Influence of mixture composition on the performance of cryogenic mixed-refrigerant cooled current leads

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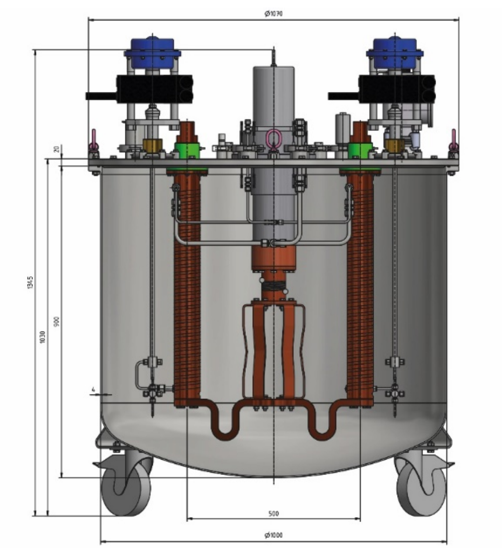
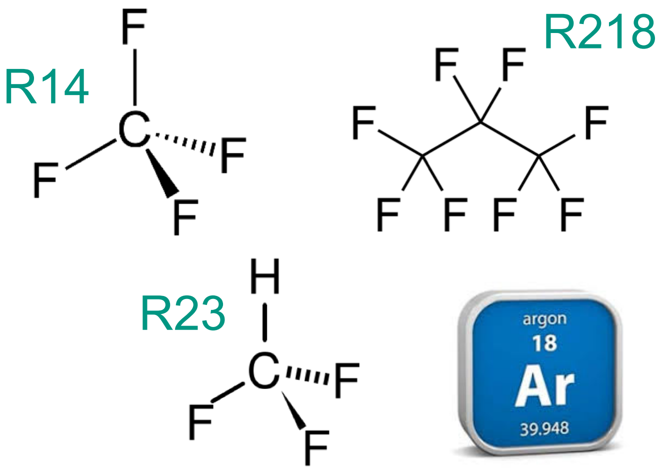
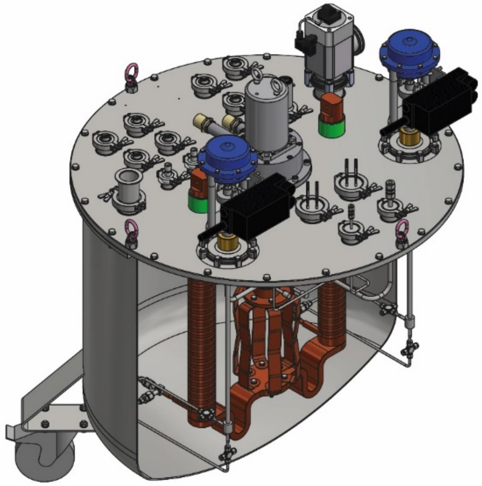
Institute for Technical Physics (ITEP)







Motivation

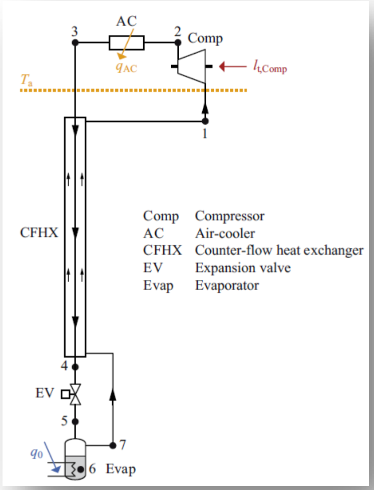
- **Efficient** transport of electrical current from room-temperature to a superconducting application at the cryogenic temperature

