A new hydrogen system development for large scale liquid hydrogen shipping

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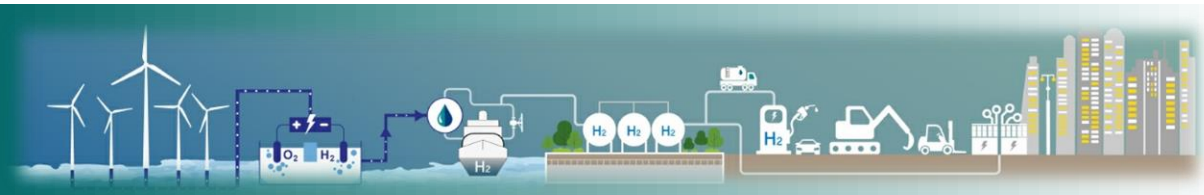
KSOE KOREA SHIPBUILDING & OFFSHORE ENGINEERING



Challenges on Realizing Liquid Hydrogen Shipping

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Large amount hydrogen loss during voyage ?

"10% of hydrogen lost during marine transport"

"Hydrogen carrier is technically impossible because there in no re-liquefaction system today"

"High Insulation tank similar to exiting hydrogen tanks on land is required for LH2 carrier"

Tank scale-up for large hydrogen transport ?

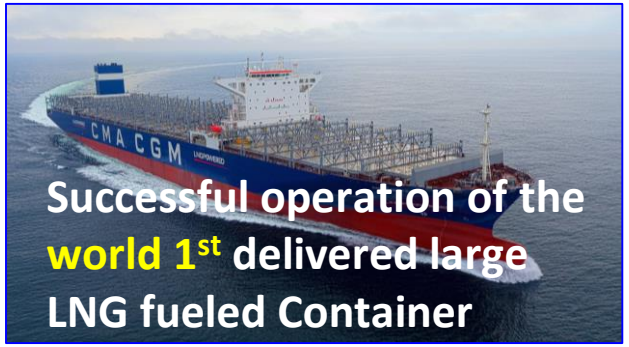
"Large storage tank is technically impossible"

"Liquid hydrogen cannot be commercialized because large transport and storage is impossible"

"Large hydrogen carrier could be commercialized in 2040s or 2050s ….not in 2030s"

HD Korea Shipbuilding & Offshore Engineering

- **HD Hyundai**, the Global TOP shipbuilding company
- HD Korea Shipbuilding & Offshore Engineering (HD KSOE),
  Sub-holding company for shipbuilding division and R&D control tower of the group



- Accumulated experiences of LNG Carrier
- Most reliable shipbuilding company realizing world first ships
- Technology company with its engine, tank, gas system, and control system

Hydrogen Solution Development from the ship technology leader's view

Why is “Fit for Purpose Design” important?

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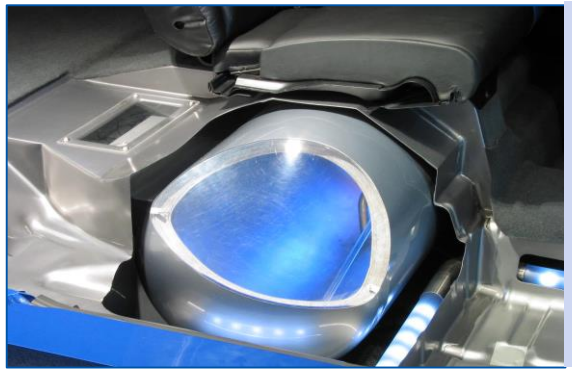
- Hydrogen system, especially hydrogen storage tank, MUST be designed fit for the purpose of its application
- NO hydrogen tanks designed for LH2 carrier application

  ➔ Liquid hydrogen system and Liquid hydrogen tanks MUST be developed by a shipbuilding company



Mobility

- Safety

→ High pressure

Aviation

- Light weight

→ Light Insulation

Fuel tank for Rocket Launcher

- Long storage
  - Hydrogen supply only when rocket launcher needs
  - To store for long time because of long-time filling and unpredictable schedule

