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Design and Operation of Liquid Hydrogen Storage Tanks

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ELVHYS

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Clean Hydrogen Partnership

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Outline

Introduction to LH2

Storage

Insulation techniques

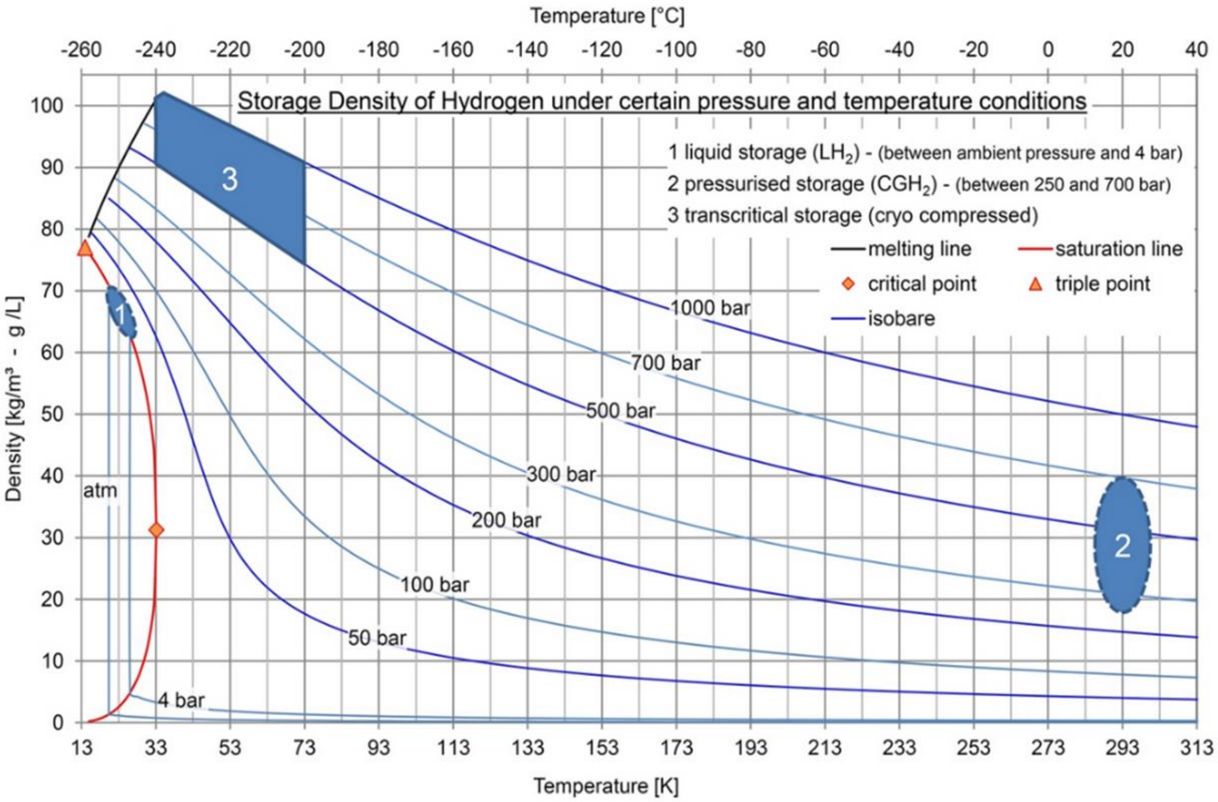
Criteria & Performance

Tank dynamic

Modelling approaches

Conclusions & Further work

Why is Liquid Hydrogen Relevant?



Source: MORITZ KUHN: Net storage density of hydrogen under certain pressure and temperature conditions

