Workshop on liquid hydrogen safety
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Liquid Hydrogen Bunker Vessel

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Contents:

LH2 Bunker Vessel
Background

- Steadily more stringent air emission requirements for ships
  - IMOs global ambition of reducing the environmental footprint from global shipping
    - 40% CO_2 reduction by 2030
    - 70% CO_2 reduction by 2050
  - National/local requirements to «emissions free» shipping in harbours and special areas (e.g. Norwegian fjords on UNESCO's world heritage list)
- Developments in FC technology and production making FC an increasingly viable alternative to conventional combustion engines on ships (especially on ferries, cruise ships, etc.)
- «Missing link» - Infra structure for supply of hydrogen!
- JDP «Ship transport solution for liquefied hydrogen (LH2 Bunke Vessel) launched 2017/2018 (Equinor, Wilhelmsen, DNV GL & Moss Maritime)
- Sponsored by Innovasjon Norge

LH2 Bunker Vessel
Objectives

- Review status and challenges with respect to design and operation
  - Applicable regulations & standards
  - Special hazards related to storage and handling of LH2 compared to LNG
  - Technology status and market availability of required equipment for storage and handling of LH2
- Develop a conceptual design for an LH2 Bunker Vessel capable of loading, transporting and discharging liquefied hydrogen to merchant ships and receiving terminals

The focus for the JDP has been on the design of the cargo containment system (storage and handling) and not on the ship as such

LH2 Bunker Vessel
Main particulars

- Length overall: Abt. 137.0 m
- Breadth mld: Abt. 19.8 m
- Cargo (LH2): 500 tonnes
- LH2 loading: 600 m^3/h
- LH2 unloading: 300 m3/h
- Cruising range: 20 000 nm
- Speed: 15 knots
- Power system: TBD 1)
- Accommodation TBD 1)

Notes:

(1) Depends on specification, operation pattern, etc.

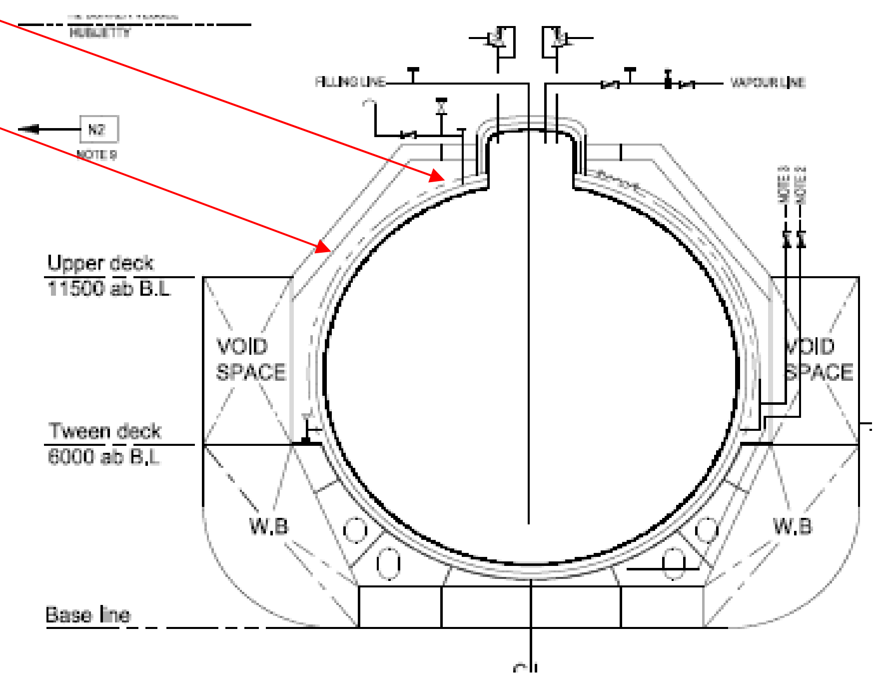
LH2 Bunker Vessel
Design philosophy for the cargo containment system

