Development of a Recondensing Cryostat for ZBO LH2 Storage in Medium-Scale Tanks

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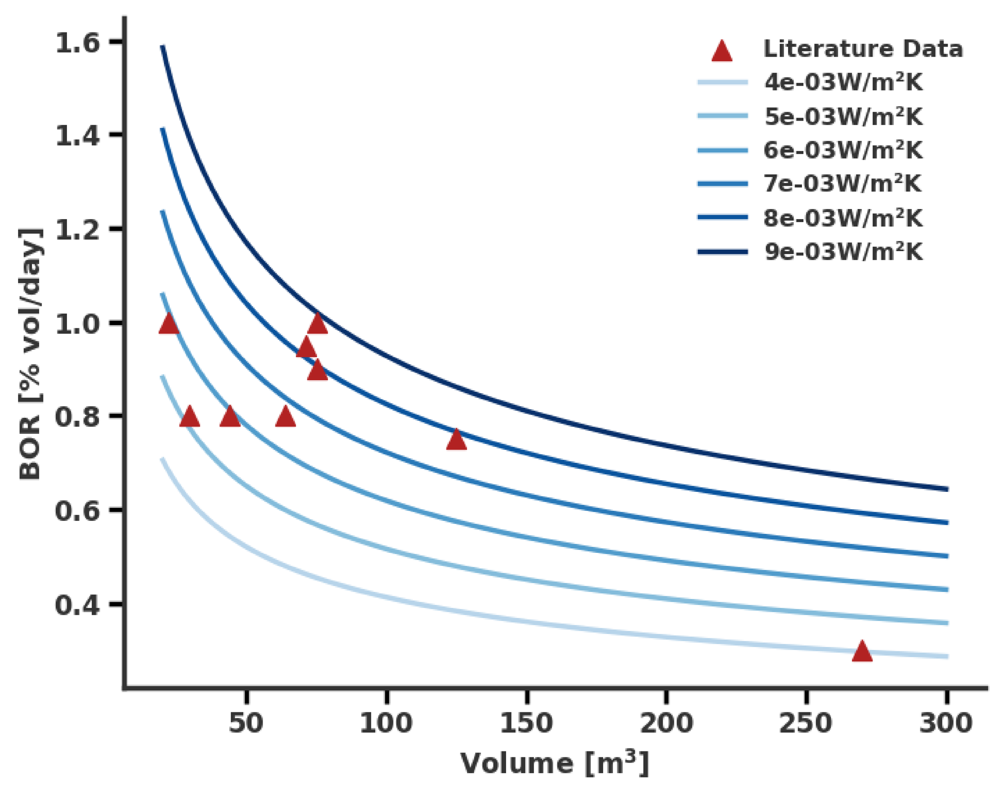
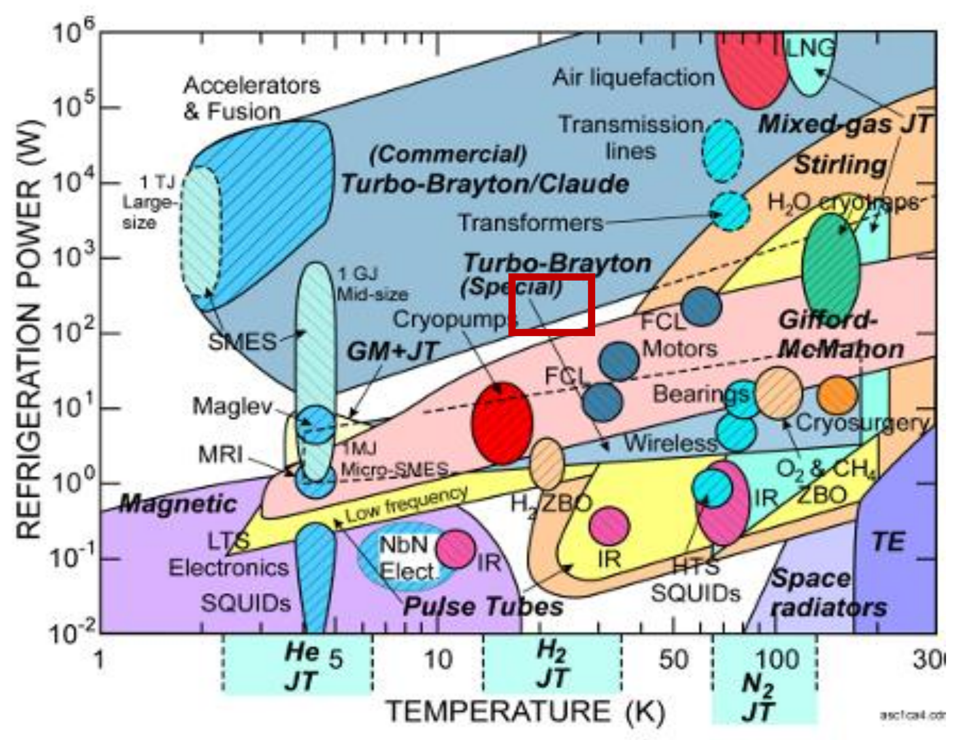
A green infrastructure: hydrogen as an energy carrier in the Netherlands