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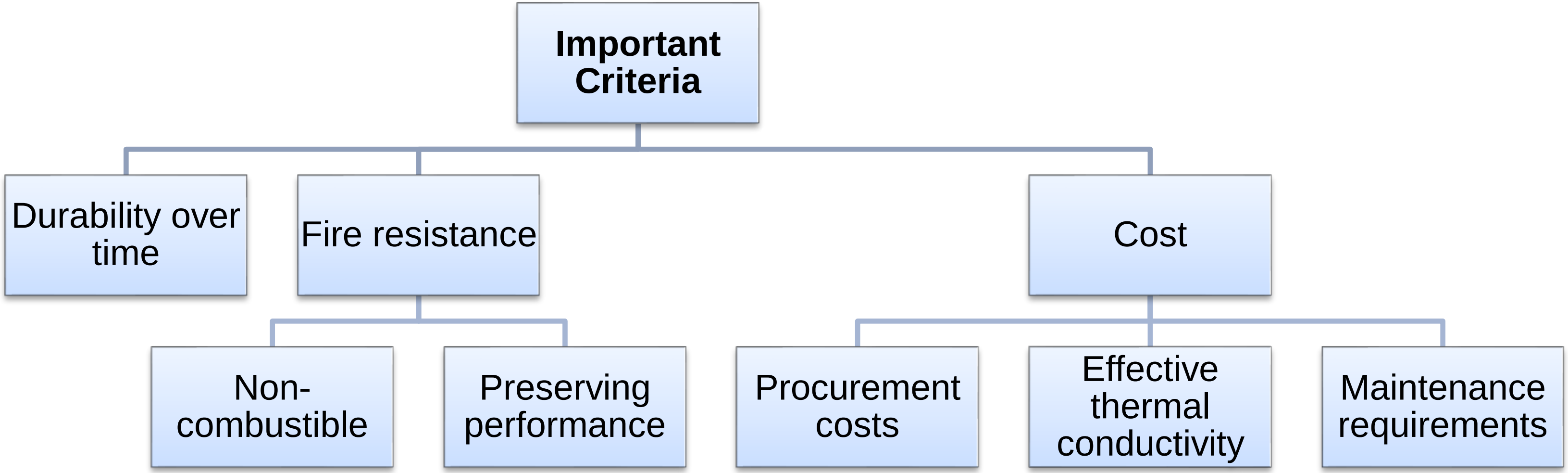
Insulation Techniques in LH2 storage tanks



Insulation Techniques in LH2 storage tanks

Multi-layer insulation (MLI)

- commonly used in mobile applications and smaller vessels
- multiple layers of thin reflective materials
- Polymer spacers
- In combination with vacuum

Perlite

- Stationary applications
- Mineral with foam-like cellular structure
- vacuumed
- Minimal environmental impact

Hollow glass microspheres (HGM)

- microscopic borosilicate spheres
- Pressure-, vibration- and heat resistant
- Ca. 3x the cost of perlite

Aerogel

- General term used by the industry
- extremely low density
- Flexible, suitable for different tank-geometries

Foams

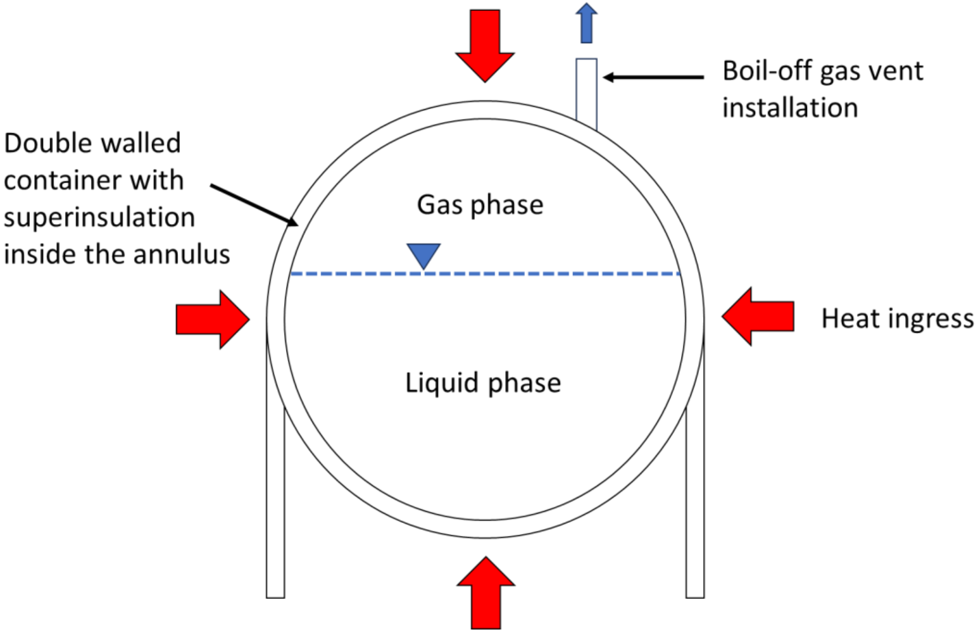
- Spray-on-foam
- Mostly used at atmospheric pressure
- Often combined with other techniques

