24 OCT 2022

PRACTICAL CONSIDERATIONS OF HYDROGEN AS MARINE FUEL.

KAUST Research Conference
Hydrogen–Based Mobility and Power

Presented by:
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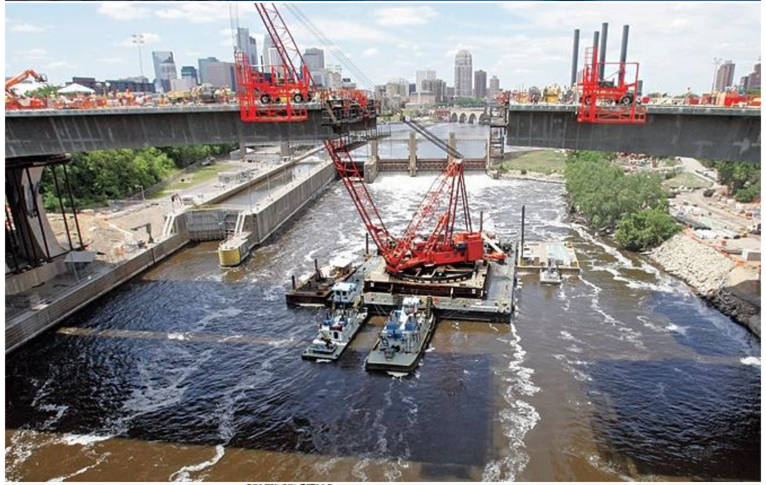
Robin Madsen, PE

Glosten

ABOUT US

WHAT WE DO BEST.

- Naval architecture
- Marine engineering
- Ocean engineering/analysis



- Marine civil construction
- Noise control engineering

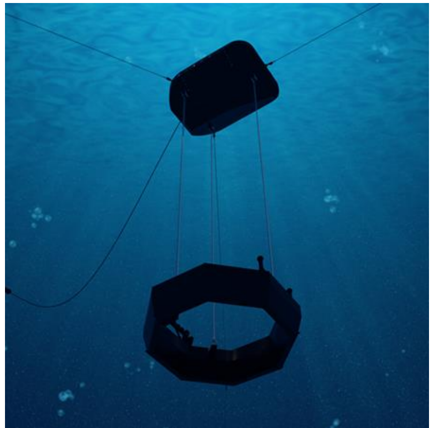
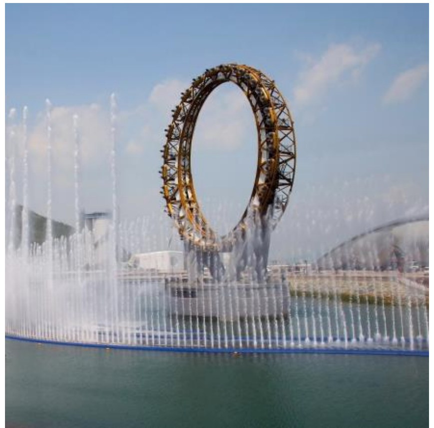
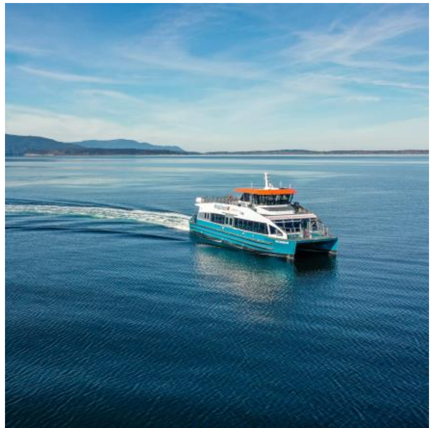
- Electrical engineering
- Production engineering

DELIVERING UNIQUE SOLUTIONS.

The depth and breadth of our experience has resulted in a body of work we’re proud to showcase. From standard builds to one-of-a-kind designs, our commitment to excellence shines through in everything we do.






REPLACING THE RV THUWAL.

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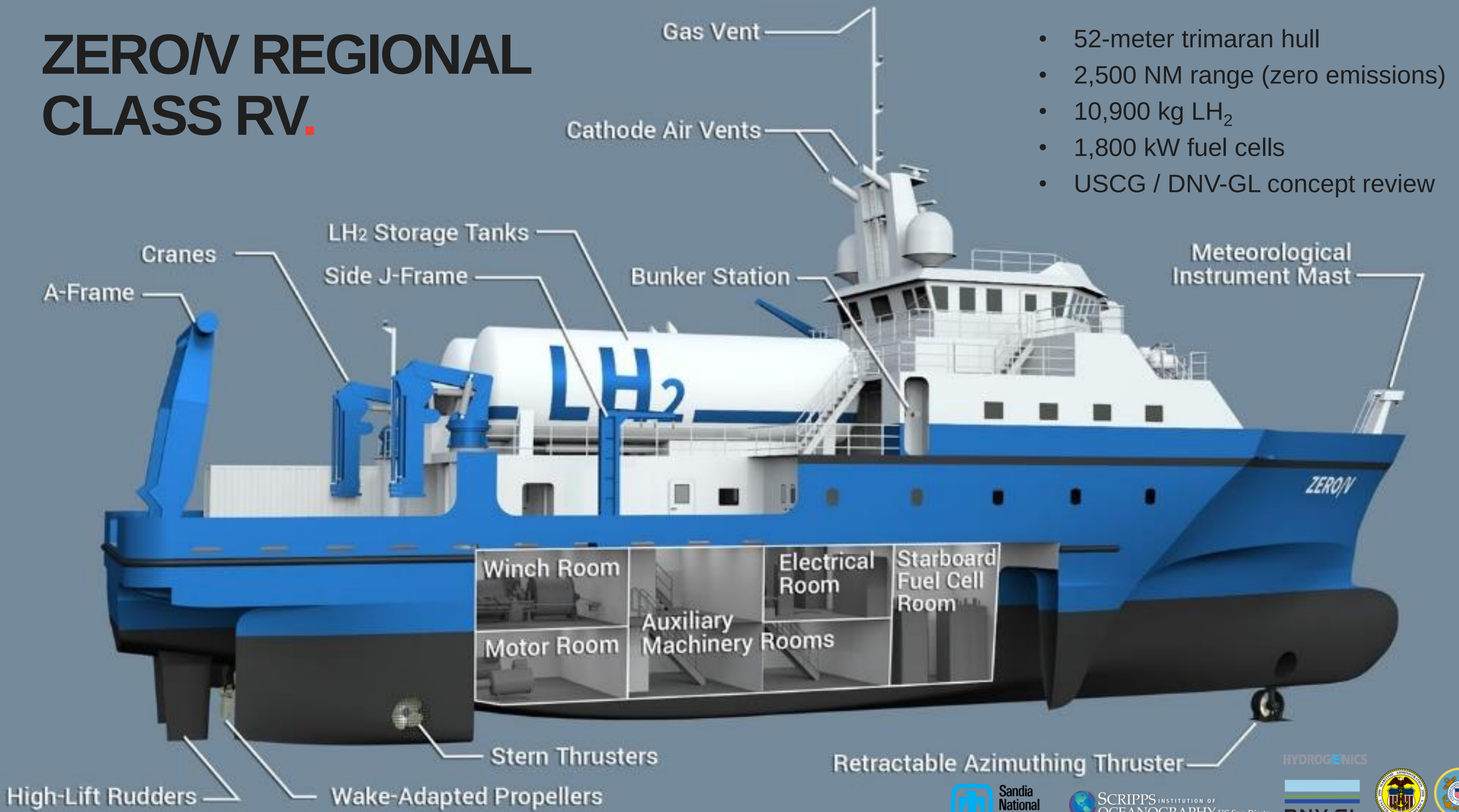
OUR RECENT HYDROGEN / FUEL CELL PROJECTS.