→ **Low BOR**

The Purpose of Ships and Terminals

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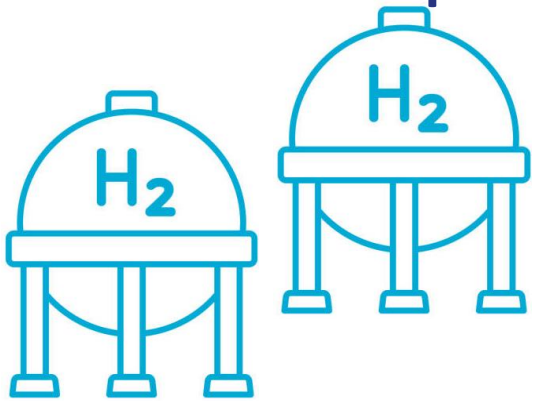
The Ship is moving for transport, so…

- ✓ Short Storage time, 10~30 days
- ✓ Continuous fuel consumption
- ✓ Interfaced with Terminals

The Terminal tank is a buffer tank

- ✓ Short filling interval, 10~30 days
- ✓ Continuous send-out
- ✓ Interfaced with Ships



HD Hydrogen System

- The integrated system, including CCS / Insulation / Propulsion / CHS,
  for the most **Affordable** and **Reliable** LH2 Carrier Solution to be commercialized in **2030**