Performance of Different Insulation Systems

Insulation material	Effective thermal conductivity (W/m*K)	Density (kg/m^3)	Melting temperature (℃)
Vacuum-multi-layer 1 (polyester)	10^{-6} to 10^{-5}	42	140-400
Vacuum -multi-layer 2 (fiberglass)	10^{-6} to 10^{-5}	-	1000-1400 (660 for Aluminium)
Glass bubbles	10^{-3} to 10^{-4}	65	1400-1600
Perlite	10^{-4} to 10^{-3}	132	1260
Aerogel Blanket	10^{-3} to 10^{-2}	133	1200

Comparison of different insulation materials (Fesmire et al., 2022; HEATERK, 2022)

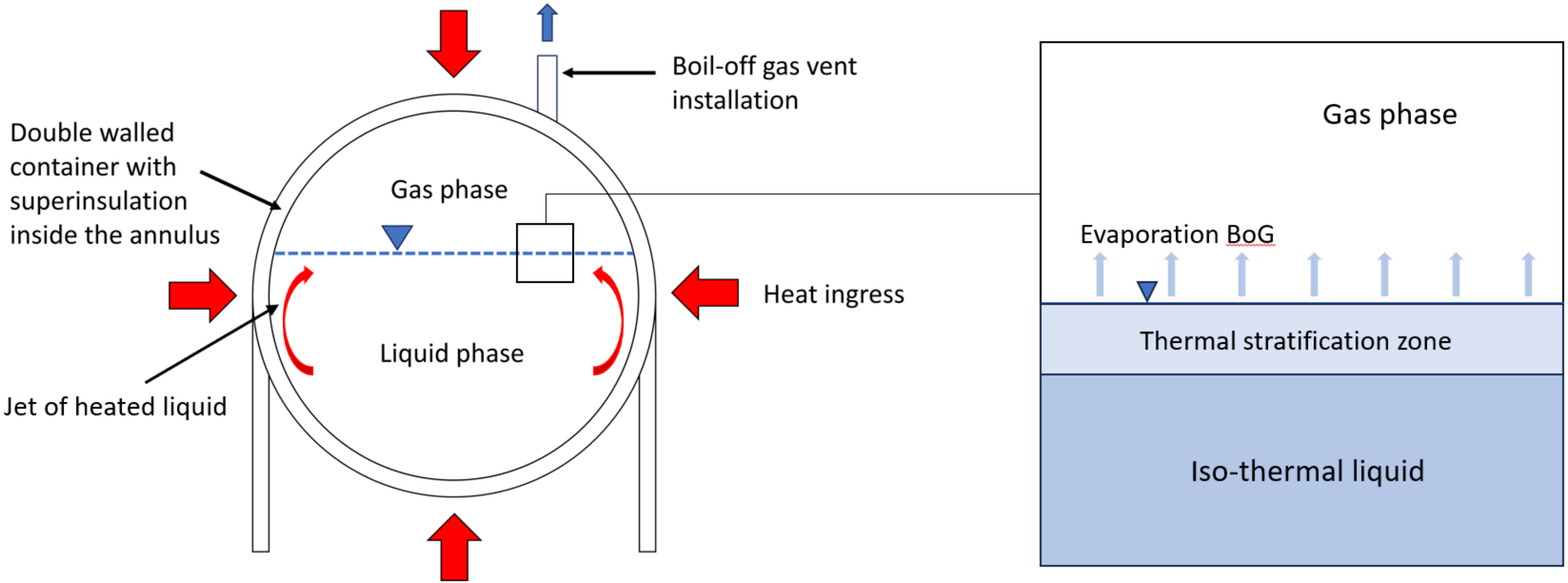
LH2 Tank Dynamic
Self-Pressurization



LH2 temp. around -252.87℃
LH2 pressure: 1 - 10 bar

- Temperature contrast
- Heat ingress into the tank
- Evaporation of liquid phase
- Formation of boil-off-gas
- Self-pressurization