ZERO/V REGIONAL CLASS RV.

- 52-meter trimaran hull
- 2,500 NM range (zero emissions)
- 10,900 kg LH_2
- 1,800 kW fuel cells
- USCG / DNV-GL concept review



Sandia National Laboratories SCRIPPS INSTITUTION OF OCEANOGRAPHY UC San Diego HYDROGENICS DNV·GL

H_2 HYBRID SRV.

- 38-meter
- 3,200 NM Range (with diesel + hydrogen)
- 330 NM zero emissions range (hydrogen only)
- 730 kg LH2
- 800 kW fuel cells

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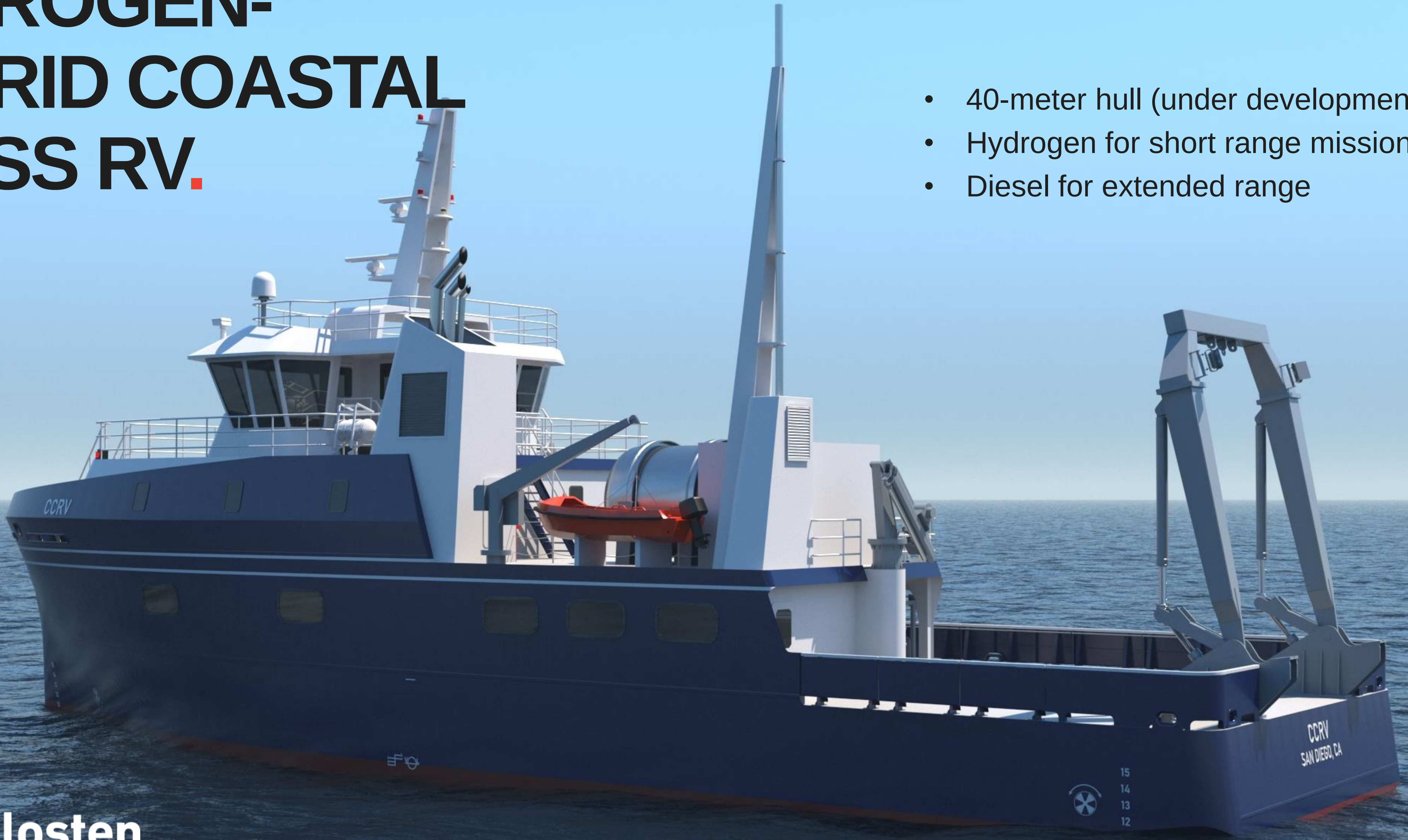
SCRIPPS INSTITUTION OF OCEANOGRAPHY UC San Diego
Sandia National Laboratories
BALLARD

HYDROGEN-HYBRID COASTAL CLASS RV.

