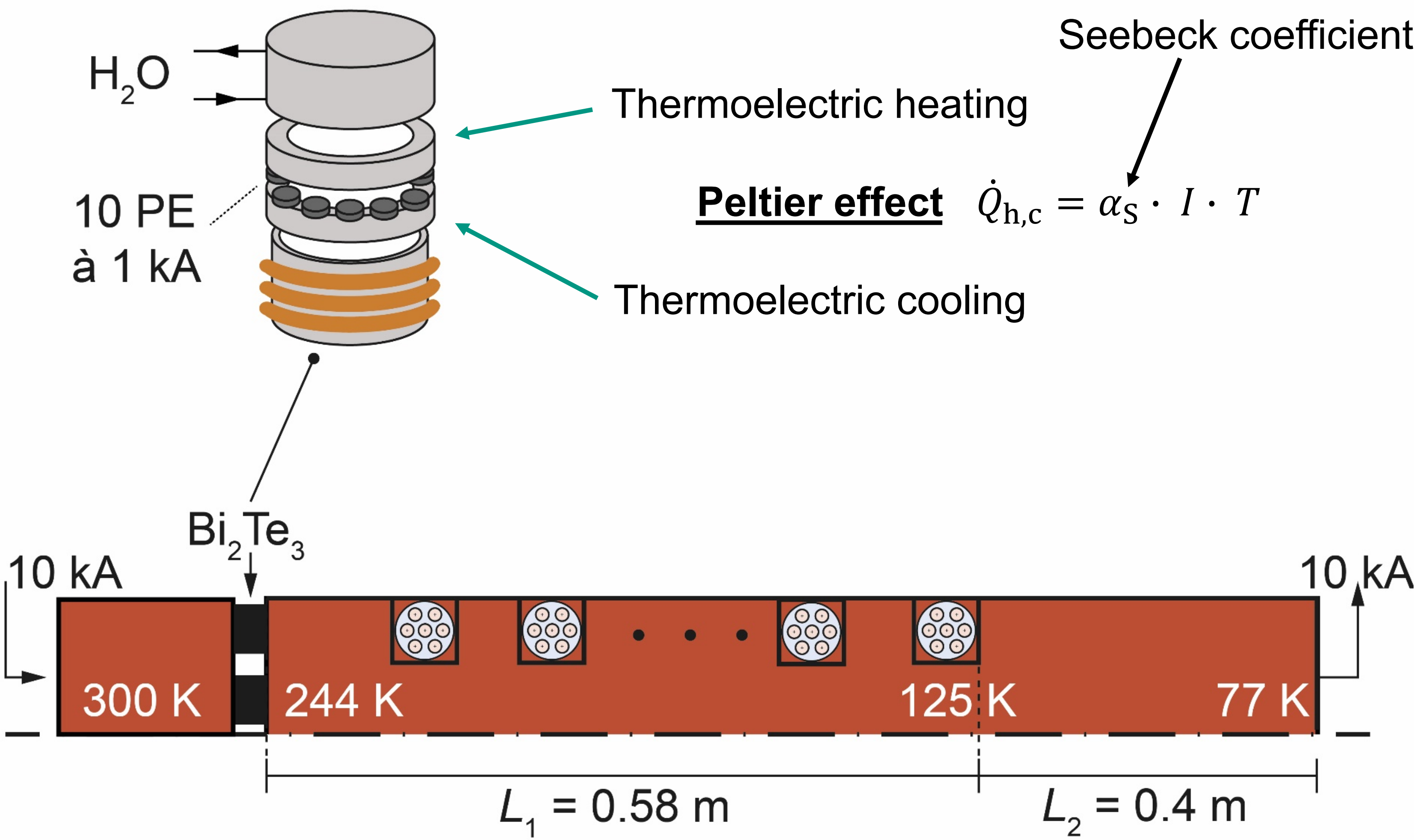
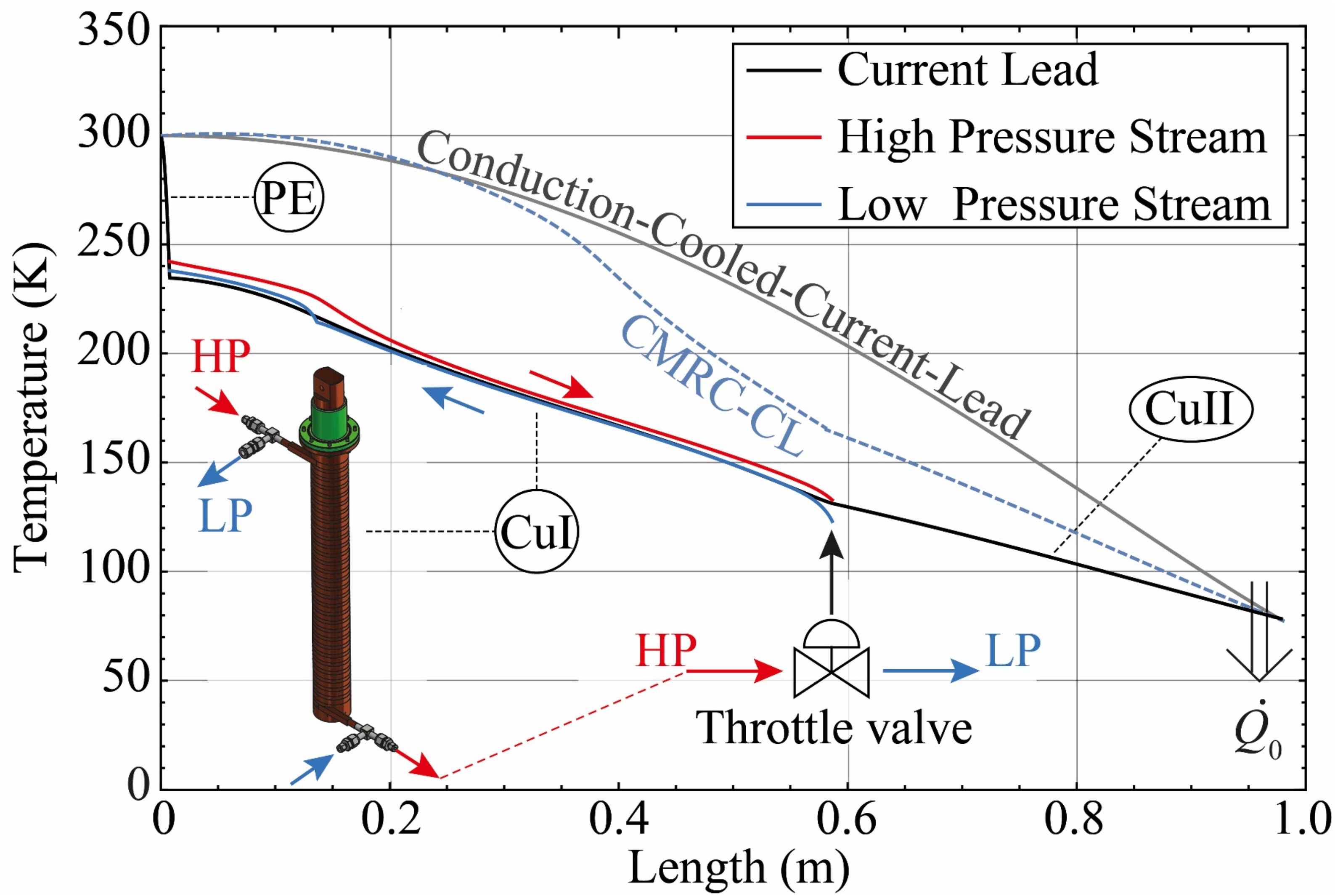