With conventional energy sources depleting and its impact on the climate increasing, the need for a sustainable energy supply and infrastructure is evident. When it comes to developing such an infrastructure, hydrogen (H_2) is gaining traction as a promising energy carrier. Especially the Netherlands, with its geography, key ports, solar- and wind power, policy and further infrastructure tailored to hydrogen, stands to become a major player [1]. Storing hydrogen in liquefied form (LH2) is attractive for various large-scale and long-term storage and transport scenarios. Amongst the various hydrogen storage methods, it offers a comparatively high energy density (~ 2.3 MWh/m^3), high purity, non-toxicity, zero emissions at point-of-use, and low storage pressure. The high boil-off rates typically characterizing LH2 tanks, however, form a major technological and economical hurdle. To address this, one of the focus points the **HyTROS** project - a consortium of 32 research and industry partners developing hydrogen infrastructure - is the development of an economic boil-off recondenser.

The need for cooling in LH_2 storage

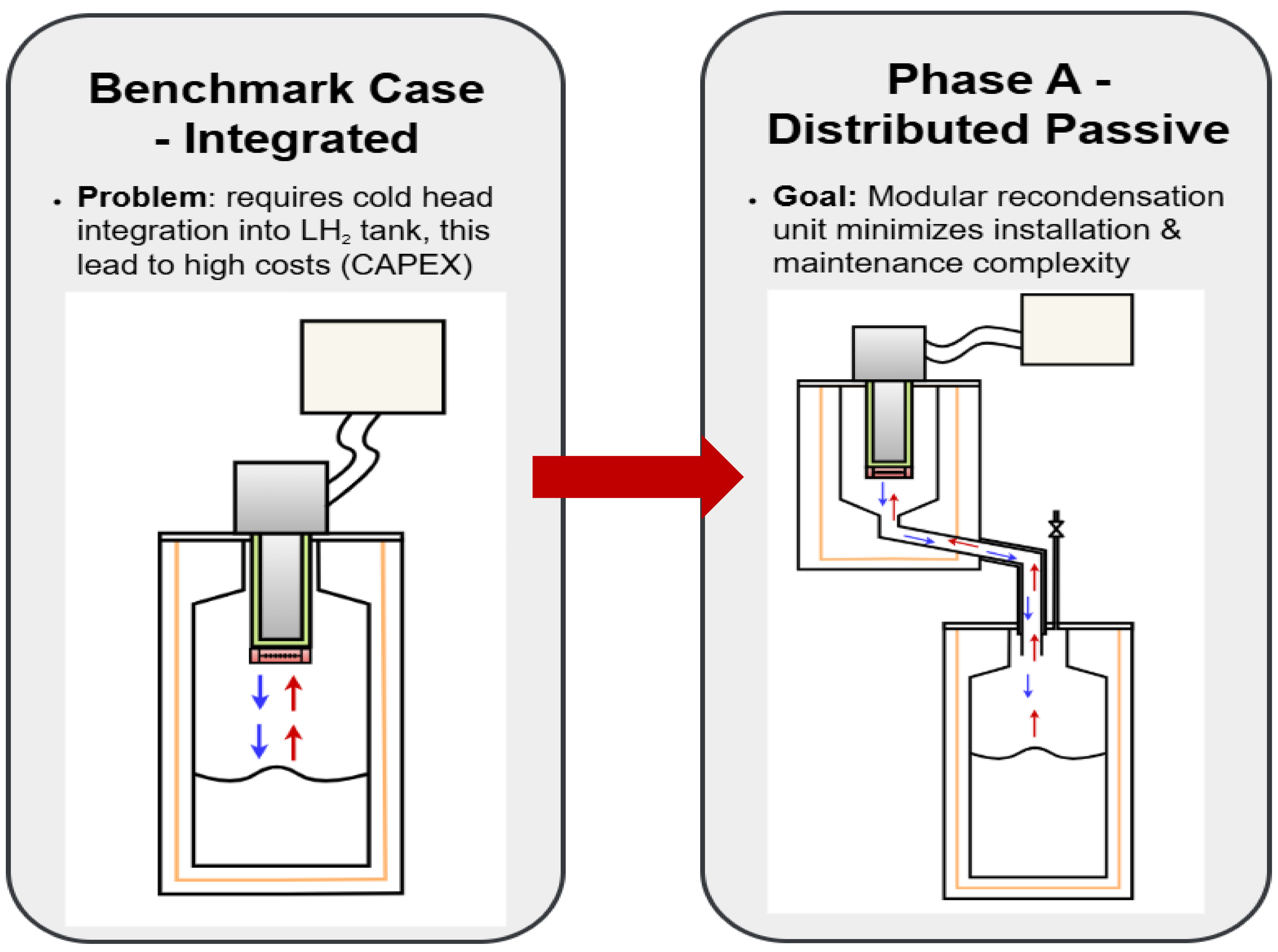
Especially down-stream in the hydrogen distribution chain, for medium sized storage units of 20-100 m^3 with state-of-the-art insulation, the BOR is substantial: **0.6-1.0 vol%/day** [2]. The heat leak into these mid-range size of LH_2 tanks is typically on the order of **~10^2 W**. For the smaller-sized vessels in this mid-range, state-of-the-art GM cryocoolers can deliver sufficient cooling capacity. For the larger tanks, new hybrid coolers with high cooling capacity need to be developed [3].