- 40-meter hull (under development)
- Hydrogen for short range missions
- Diesel for extended range



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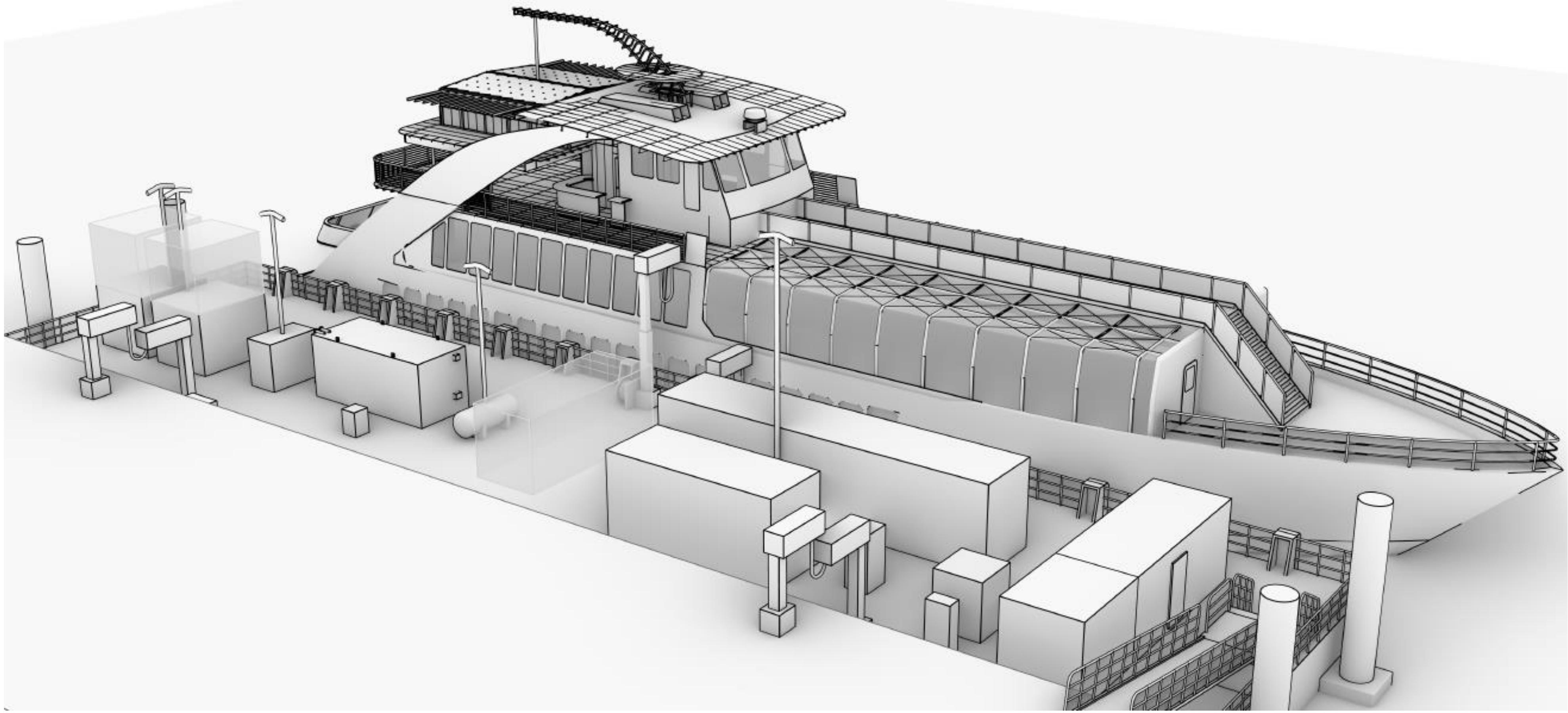
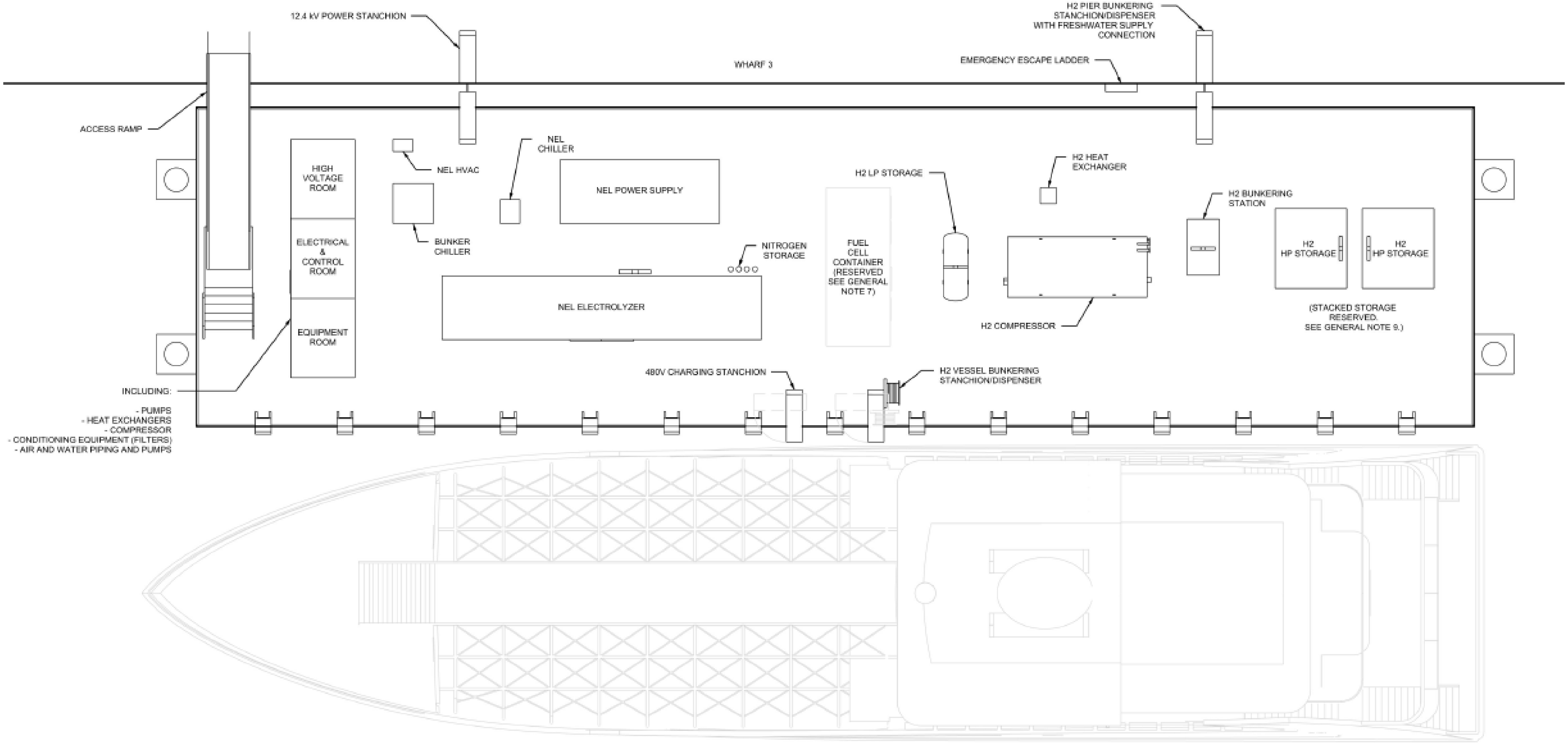
HYDROGEN FUELING STATION.