# Temperature Profiles



# 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 | 8765 | **73.5 %** |
| PE-CMRC-CL | 704 | **204** | 854+500 | 7500 | 9558 | 80.2 % |

$P_{CMRC}$ = compressor rating

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

Source: www.cryomech.com

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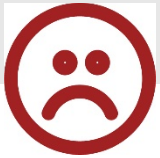
| CMRC-CL | 525 | 310 | 740 | 7500 |  | **73.5 %** |
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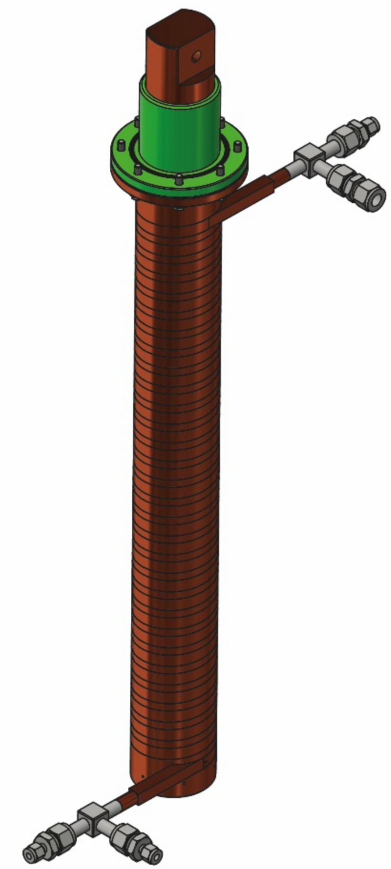
$P_{CMRC}$ = compressor rating

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
  - 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**

# Thank you for your attention !