Hull Design

1 **Optimized Design for LH2 Cargo**

* OPEX minimizing

Propulsion

2 **Hydrogen DF Engine**

* Proven and cost effective propulsion

Insulation

3 **Powder Insulation in Soft Vacuum**

* Easy & fast manufacture with proven material

CCS

4 **Double Wall Vacuum Tank**

* Proven technology

CHS

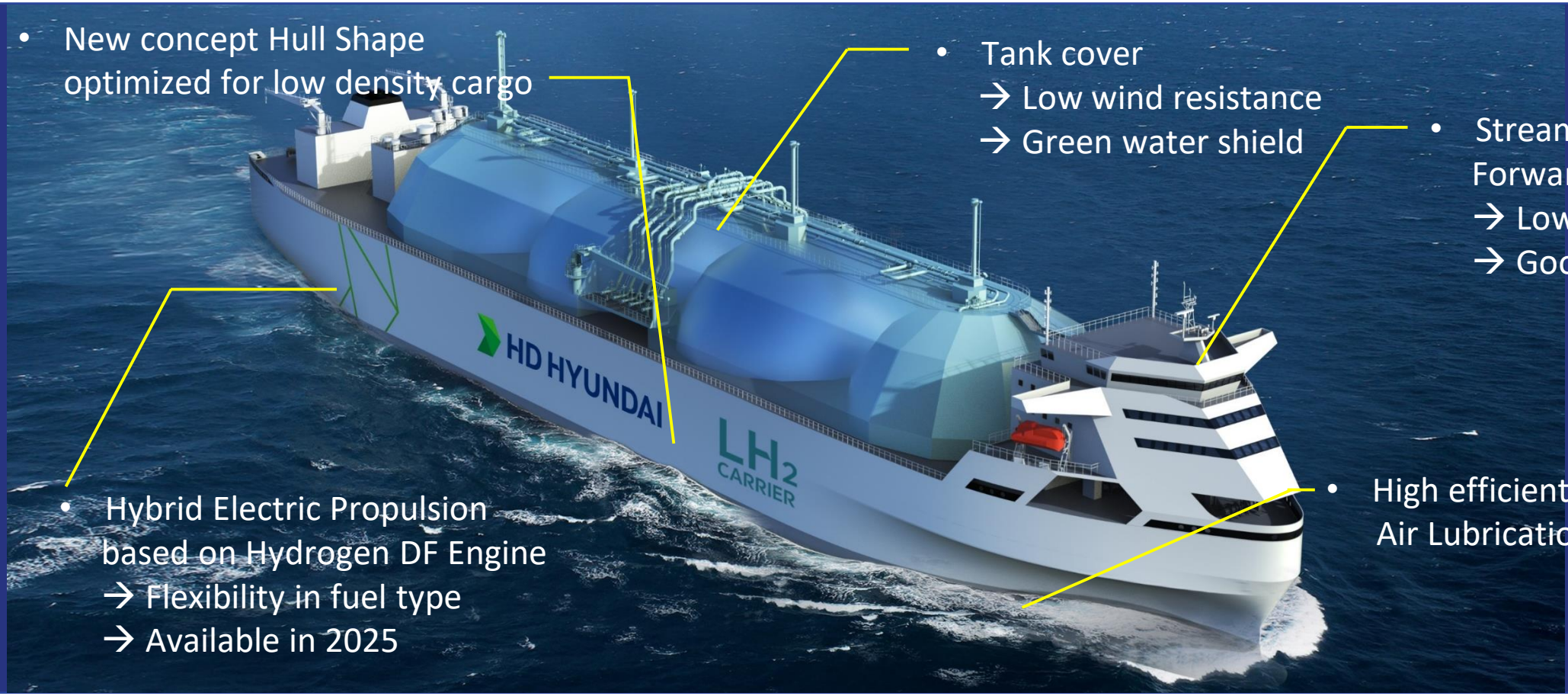
5 **Compact Cargo Handling System**

* Risk minimizing without complex new system

1 Hull: New Design of High Efficient Large LH2 Carrier

- New hull shape with low resistance and high efficiency, optimized for low density hydrogen cargo

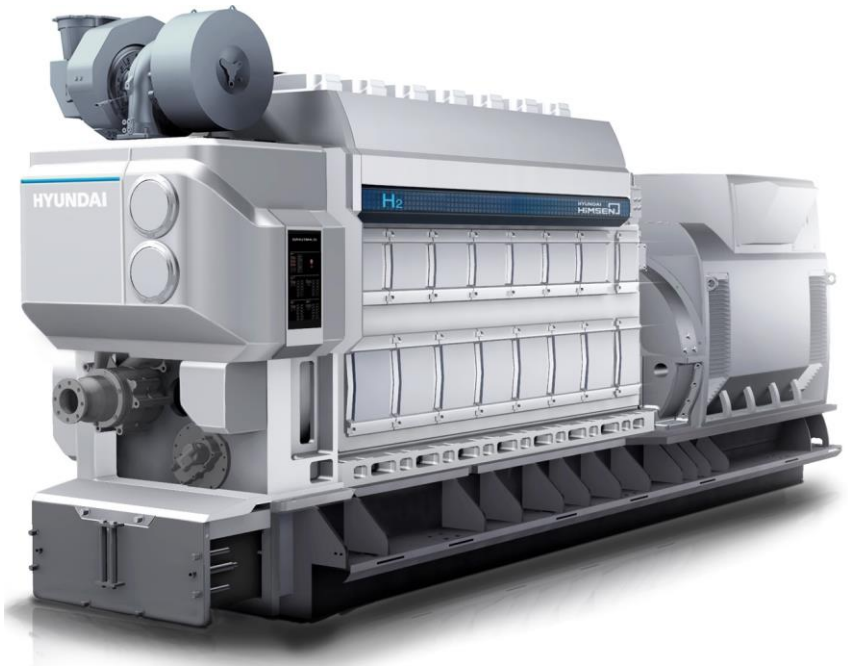
↳ **OPEX saving by lower fuel consumption and shorter voyage time**



- New concept Hull Shape optimized for low density cargo
- Tank cover
  → Low wind resistance
  → Green water shield
- Streamlined Forward Accommodation
  → Low wind resistance
  → Good visibility
- Hybrid Electric Propulsion based on Hydrogen DF Engine
  → Flexibility in fuel type
  → Available in 2025
- High efficient Air Lubrication system (Hi-ALS)