- Producing H_2 with power from hydroelectric
- ~500 kg/H_2 per day production with 1.2MW Electrolyzer
- H_2 vessel bunkering from onboard storage tanks
- H_2 supply to on shore tube trailers for supply to landside consumers
- Electric vessel charging



HYDROGEN FUELING STATION.



HYDROGEN IN USE.

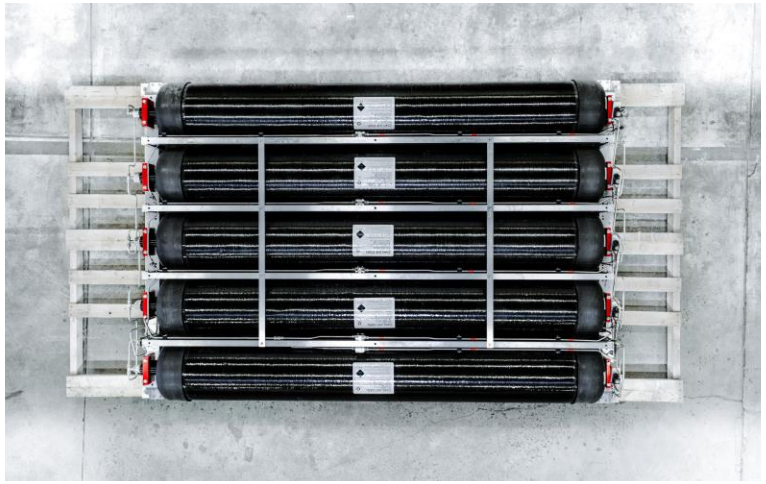
Source: MAN Energy Solution (www.man-es.com)

LIQUID HYDROGEN

- Cryogenic (−253°C)
- Requires pressure management of boil-off
- Limited holding time
- Higher volumetric density
- Typically located on open deck
- More appropriate for large quantities

H_2 IN USE

H_2 FUEL STORAGE.



Source: Hexagon Purus (www.hexagonpurus.com)