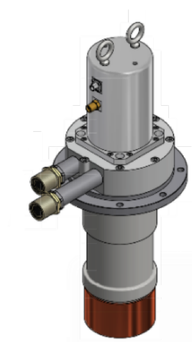
Electrical current @ **300 K**

Current Lead

Heat conduction
+
Joule heating

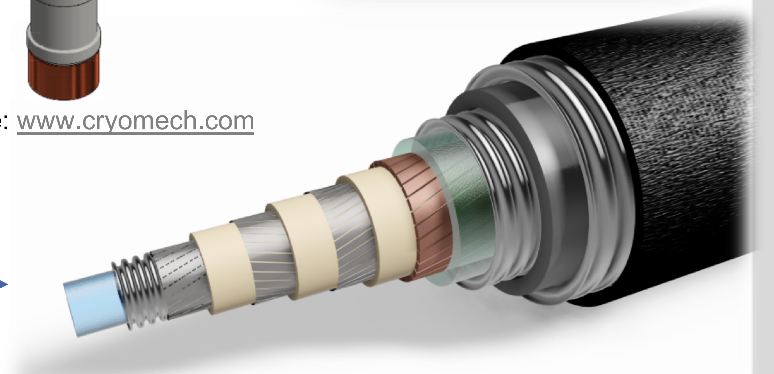
Liquid Nitrogen





Source: www.cryomech.com

Electrical current @ < **77 K**



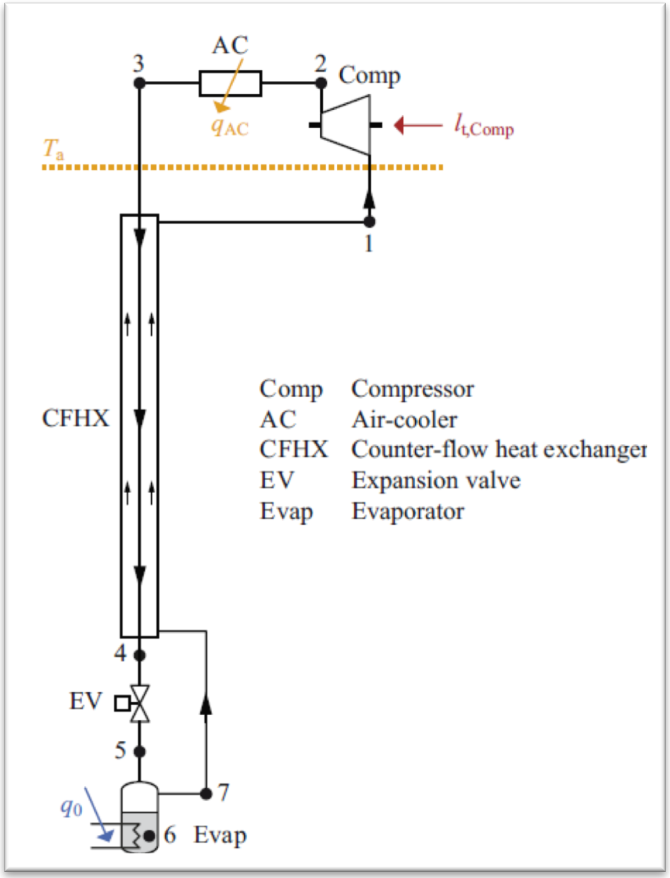
Current Lead Technologies (Overview)

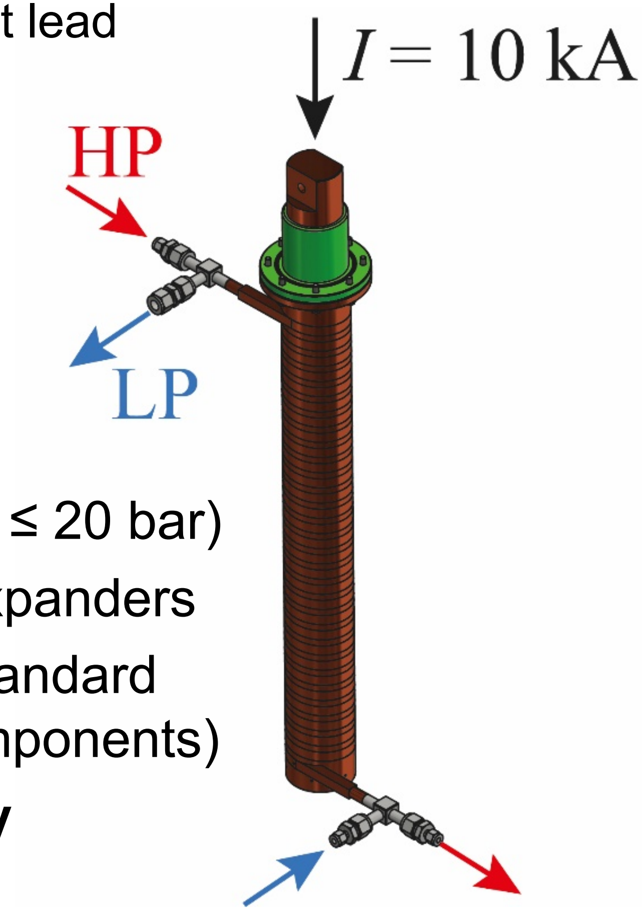
	Open cycle	Closed cycle	
	Evaporation of LN_2	1 Stage Cryocooler	Multistage
Principle	Gas-cooled (forced flow / self-sufficient)	Conduction cooled	Conduction cooled
Cooling power	Any @ 80K	Max~ 600 W @80K	Limited
Ampacity	Any	42,5 W/kA ► 14 kA (1 Cryocooler)	Limited (20 kA possible **[1]**)
Operation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