2 Propulsion

- Hybrid electric propulsion system with hydrogen DF engine & fuel cell,
- **HiMSEN Hydrogen DF engine** utilizing Hydrogen & Diesel fuel, minimizing CAPEX and OPEX
  - Hydrogen DF engine with hydrogen mixing ratio higher than **50%** to be **commercialized in 2025**
  - Hydrogen Engine for land applications to be commercialized in 2025



[Hyundai HiMSEN Hydrogen DF Engine]

Affordability
- Lower CAPEX than fuel cell or gas turbine
- OPEX, fuel cost saving by utilizing diesel together

Flexibility
- Easy control of hydrogen mixing ratio considering hydrogen cost and CO2 emission requirement

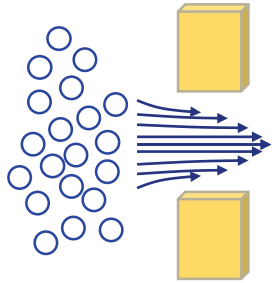
Reliability
- Proven technology in LNG DF engine
- To be commercialized in 2025
  : HD Hyundai Heavy Industries' HiMSEN engine

3 Insulation

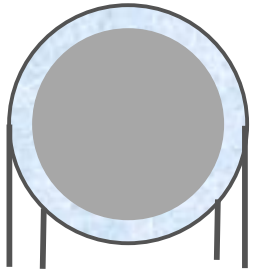
- **Glass Bubbles in SOFT vacuum,**
  - providing proper insulation performance, which results that **all BOG can be consumed at all speed**
  - enabling **short vacuuming time**
- Onboard vacuum pumps for maintaining vacuuming level

HD Hydrogen System

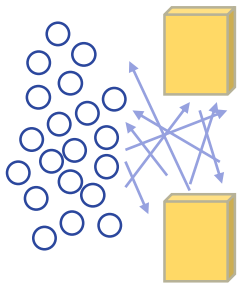
Soft Vacuum ⇨ Non-Molecular Flow regime : Short Vacuuming Time

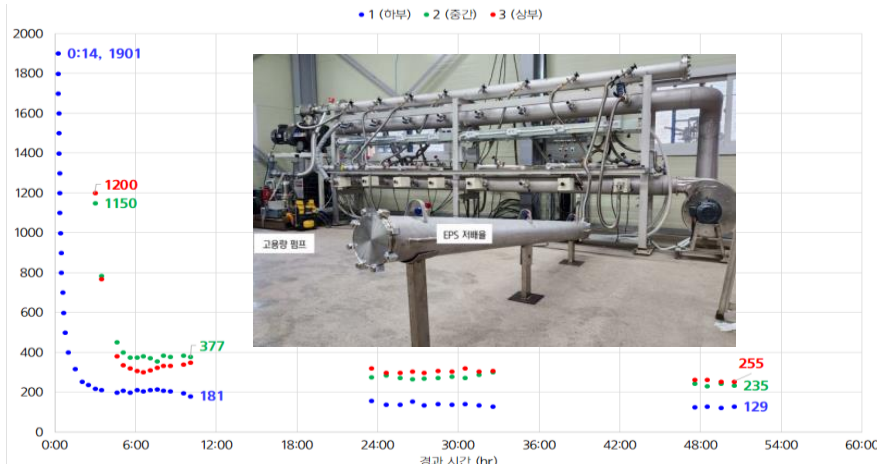


Existing Land Tank



High Vacuum ⇨ Molecular Flow Regime : Long Vacuuming Time



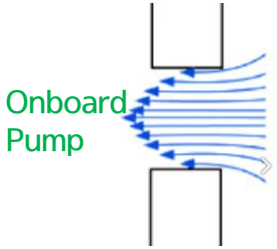


Lab scale test clearly shows that soft vacuum can be achieved in dramatically short time compared to high vacuum insulation in existing land tanks