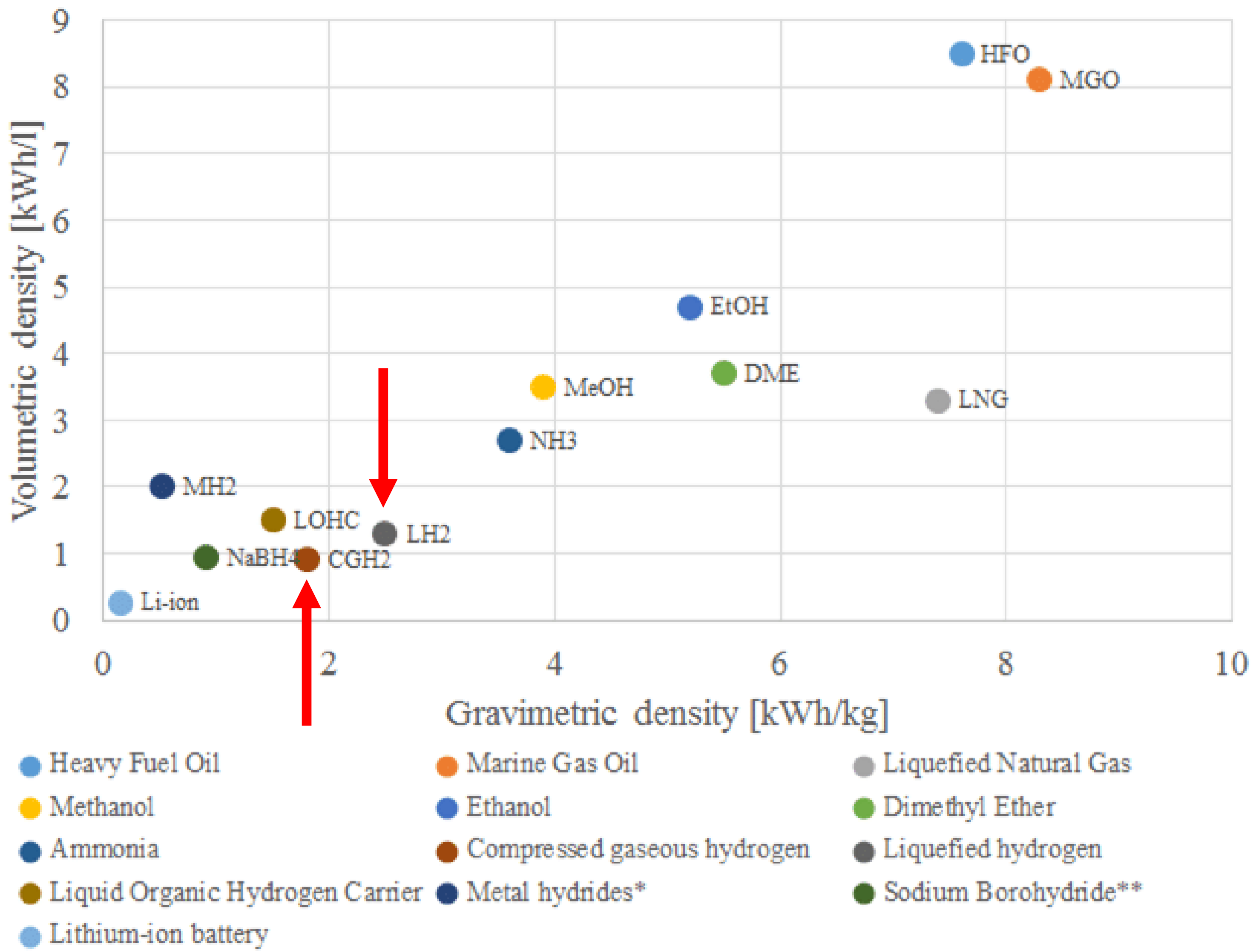
COMPRESSED HYDROGEN

- High pressure (250+ Bar)
- Indefinite holding time
- Many connections, large hazardous zones
- Low volumetric density
- Higher pressure (500+ Bar) is still developmental for ships.
- Typically located on open deck
- More appropriate for smaller quantities

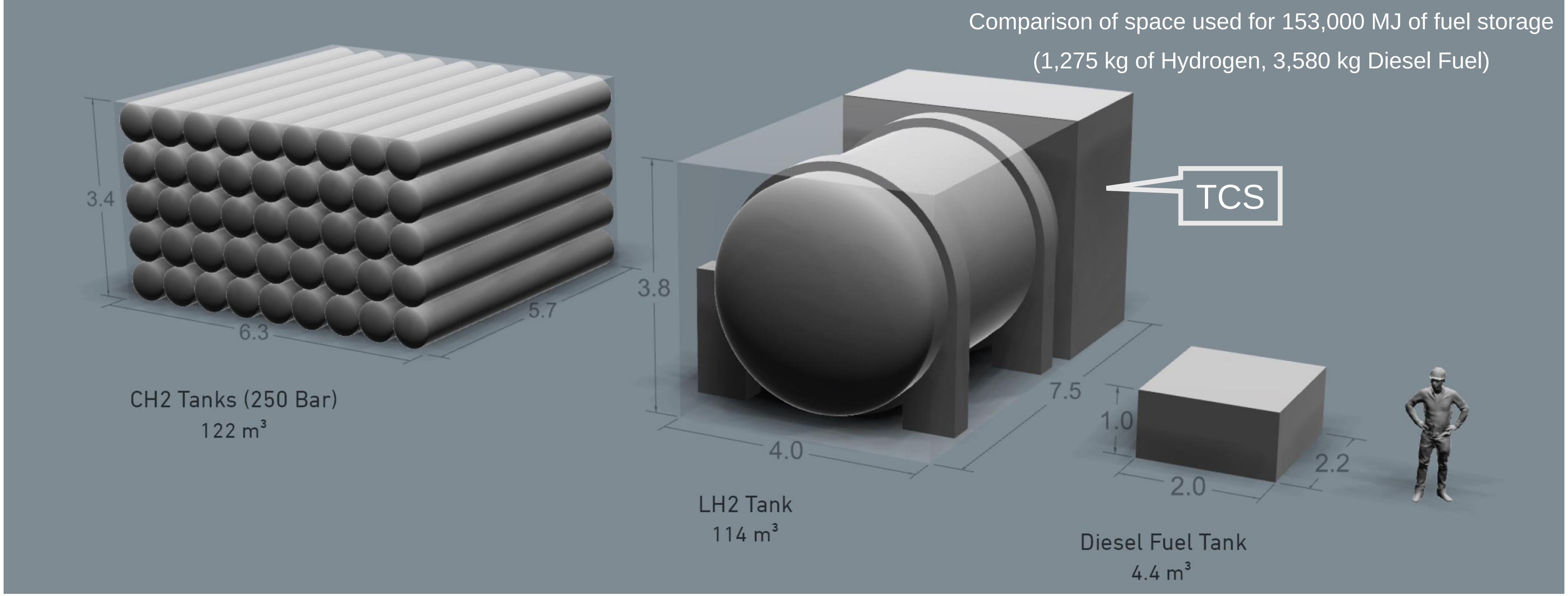
H_2 FUEL STORAGE.

- Must consider more than just the energy density of the fuel itself.
- Tank systems are an order of magnitude more weight than the hydrogen they contain.
- Hydrogen alone (without tank) is 33kWh/kg

Volumetric and gravimetric energy density of logistic fuels including the tank system



Source:
Mestemaker, Benny & Castro, Bernardete & Blom, Erik & Cornege, Henk & Visser, K.. (2019). *Zero emission vessels from a shipbuilders perspective.*



H_2 FUEL STORAGE.

- Hydrogen tanks are cylindrical pressure vessels.
- Space and volume claim of tanks is increased because of unused space around the tanks.
- Liquid hydrogen tanks typically require a tank connection space (TCS).
- For relatively small tanks, such as shown, the TCS is a large portion of the tank system.

H_2 IN USE

FUELING.