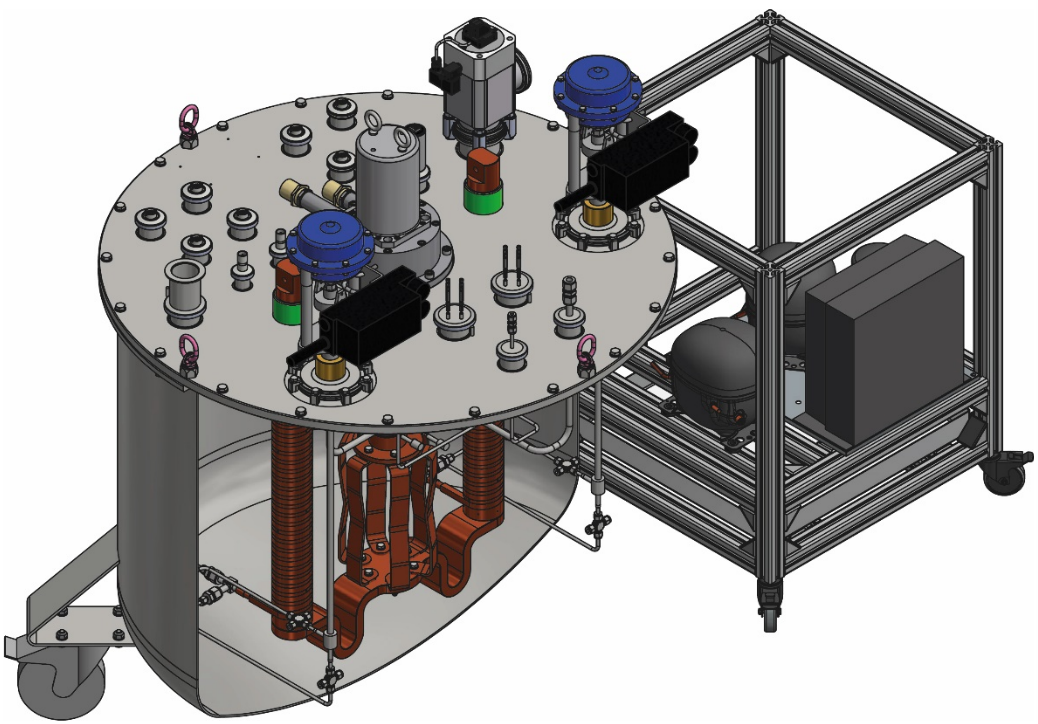


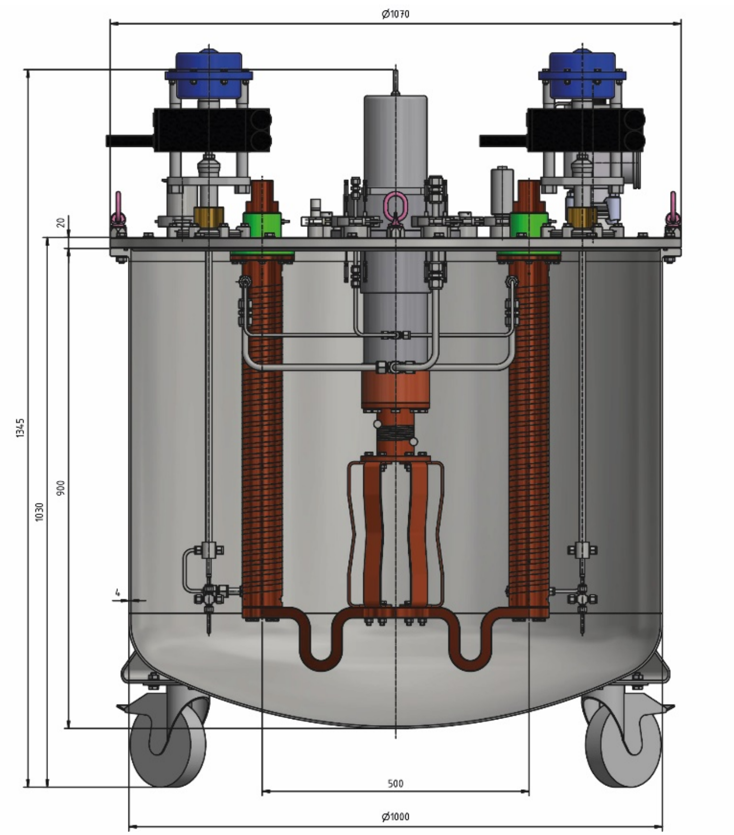


- Low pressure ($p \leq 20$ bar)
- No cold turbo-expanders
- **Inexpensive** (standard refrigeration components)
- **Good efficiency**
- **Scalable**

New Solution for HTS Power Application

- Development of a pair of **10 kA current leads** cooled with <u>one</u> cryogenic mixed refrigerant cycle (CMRC)



