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C1Po1A-11: Mega-Scale Liquid Hydrogen (LH2) Storage for Energy Storage & Transportation

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Hydrogen is rapidly gaining recognition as a pivotal energy carrier capable of driving the transition to net-zero emissions by replacing conventional fossil fuels. When produced using renewable energy sources, hydrogen can achieve a completely net-zero lifecycle. Moreover, it provides an effective solution for addressing the intermittency of renewable energy by serving as a reliable storage medium. Among the various hydrogen storage technologies, liquid hydrogen (LH2) stands out as the most promising for large-scale storage and transportation. LH2 offers the highest volumetric density of hydrogen storage without requiring chemical conversion to other substances. While hydrogen liquefaction is energy-intensive, this process can be conducted in regions with abundant renewable energy. Consequently, in the hydrogen supply chain, energy-importing regions with limited renewable energy resources are relieved of the need for dehydrogenation processes. This characteristic makes liquid hydrogen particularly advantageous compared to other large-scale storage options, such as ammonia.

The primary challenge to the widespread adoption of LH2 is the current lack of infrastructure for its storage and transportation. As a cryogenic liquid, LH2 shares similarities with liquefied natural gas (LNG), suggesting that the development of LH2 infrastructure can draw valuable insights from the LNG industry. While the largest existing LH2 storage tank has a capacity of 4,732m^3, LNG storage tanks have already reached scales of 200,000m^3. This comparison highlights the future need for mega-scale LH2 storage infrastructure, leveraging lessons from the LNG market to support the mainstream adoption of LH2 as a global energy carrier.

A key challenge in developing LH2 storage tanks lies in accommodating hydrogen's extremely low boiling point of 20K in an unpressurized state. Designing storage systems to maintain such cryogenic temperatures at a mega-scale requires precise thermal and structural considerations. This study focuses on the design and analysis of a mega-scale LH2 storage tank through finite element methods, addressing these challenges comprehensively.

The typical configuration of LH2 tanks includes an inner tank and an outer tank, with a vacuum-insulated space in between. The vacuum minimizes convective heat transfer, while insulation materials placed around the inner tank reduce radiative heat transfer. Spherical tanks are preferred due to their low surface-to-volume ratio, which helps limit heat ingress. A crucial component in this system is the internal support structure, which connects the inner tank to the outer tank. This structure not only transfers mechanical loads but also plays a significant role in minimizing conductive heat transfer, which is one of the primary heat transfer mechanisms in the system. By optimizing the internal support structure and insulation system, the tank design aims to reduce boil-off rates and ensure thermal efficiency. These elements work together to address the dual challenges of maintaining cryogenic temperatures and ensuring structural integrity at a scale required for mainstream LH2 applications.

The analysis revealed that the internal support structure contributes significantly to the heat transfer into the liquid hydrogen, even at the mega-scale. This finding underscores the critical need for optimizing the internal support structure to minimize thermal conduction. Such optimization can be achieved through strategic adjustments to the geometry and material selection of the supports, as demonstrated in this study. Additionally, the incorporation of thermal intercepts was shown to effectively remove part of the heat load, further reducing overall heat transfer into the tank.

Additionally, the analysis concluded that the boil-off rate of LH2 decreases as the tank capacity increases, offering an inherent thermal efficiency advantage for larger tanks. However, the practical challenges of constructing mega-scale spherical tanks prompted a comparative evaluation of cylindrical designs. A cylindrical mega-scale storage tank was designed, and its thermal and structural performance was analysed against that

of spherical tanks, addressing both feasibility and efficiency.
This study provides valuable insights into the design of mega-scale LH2 storage tanks, highlighting key considerations for thermal management, structural integrity, and practical constructability. These findings contribute to the advancement of LH2 infrastructure, enabling its role as a scalable and sustainable energy carrier in the global energy transition.

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