LIQUID HYDROGEN

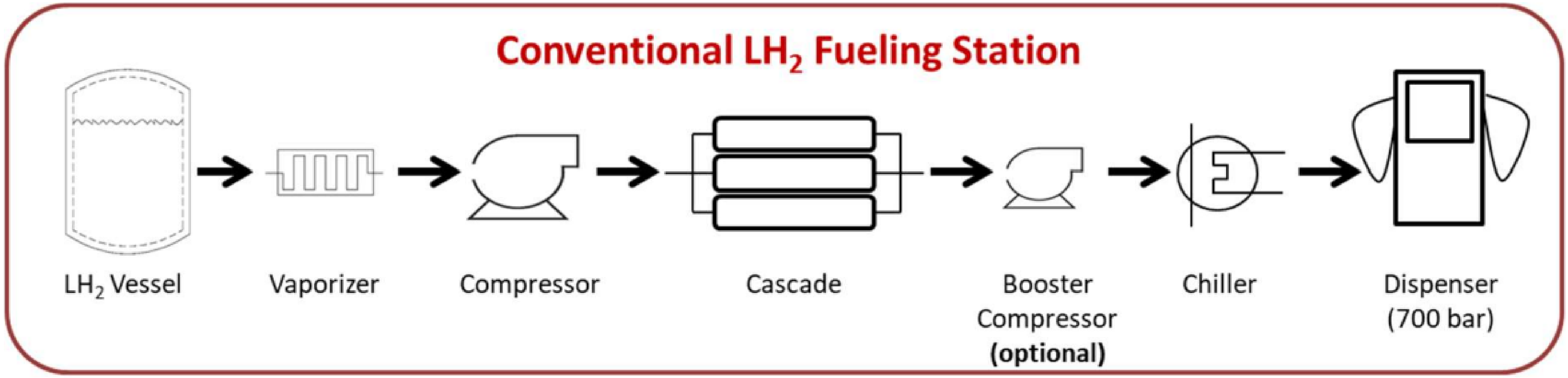
- High rates of fuel transfer are possible.
- Requires special procedures for cryogenic liquid.
- Purging with nitrogen is not possible, it will freeze. Helium can be used.
- Shore based fueling infrastructure is required.

Liquid Hydrogen Loading Arm
(Tokyo Boeki Engineering, Ltd.)

FUELING.

COMPRESSED

- High rates of fueling is challenging
- Bunker cooling likely required
- Large compressors required for high pressure storage
- Large quantities likely require a fueling station using stored liquid hydrogen

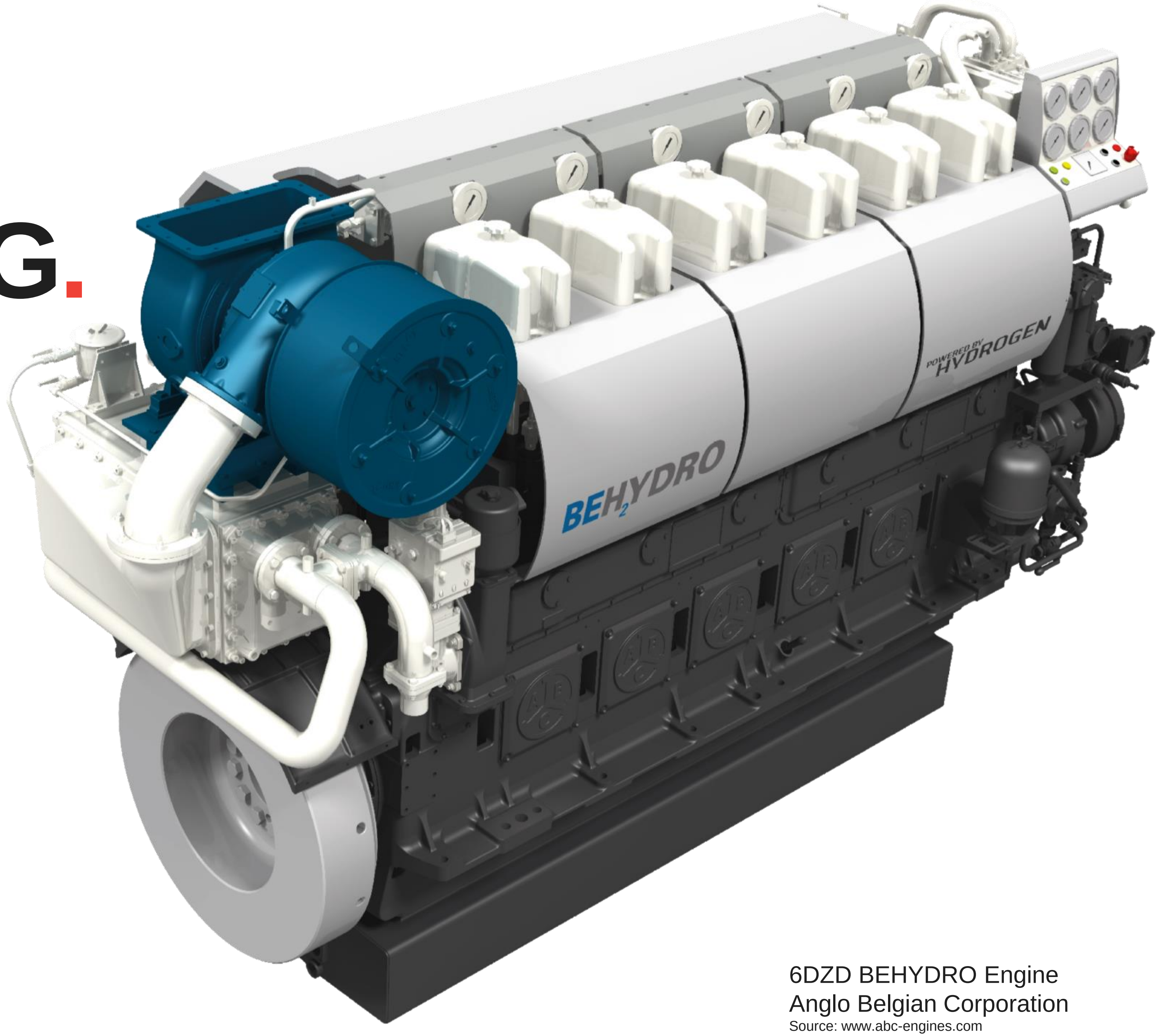


Source:
Kriha, Kenneth, Petitpas, Guillaume, Melchionda, Michael, Soto, Herie, Feng, Zhili, and Wang, Yanli. *Hydrogen Fueling Station Using Thermal Compression: a techno-economic analysis*. United States: N. p., 2017. Web. doi:10.2172/1375731.