- Philosophy
  - Minimize loss of hydrogen during storage and transfer in order to ensure LH2 as a cost efficient fuel
  - Vapour pressure after 25 day voyage < Operating pressure of the receiving tank
- Remedies
  - Use of high performance insulation ensuring low heat ingress
  - Use of in-tank pumps for transfer of LH2
- Why?
  - Enables pressure accumulation in tanks instead of removal of boil-off gas
  - Loading without need for cooling of tanks after ballast voyage
  - Reduces flashing during transfer due to favourable delta-p between bunker vessel and receiving vessel
  - Enables vapour return by free-flow (avoiding blowers), if possible
  - In-tanks pumps add less energy than unloading by tank pressurization by vaporization

LH2 Bunker Vessel
Cargo containment system

2 x IMO Type C cargo tanks

- Double wall stainless steel cylindrical tank with MLI installed inside vacuum space
- Supplementary insulation (PUR, 300 mm) on the outer surface of the outer tank provided for redundancy (i.e. avoid abrupt evaporation of cargo in case of loss of vacuum)
- Vacuum insulated dome provided at top of each tank for arrangement of pipe connections, fittings and access into the tanks



Main particulars:

- Gross volume: 2 x 4500 m^3
- Design pressure: 5 barg
- Boil off rate: Low

Main features:

- Well proven technology
- Heat ingress to cargo tanks handled by tank pressure accumulation
- Protected by weather cover
- Space between weather cover and tanks filled with N2 and kept slightly higher than atmospheric pressure

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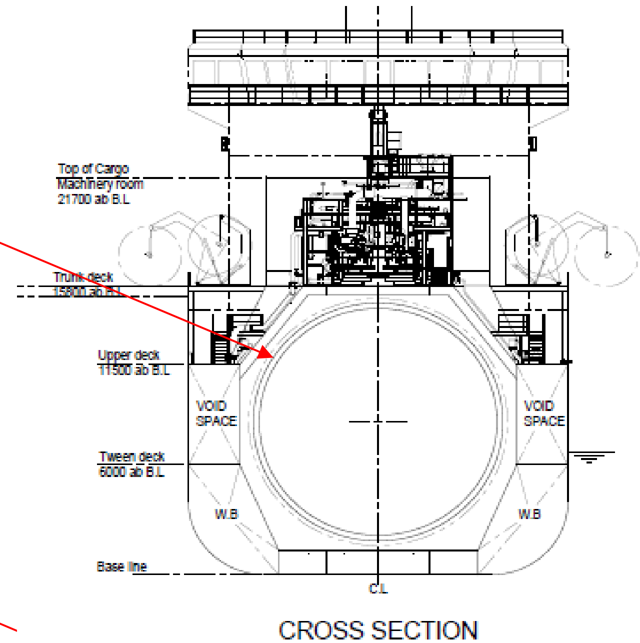
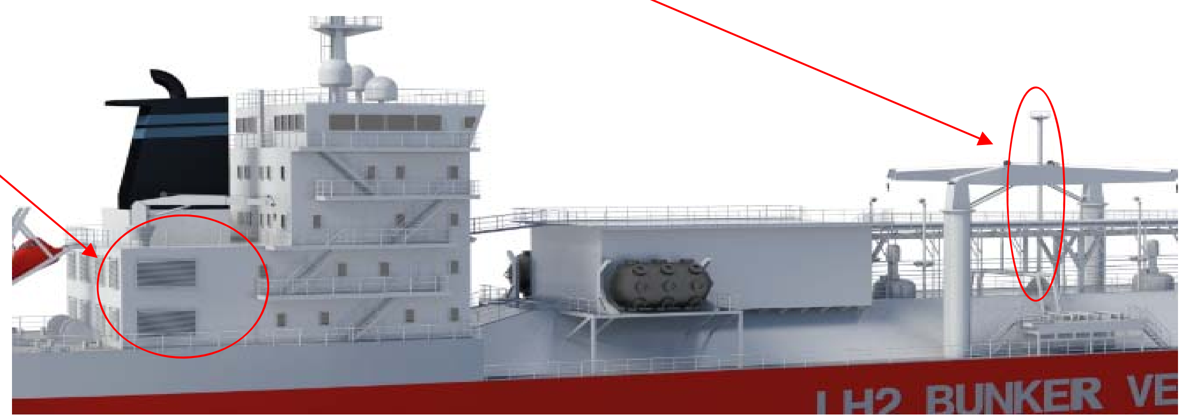
LH2 Bunker Vessel
Safety

