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Towards Economic Zero Boil-Off Technology for Liquid Hydrogen Storage

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Hydrogen is increasingly recognized as a cornerstone of the transition to sustainable energy systems. Storing hydrogen in liquefied form (LH_2) is particularly advantageous due to its relatively high energy density and scalability for storage and transport. However, managing boil-off rates (BOR) during storage and transportation remains a significant challenge. Hydrogen boil-off leads to safety concerns, environmental impacts, and economic losses, highlighting the critical need for zero boil-off (ZBO) systems. Depending on the size and application, the BOR ranges from 0.05–0.2% per day for large-scale, stationary, spherical storage tanks (>500 m^3) to 0.3–1% per day for stationary cylindrical vessels (1–100 m^3), and even up to 1.5% per day for 0.1 m^3 tanks typically used in mobile applications.

Advances in passive insulation technologies, such as vacuum-insulated multi-layer insulation (MLI) and variable density MLI (VDMLI), have shown potential to reduce BOR further compared to conventional vacuum-perlite. However, passive measures alone are insufficient due to the high liquefaction energy costs (˜30% of hydrogen's energy capacity) of LH2. This underscores the need for active cooling systems to achieve ZBO in LH_2 storage and transport applications. While existing ZBO systems in aerospace demonstrate feasibility, their high energy requirements and costs limit large-scale industrial deployment.

An in-depth review of the current state of LH_2 storage technologies was conducted, focusing on BOR mitigation strategies and their limitations. A framework for the design and development of economic ZBO systems is proposed, with an emphasis on bridging the gap between laboratory-scale solutions and practical implementation. This work is part of the HyTROS program under the Dutch GroenvermogenNL initiative to advance hydrogen storage and transport technologies.

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Authors: BEENS, Harro (University of Twente); Prof. VANAPALLI, Srini (University of Twente)

Presenter: BEENS, Harro (University of Twente)

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