POWERING.

COMBUSTION ENGINES

- Similar to diesel engines
- Dual fuel (H2 and diesel) or spark ignited (H2 only)
- Can use lower purity H2
- Low onboard emissions, but not zero
- Can be use for direct mechanical (propulsion) or for generators



6DZD BEHYDRO Engine
Anglo Belgian Corporation
Source: www.abc-engines.com

H$_2$ IN USE

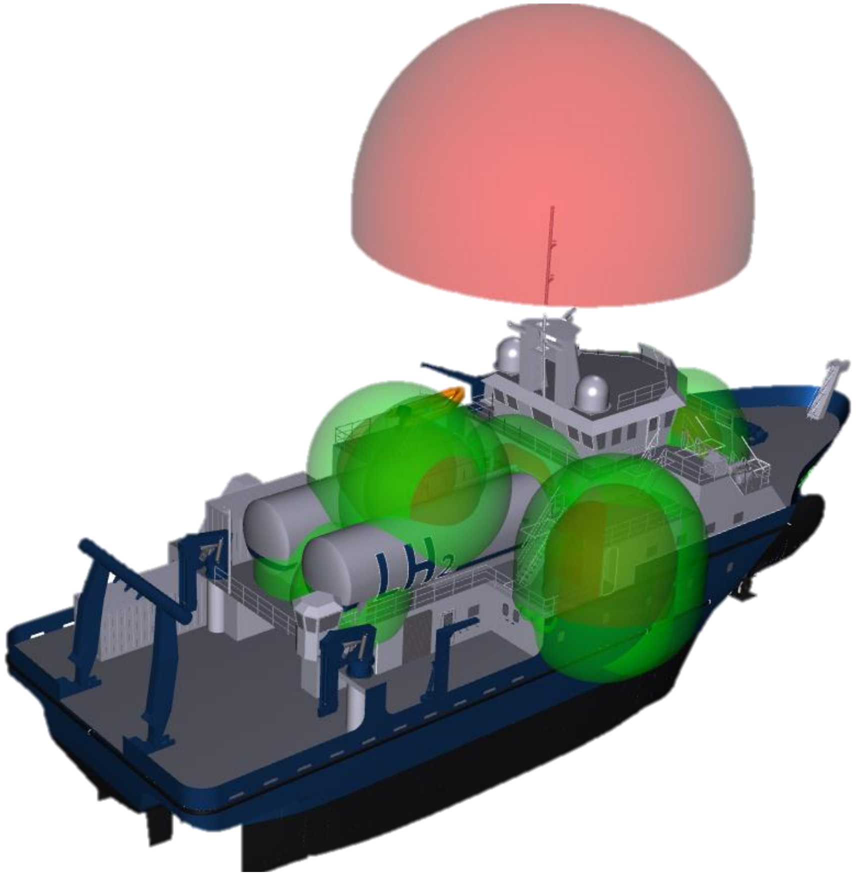
POWERING.

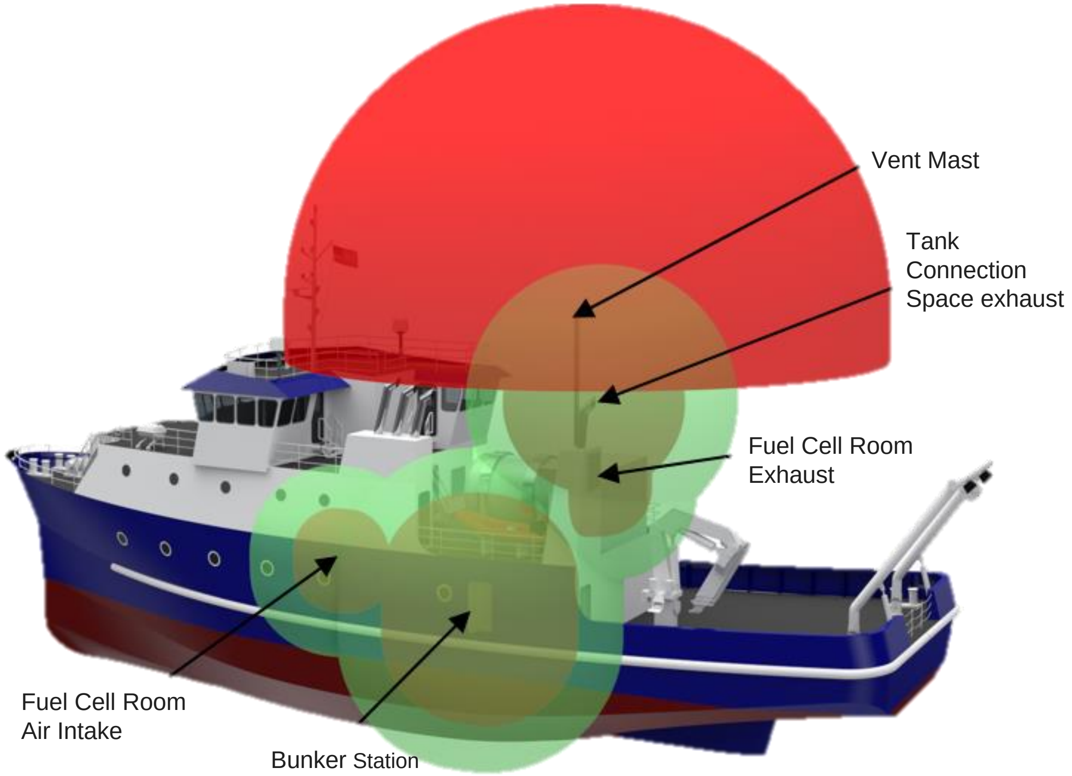
FUEL CELLS

- Very efficient electrochemical process
- Zero onboard emissions
- Near silent operation, few moving parts
- DC power (requires conversion to AC for practical us onboard)
- Requires high purity H2