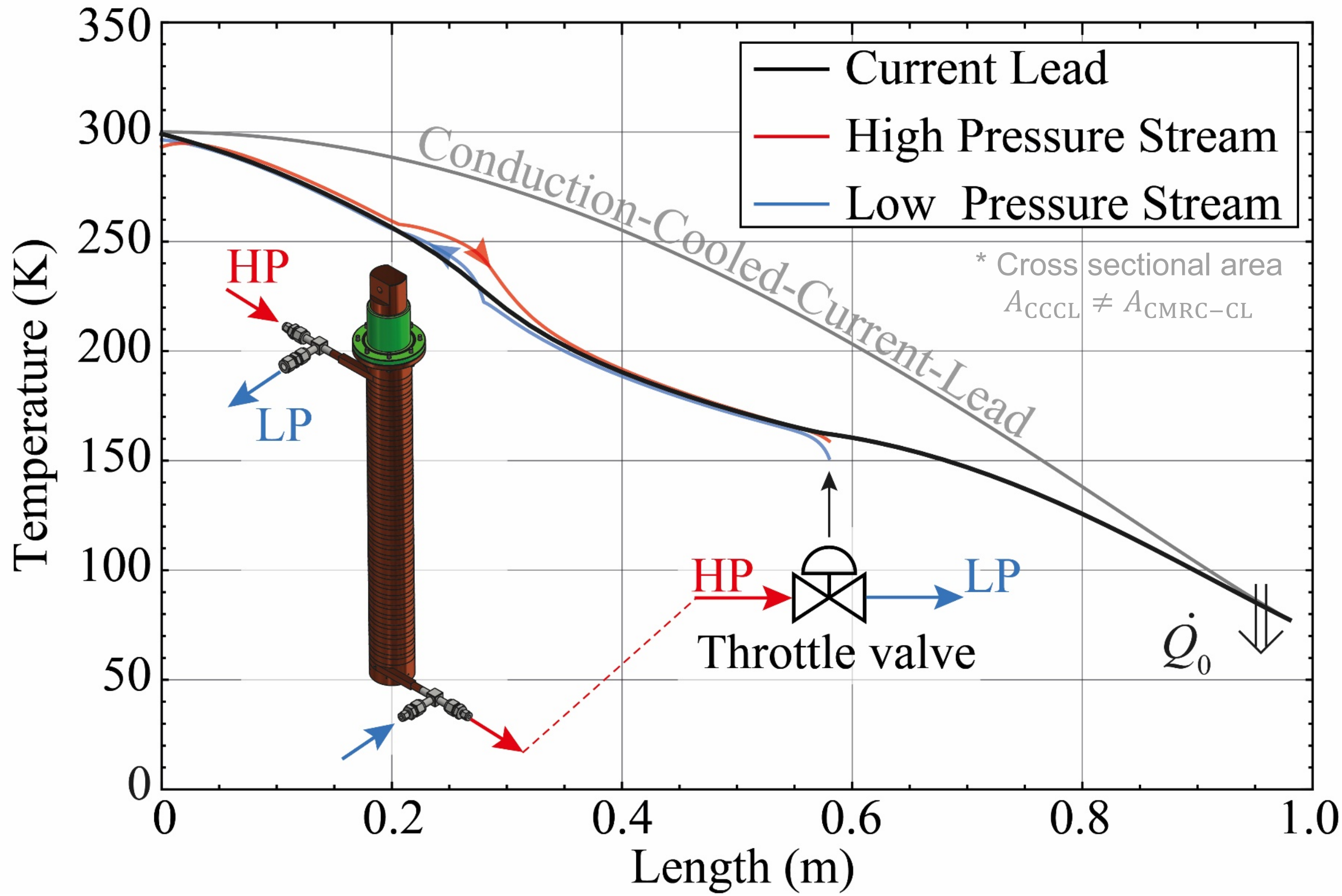


Cryogenic fluid mixtures

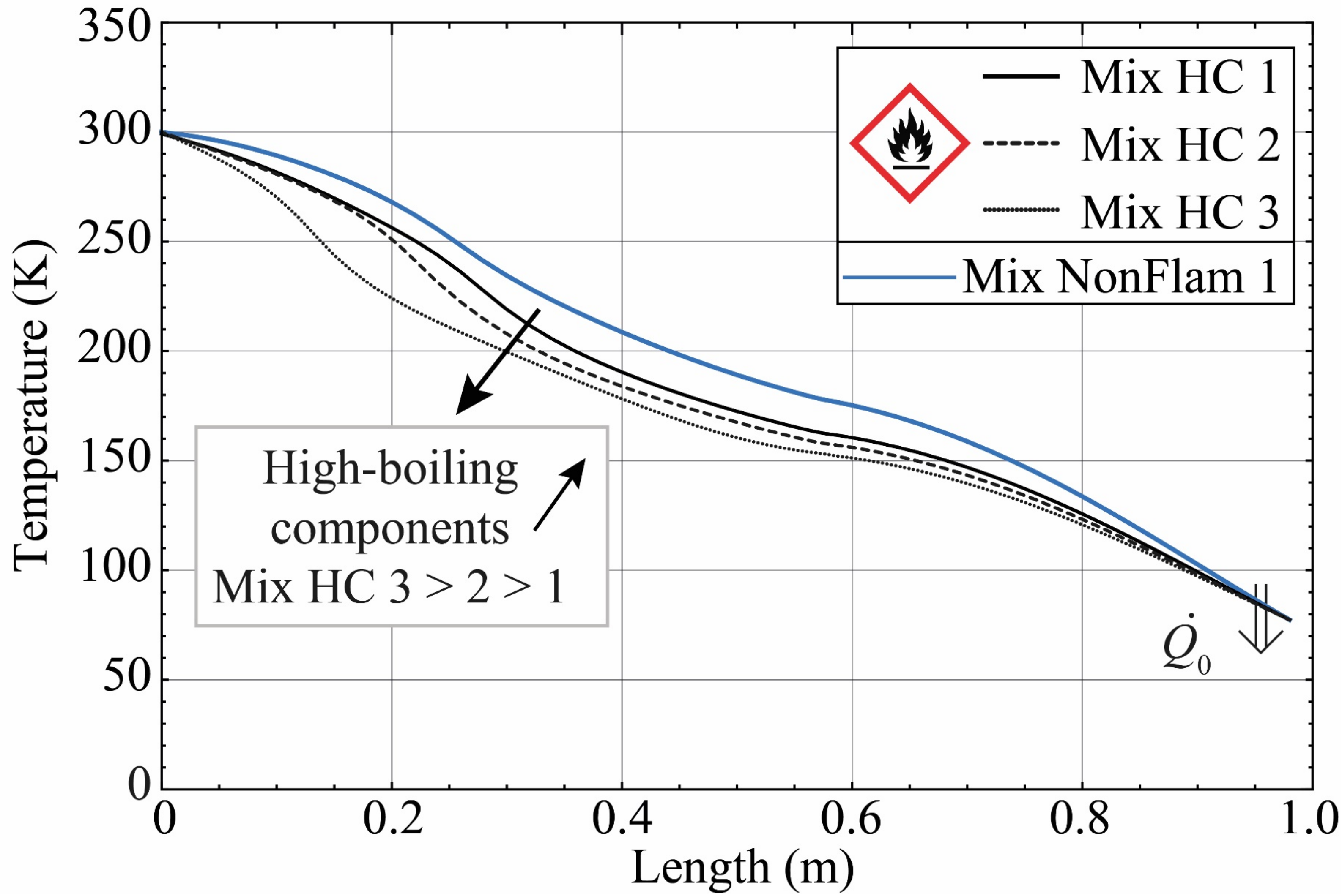
- Investigation of **flammable** and **non-flammable** mixtures as refrigerants for current leads
  - Mixtures consist of: **High-boiling** & **Low-boiling** components
    - ➢ Which mixture composition is advantageous for current lead cooling?