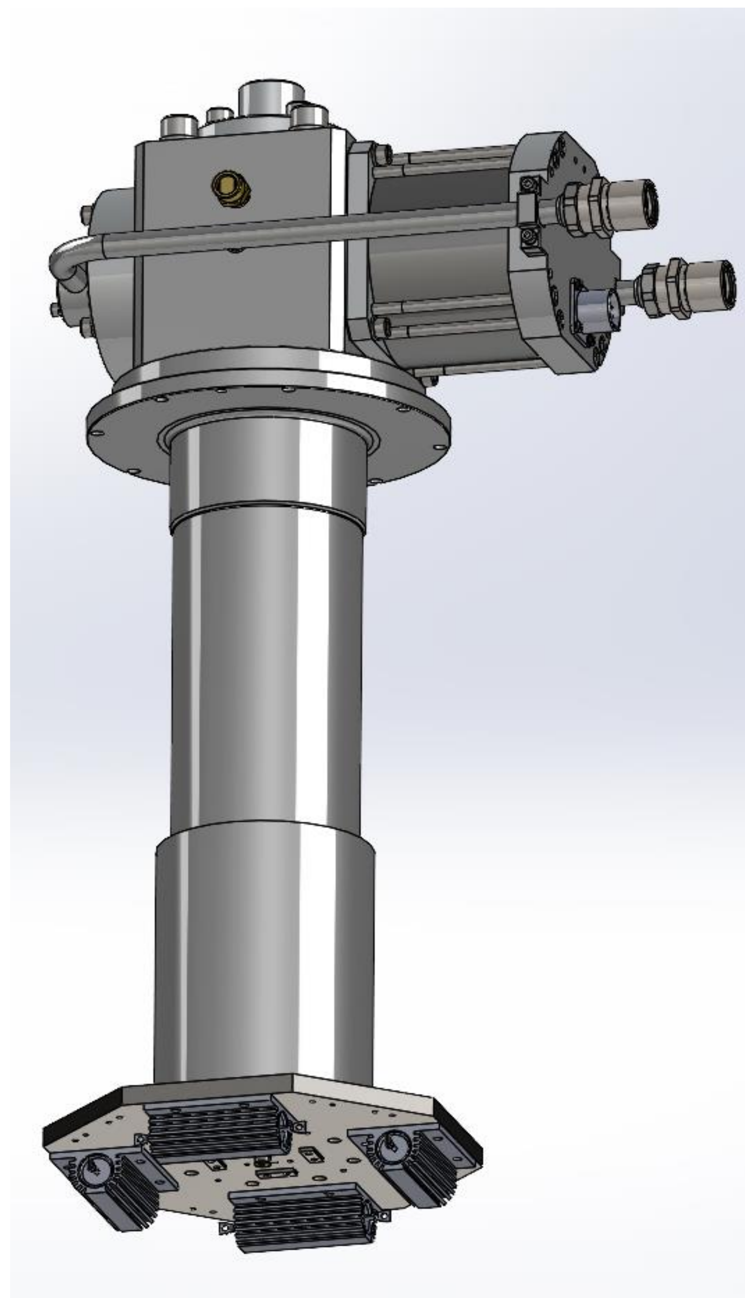
Key focus: development of ZBO demonstrator of **50 W at 20 K**

For an industry-standard stationary storage tank of 71m^3 volume (4600 kg LH_2, 5% ullage) BOH can result in losses of **~€137k** per year. A state-of-the-art cooling cycle (second law efficiency of η_C = **10%**) recondensing boil-off hydrogen, can annually save up to **~€110k** (approx. 80%) from an operating point of view (OPEX). To limit the CAPEX [4], a modular distributed recondenser is proposed:



Design of a recondensing hydrogen cryostat

The following key design activities were undertaken:

