GSP Pilot

Ammonia-powered tanker in global shipping

Pilot owner: Equinor (Tomas Ryberg)

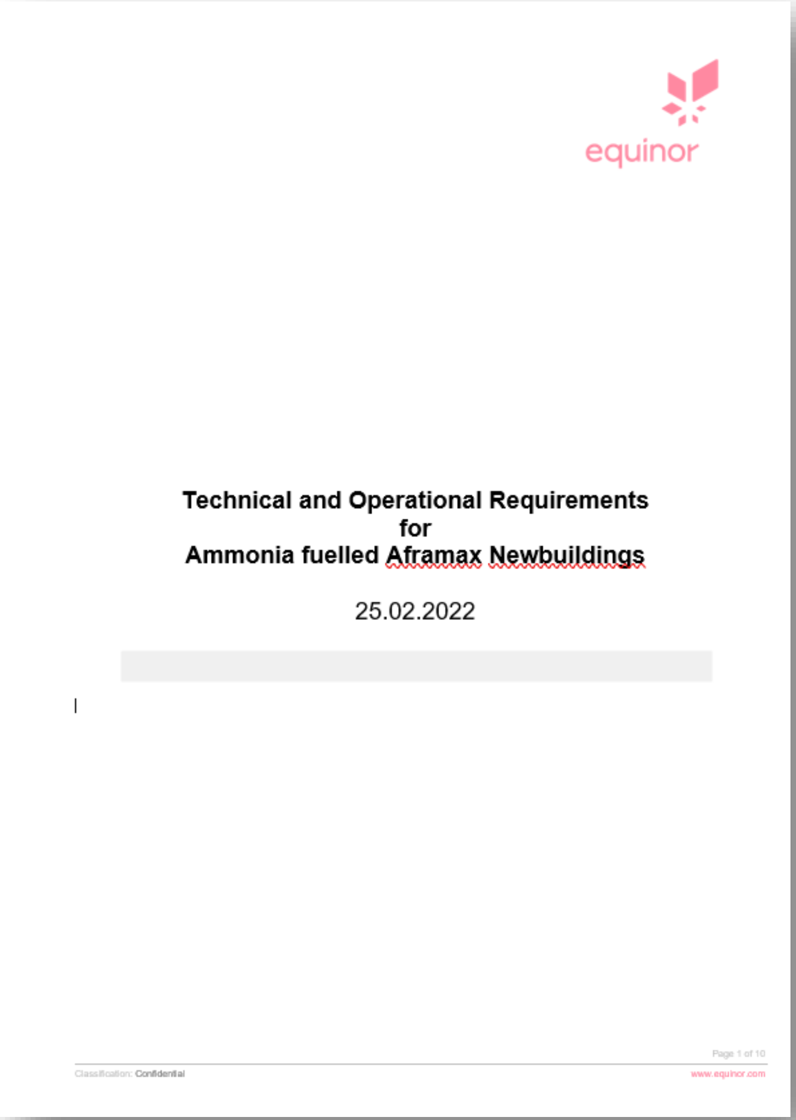
Mini seminar 29.03.2023

The purpose of the pilot

- Investigate the technical and economical applicability of implementing ammonia-eligible engines, fuel, and bunkering systems on an Aframax tank ship design.
- Understand operational safety aspects and competence requirements.
- De-risk key elements of the design and identify barriers.
- The overall purpose of the pilot is to improve the decision-basis for Equinor for realizing a chartered tanker powered by ammonia.

Participants

Framing the Aframax case - Spec



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Technical and Operational Requirements
for
Ammonia fuelled Aframax Newbuildings

25.02.2022

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Classification: Confidential