	Low-boiler		High-boiler	
Mixture	**N_2**	**CH_4**	**C_2H_6**	**C_3H_8**
Mix HC 1	45 %	30 %	5 %	20 %
Mix HC 2	30 %	20 %	20 %	30 %
Mix HC 3	20 %	5 %	30 %	45 %
	Ar	**CF_4**	**CHF_3**	**C_3F_8**
Mix NonFlam	35 %	15 %	15 %	35 %

Temperature Profiles



Investigation of mixture composition



Investigation of mixture composition

Karlsruhe Institute of Technology

I = 10 kA	P_{el} (W)	Q_0 @80K (W)	P_{CMRC} (W)	P_{GM} (W)	P_{total} (W)	P_{total} / P_{CCCL}
CCCL - GM	425	425	0	11500	**11925**	100 %
		57 % reduction				
Mix HC 1	562	200	873	7000	8435	70.7 %
Mix HC 2	546	192	711	7000	8257	69.2 %
Mix HC 3	518	**182**	558	7000	8076	67.7 %
			68 % reduction			
Mix NonFlam	606	229	**175**	7000	7781	**65.2 %**

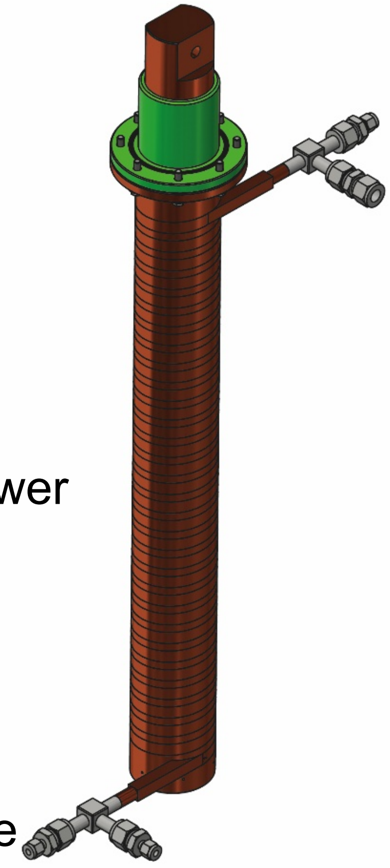
P_{CMRC} = compressor rating

- **GM 1**: 600 W @ 80 K ► **11.5 kW**
- **GM 2**: 270 W @ 80 K ► **7.0 kW**

Source: www.cryomech.com

Summary

- Development of a pair of **10 kA current leads** cooled with a cryogenic mixed refrigerant cycle (CMRC)
  - 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 57 %** compared to conventional conduction-cooled current leads
  - **Mixtures with more high-boiling** components lead to a lower total energy consumption
  - **Non-flammable mixtures** lead to a **better** performance of CMRC-CL compared to flammable mixtures
    - **Reduction** of **compressor rating** by **68 %**
  - **Aim:** Development of **efficient** and **compact** microstructure heat exchanger [3]/ current leads