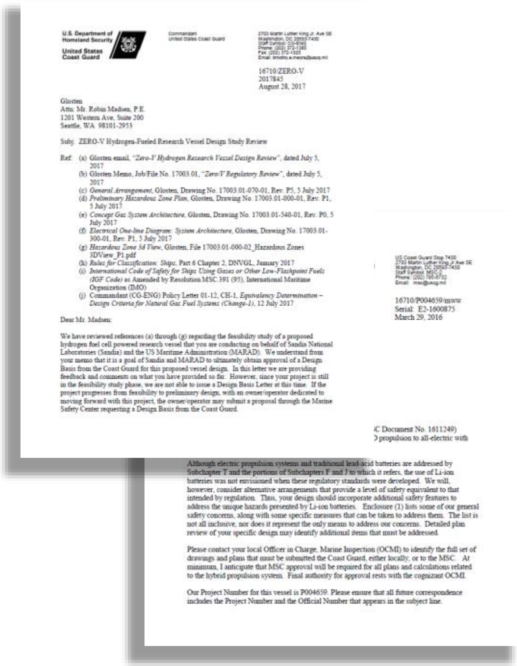
FCwave™ Fuel Cell Power Module
Ballard Power Systems
Source: www. www.ballard.com

ARRANGEMENTS: HAZARDOUS ZONES.





RULES AND REGULATIONS.



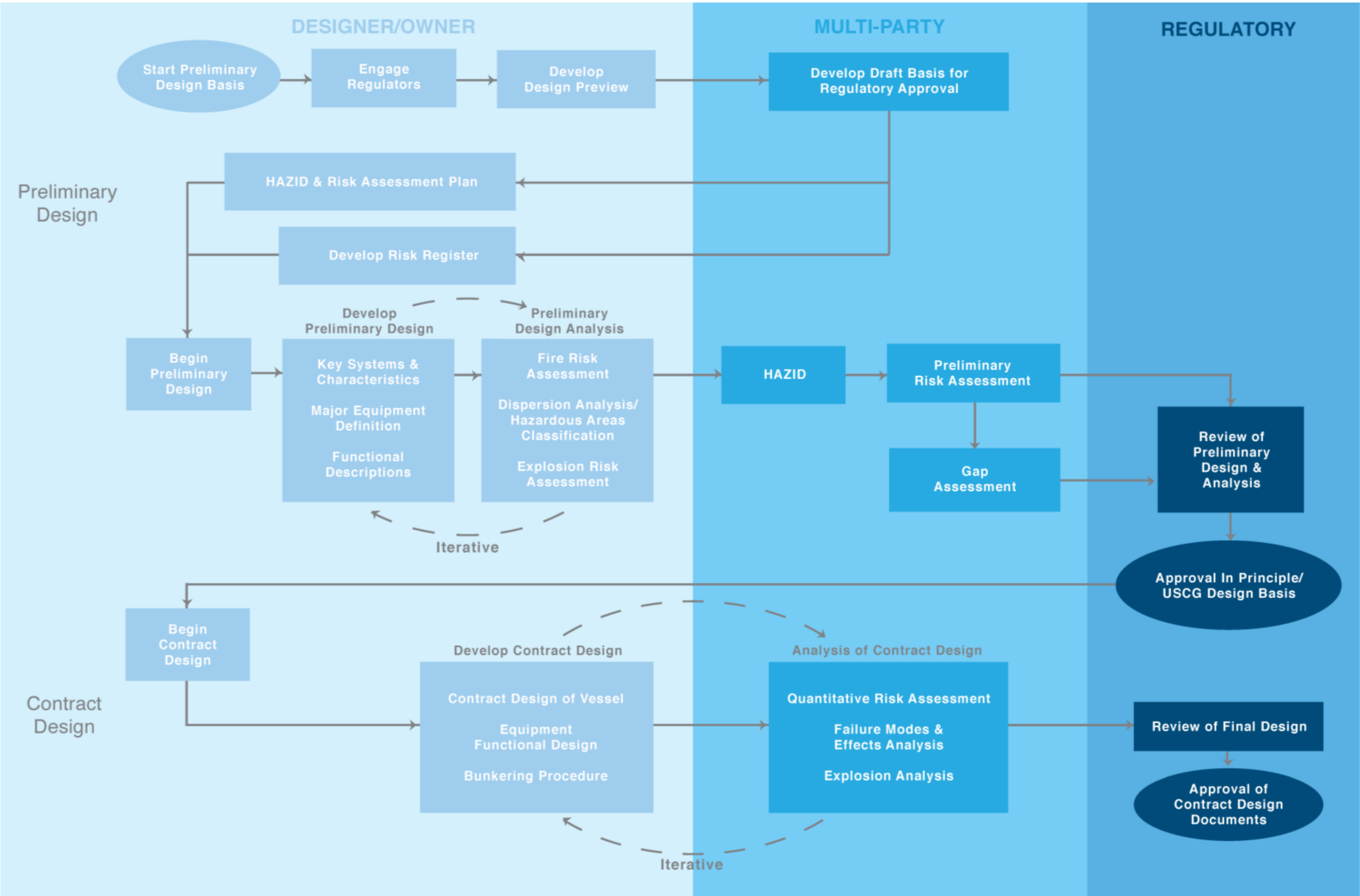
Flag Administration

Class Rules

International

RULES AND REGULATIONS.

- Regulatory definition is increasing, yet limited rules presently exist.
- Acceptance of design must follow Alternative Design approach:
  - Must have equivalent safety and reliability as conventional oil fuel.
  - Risk based design and analysis must be used to demonstrate equivalency to Class and Flag Administration.
- Requires close coordination with regulators.



THANK YOU.

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