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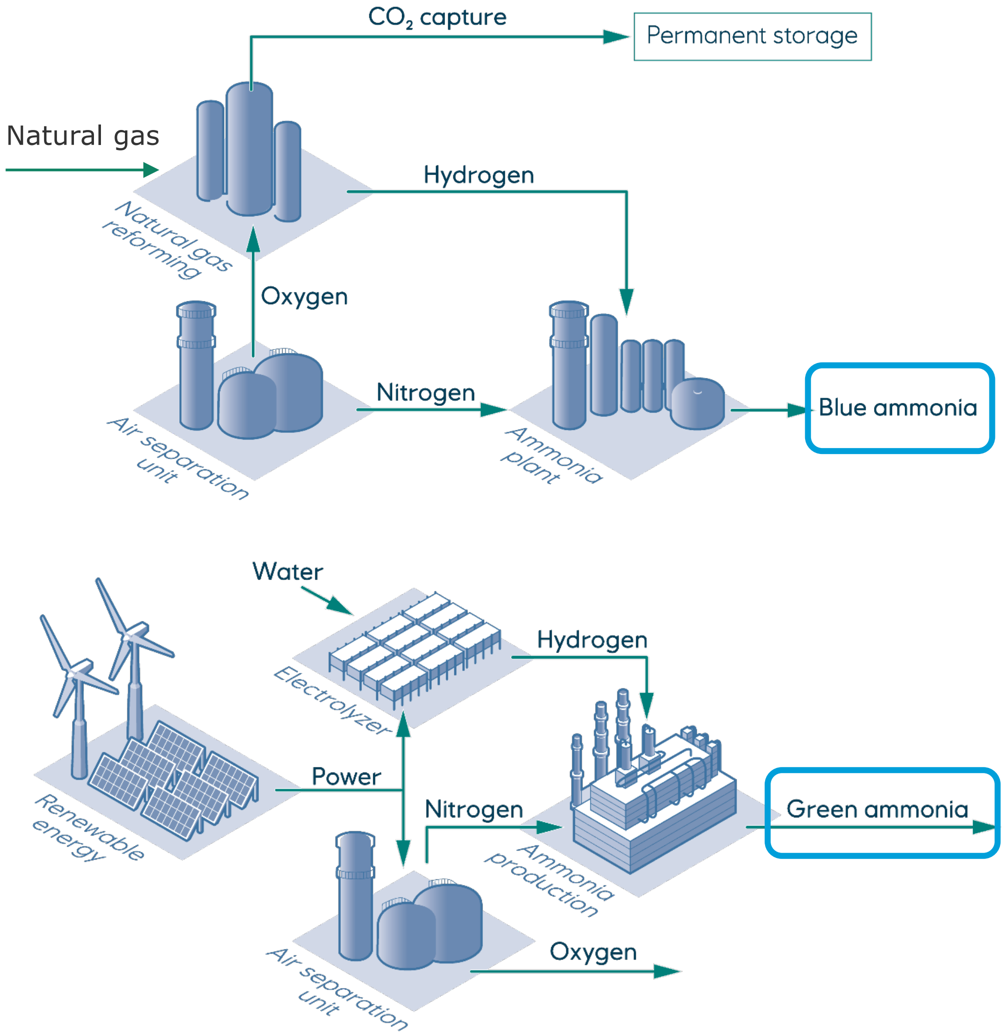
- **+1A**,**Tanker for Oil**, **E0, ESP**, **CSR**, **LCS, BWM(T), Clean(Design)**, **VCS(2,B)**, **Coat-PSPC(B,C)**, **BIS**, **GAS FUELLED Ammonia, SPM, TMON**
- The summer deadweight shall be between 109 000 to 115 000 metric tonnes.
- Service speed shall be minimum 14.5 knots at design draft with main engine at NCR, including 15% sea margin and shaft generator engaged.
- Economy Speed
  - 13 kts ballast/laden
- Cruising range in Ammonia mode shall be approximately **15 000** nm

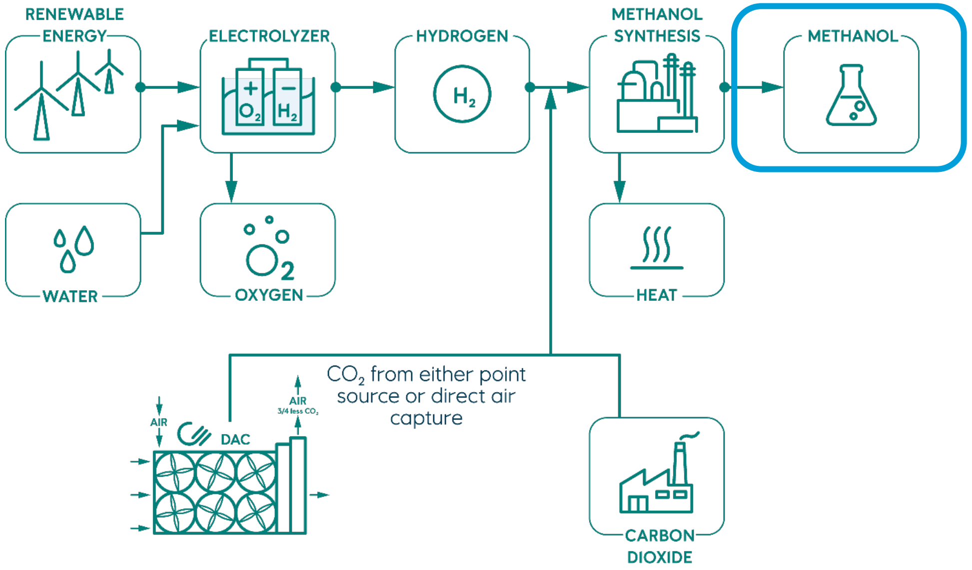
Framing the Aframax case – Location Mongstad