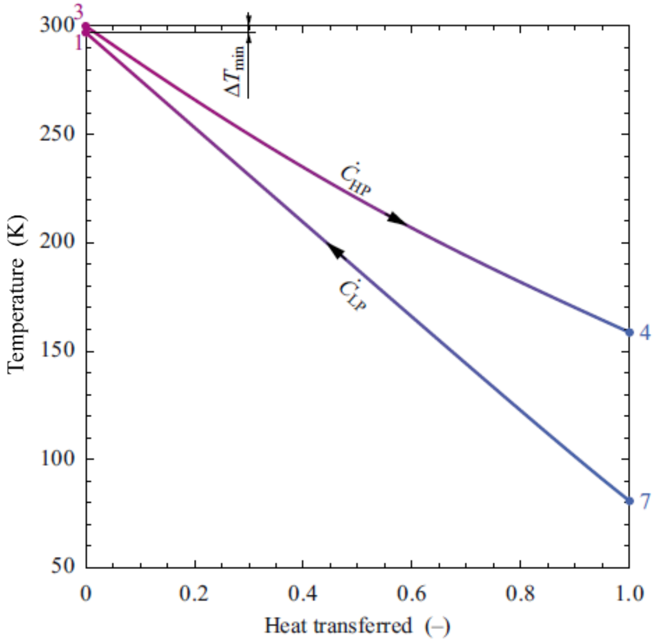


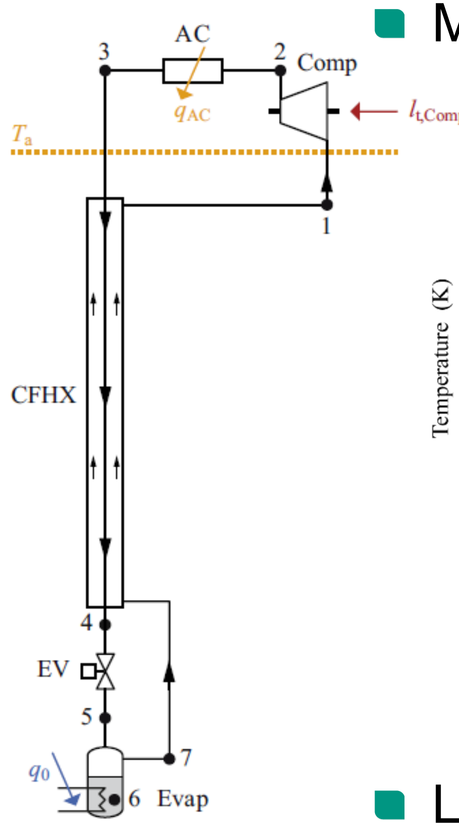
[3] D Gomse, Reiner A, Rabsch G et al. 2017 *IOP Conf. Series: Materials Science and Engineering* **278** 012061; doi:10.1088/1757-899X/278/1/012061.

Thank you for your attention !

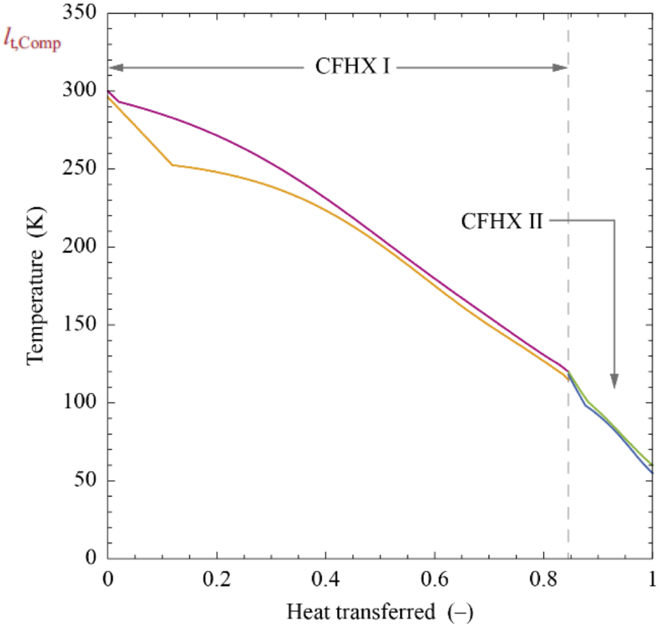
Pure- vs. mixed-refrigerant cooling

- Pure-refrigerant cooling





- Mixed-refrigerant cooling



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

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