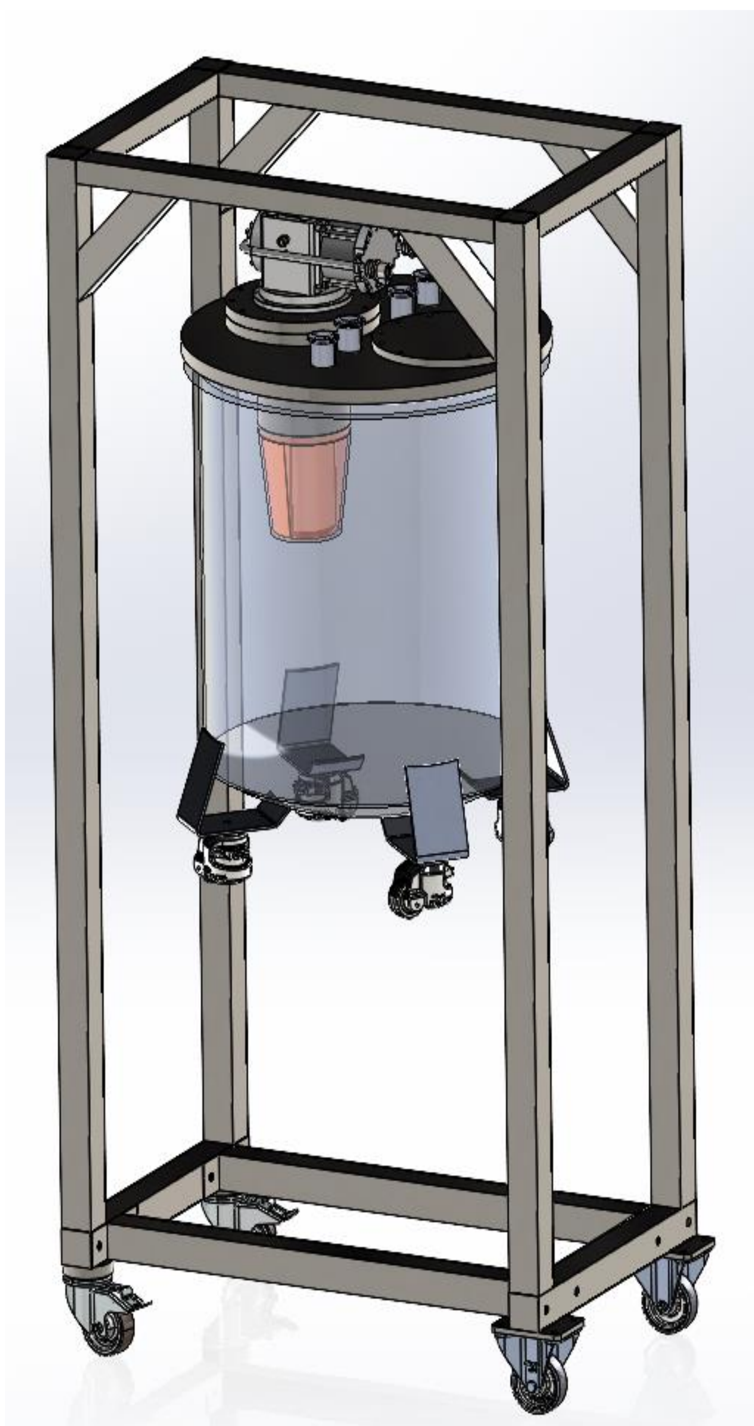


<u>Instrumentation mount</u>

- SHI RDK-500B2 GM cryocooler selected for demonstrator.
- Instrumentation mount includes 4x 12Ω resistive heaters capable of mapping **400W** of cooling power across the temp. range.
- Set-up also suitable for simultaneously calibrating 4x PT-1000 temperature sensors. → equip the cryostat with an array of temperature sensors to monitor thermal performance of system.

<u>Suspension system</u>

- Inbuilt lifting system to bring cryostat sufficiently high to accommodate gravity-driven liquid return to the dewar.
- Compatible with HPL hydrogen bunker (UT facility).



<u>Cryocooler sleeve</u>

- Cold head not compatible with hydrogen → sleeve required.
- Additional benefit of the sleeve: serviceability of cold head without losing vacuum.
- Conical fit to ensure sufficient contact force between the sleeve and the sides of the cold head.
- Spring force of bellows i.c.w. thermal grease utilized to minimize thermal contact resistance → ΔT is minimized to ~10 mK.

Upcoming developments

- Experimental campaign: capacity mapping of cryocooler with and without sleeve.
- Design of inner recondensation vessel, thermosyphon-based liquid return line and its interfacing with the outer vacuum vessel.

References

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[2] Verfondern, Karl. "Hydrogen fundamentals." Hydrogen safety for energy applications. Butterworth-Heinemann, 2022. 1-23.
[3] Radebaugh, Ray. "Review of refrigeration methods." Handbook of Superconductivity. CRC Press, 2022. 501-518
[4] Karayel, G. Kubilay, and Ibrahim Dincer. "Hydrogen storage and refueling options: A performance evaluation." Process Safety and Environmental Protection 191 (2024): 1847-1858.

Applied Thermal Sciences
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