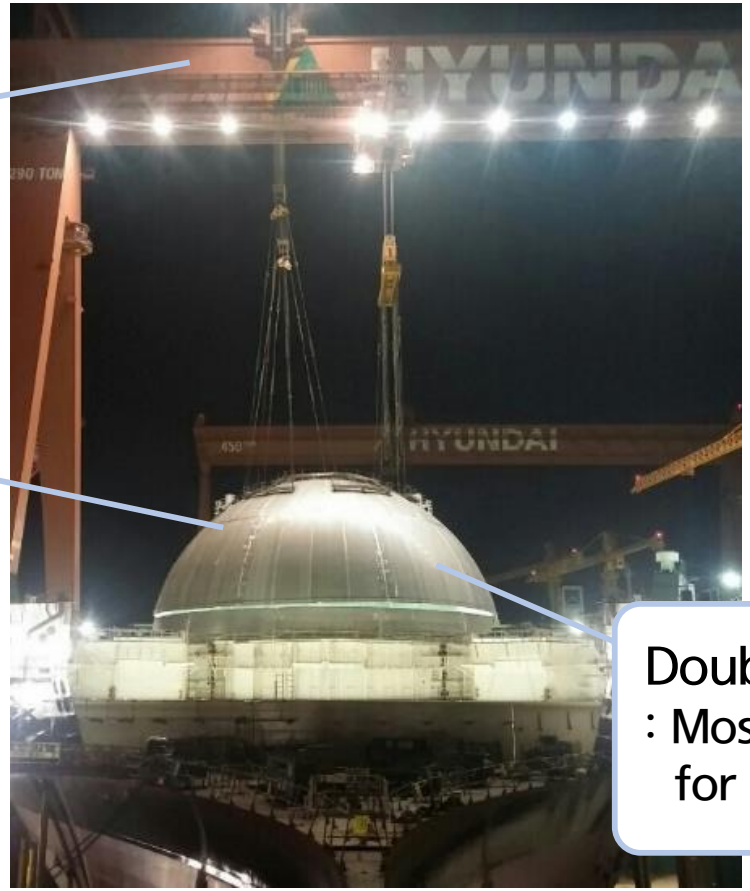
- The most proven system providing affordable and reliable **Solution for tank scale-up**
- Large size insulation filling & vacuuming test to be conducted (’24)

HD KSOE
: Top Shipbuilder experienced with high accuracy large steel structure
: Facilities, High-level Quality Control

Soft Vacuum
: easy to vacuum



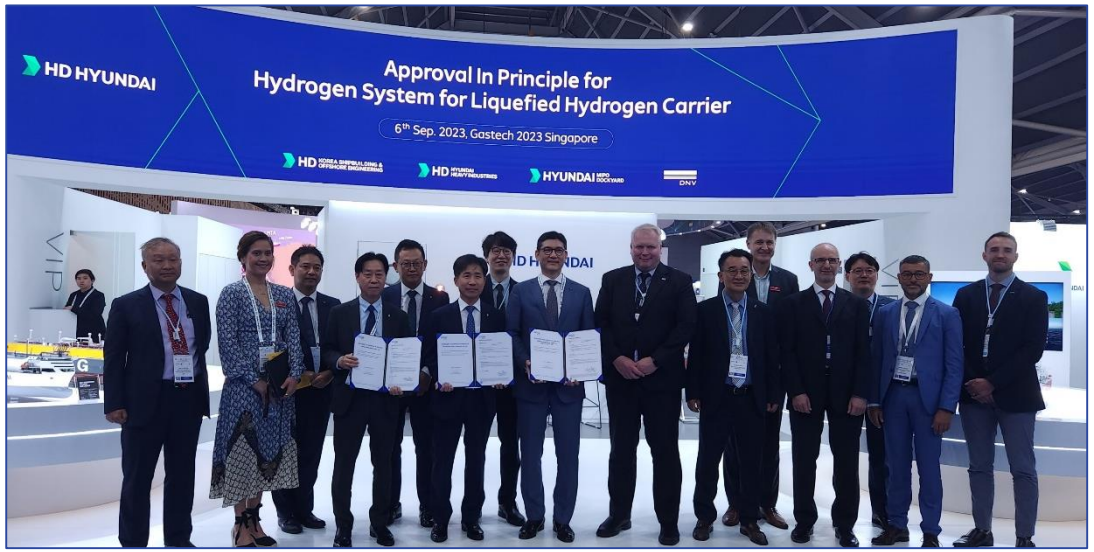
Glass Bubbles
: Most proven for liquid hydrogen
: Factory in Korea