LH2 Tank Dynamic
Temperature stratification



Importance of BoG Formation

Safety

- necessary to release the BOG when the pressure within the storage tank reaches a certain threshold
- Threshold defined by construction of the tank

Efficiency

- understanding the self-pressurization dynamics of the tank is vital to prevent hydrogen loss through BOG
- predictive pressure adjustment techniques can be employed to establish optimal conditions to bridge limited time periods when economical hydrogen utilization is not feasible

Transfer

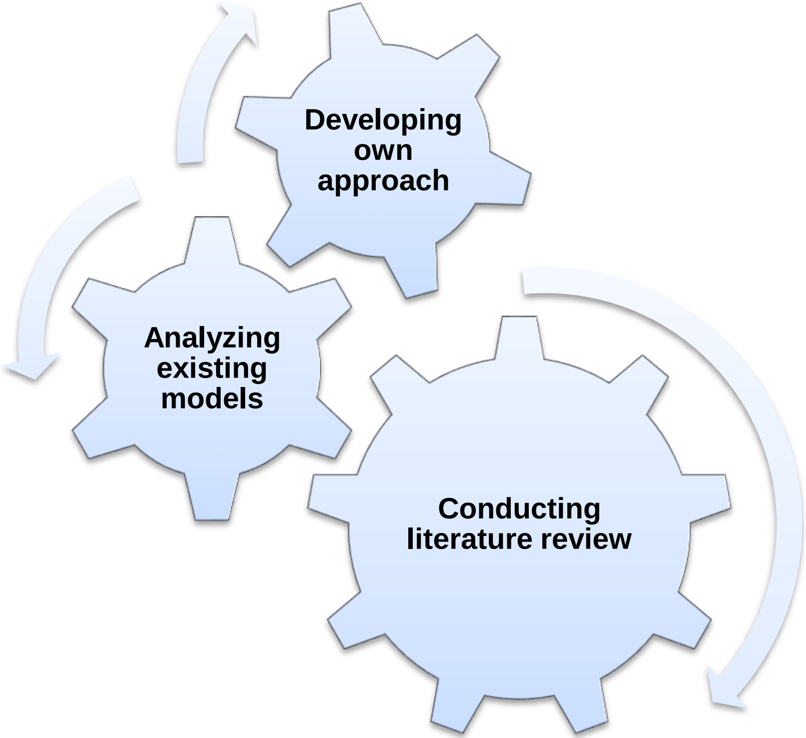
- extract hydrogen from the tank for conversion into electricity of for combustion as fuel
- Transfer hydrogen between storage installations

Modelling Approaches

Model	Model Focus	Validation	Modelling Approach
Kassemi et al. (2014)	Self-pressurization of large volume LH_2 storage tank	Experimental testing with a multipurpose hydrogen test bed (MHTB)	CFD model utilizing kinetics-based Schrage equation
Stewart et al. (2016)	Self-pressurization	Comparison with experimental data for pressure evolution and temperature	CFD simulation in ANSYS Fluent
Agrawal et al. (2017)	Thermal stratification	Experimental data from literature	-
Joseph et al. (2017)	Thermal stratification	-	Transient two-phase thermodynamic lumped model
Ustolin et al. (2021)	Thermal behavior of LH_2 tank when exposed to fire	Experimental validation	Lumped-element model
Ustolin et al. (2022b)	Thermal behavior of LH_2 tank when exposed to fire	Small scale fire test on LH_2 tank	Two-dimensional CFD analysis
Matveev and Leachman (2023)	Pressurization- and venting rates	-	Lump-element model

Conclusions and Recent Developments

- LH2 storage is demanding due to its properties
- The efficient operation of LH_2 tanks is tied to adequate insulation techniques and to self-pressurization
- Modelling techniques in understanding and predicting these processes play a key role
- Various models, analytical and numerical are already developed for a wide range of cryogenic applications
- However, there is no approach for LH2 pressurization adaptable to a range of tank types



Thank you for your attention

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