- Safe cargo containment system
  - IMO Type C tanks (double wall)
  - Safe distance from shipside and bottom
  - Designed for pressure accumulation during laden voyage
- Common vent mast for emergency disposal of H2
  - Molecular seal/Buoyancy seal
  - Continuous helium purge
  - Gas snuffing system
- Gas combustion Unit (GCU)
  - Redundancy (Vapour/BOG handling)
  - Special cargo operations
  - Safe disposal of contamimated H2 (N2/H2 mixes from purging)





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LH2 Bunker Vessel
LH2 transfer system

- BV equipped with transfer system for bunkering to receiving ships and onshore receiving terminals
  - Vacuum insulated flexible pipes,or
  - Vacuum insulated loading arms (hard arms)
- Transfer system equipped with emergency stop and disconnection system designed for safe isolation and disconnection in case of an emergency (similar to those used on LNG ships)
  - QCDC (Quick Connect/Disconnect Couplings)
  - ERC (Emergecy Release Couplings)
    - Double shut-off valves with powered emergency release coupling(PERC)
    - Manual or automatic emergency release
- Offloading to receiving ship in side-by-side mode or at jetty if delivering to onshore receiving terminals

LH2 Bunker Vessel
Loading and unloading

- Loading
  - BV arrives jetty at loading terminal with cargo tanks in cold condition
  - Inerting and cooldown of liquid loading lines
  - Excess H_2 vapour (displacement and flash gas) returned to shore terminal for reliquefaction
  - Drainage and inerting of liquied loading lines
- Unloading (bunkering)
  - BV arrives receiving vessel and moors side-by-side (both sides)
  - Inerting and cooldown of liquid lines prior to unloading
    - LN_2 and/or LH_2
    - Vacuum pumps used to remove N_2 from piping system prior to loading to avoid frozen nitogen
  - Transfer with use of submerged cargo pumps
    - Two (2) pumps in each tank
    - Pressure discharge as redundancy
  - Excess vapour from receiving vessel returned to BV cargo tank
  - Drainage and inerting of liquied loading lines

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Technology evaluation

- No show-stoppers identified
  - Vendors of critical equipment have confirmed that their existing equipment for LNG may be modified/adapted to LH2
- Modification/adaption of existing equipment for LNG to LH2 will require further engineering and testing (qualification)
- Required qualification of equipment will first take place when it has been established a more definite LH2 market

LH2 Bunker Vessel
The way ahead

- Develop detail design of the cargo tanks to achieve the target BOR
- Clarify interfaces with LH2 production terminal (s)
- Clarify interfaces with receiving ships and/or onshore terminals
- Qualify for LH2 service equipment currently being used for LNG
  - Ship-To-ship (STS) transfer systems
  - Submerged offloading pumps
  - Heaters
  - Vaporizers
  - GCU
  - Etc.
- Conduct detailed analysis concerning safety of vented hydrogen gas (particularly when moored alongside receiving vessels)

LH2 Bunker Vessel
Conclusion

The feasibility of a LH2 bunker vessel has been proven!

Moss Maritime is ready to support the maritime industry in taking this LH2 bunker vessel design to the next level and/or developing solutions for more large scale transport of liquefied hydrogen in future projects.