Double Wall Tank
: Most proven for liquid hydrogen

5 Cargo Handling System

- **Compact** cargo handling system optimally integrating CCS, insulation system, and Hydrogen DF engine
- Developed under **collaboration** with hydrogen technology leading companies and global makers,
  - KSOE-Linde Engineering, for hydrogen cargo handling system and main equipment (AIP in Gastech, ’23)
  - KSOE-Chart Industries-KR, for hydrogen pipeline for LH2 carrier



[AIP Ceremony on 6th September, Gastech 2023]

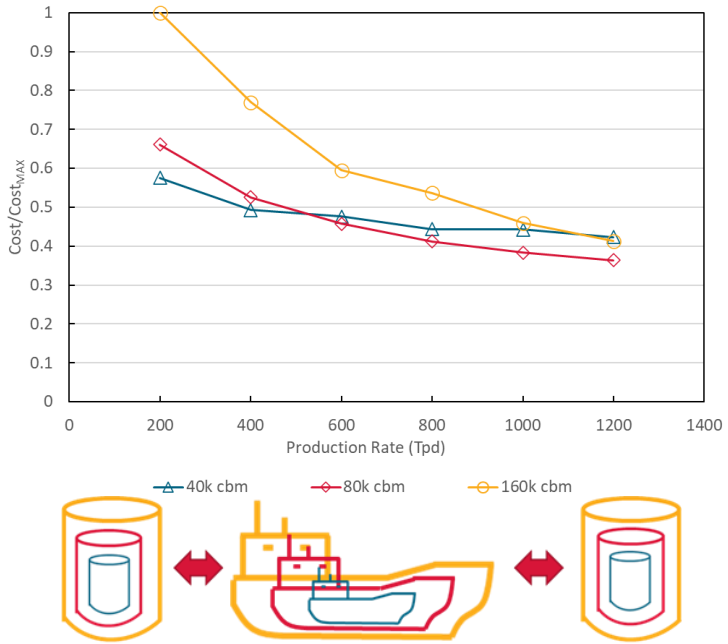
HD KSOE opens to collaboration with all of leading hydrogen companies

LH2 Shipping Simulation Study with Global Partners

- Simulation study for finding optimal LH2 shipping value chain based on HD Hydrogen System
- Main findings
  - **80,000 m3** LH2 carrier comparative than 40,000 m3 or 160,000 m3 LH2 Carrier
  - **No hydrogen leakage** into the air for long voyage distance
  - Process compatibility checked between LH2 carrier and terminals under new operation philosophy

One way sailing distance: 2500 nm	
Production Capacity#	1000 tpd
Fleet Size	4 x 80,000 m^3
Optimal Speed (at sea), kn	~16.2
Cycles per Year	77
Single Round Trip, days	16
Shipping Emissions*, $kgCO_2/kgH_2$	0.1 - 0.86

*Emissions calculations depends on H2 use as fuel. Model allows for evaluation of very low emission options



Conclusion

- HD Hydrogen system to provide the most **affordable** and **reliable** solution for
  - hydrogen transport **without loss**
  - **Tank scale-up** for large transport and storage

- HD KSOE to lead **HD Hydrogen System** development with global partners
  - Core technologies such as new insulation system and Hydrogen DF engine to be verified in 2024
  - All solutions to be realized targeting LH2 carrier operation in **2030**

- **Global partnership** to accelerate LH2 carrier development and commercializing LH2 shipping