Jetty7

WP2 - Clean fuel production pathways



Clean Ammonia



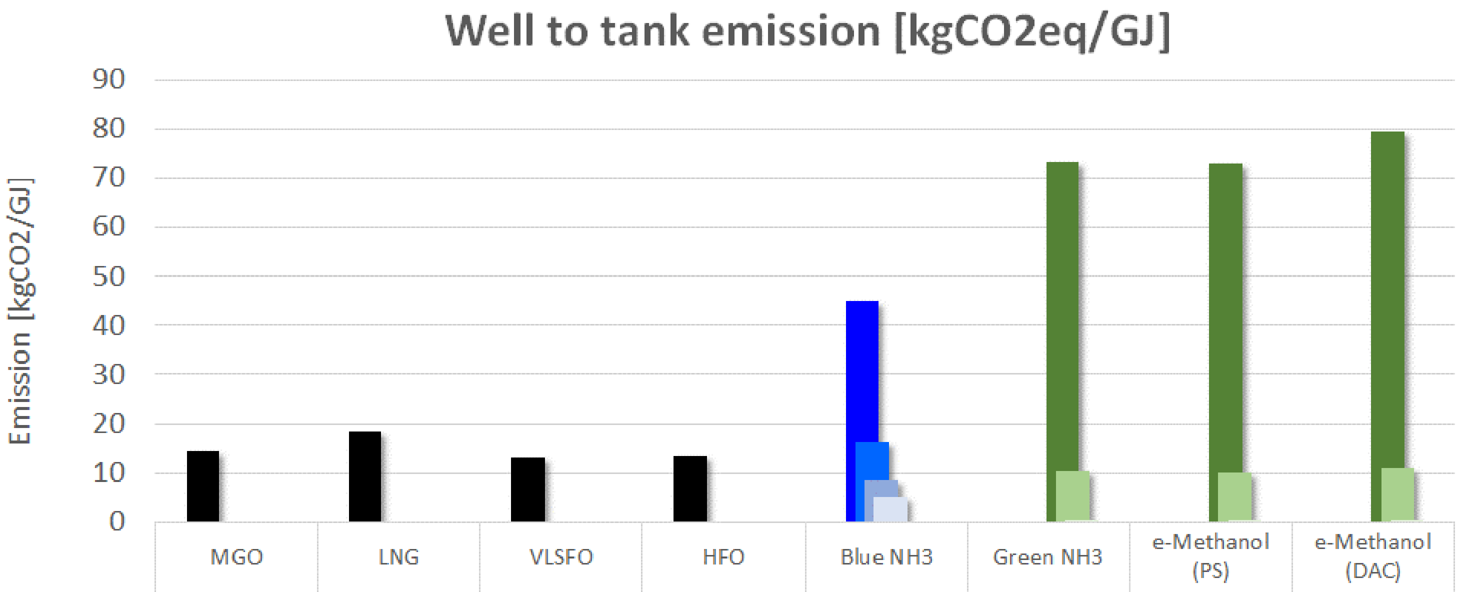
e-methanol

Green Shipping Programme

WP2 - Carbon intensity – Well to tank sensitivity

Upstream carbon footprint

- Upstream emissions for new fuels will vary depending on plant design, efficiency and the input factors' carbon footprint:
  - Footprint of gas/electricity
  - CO_2 capture rate
  - The plant's efficiency
  - CO_2 source
- Both ammonia and e-Methanol **can** be produced with a low footprint
- Certification of footprints are required

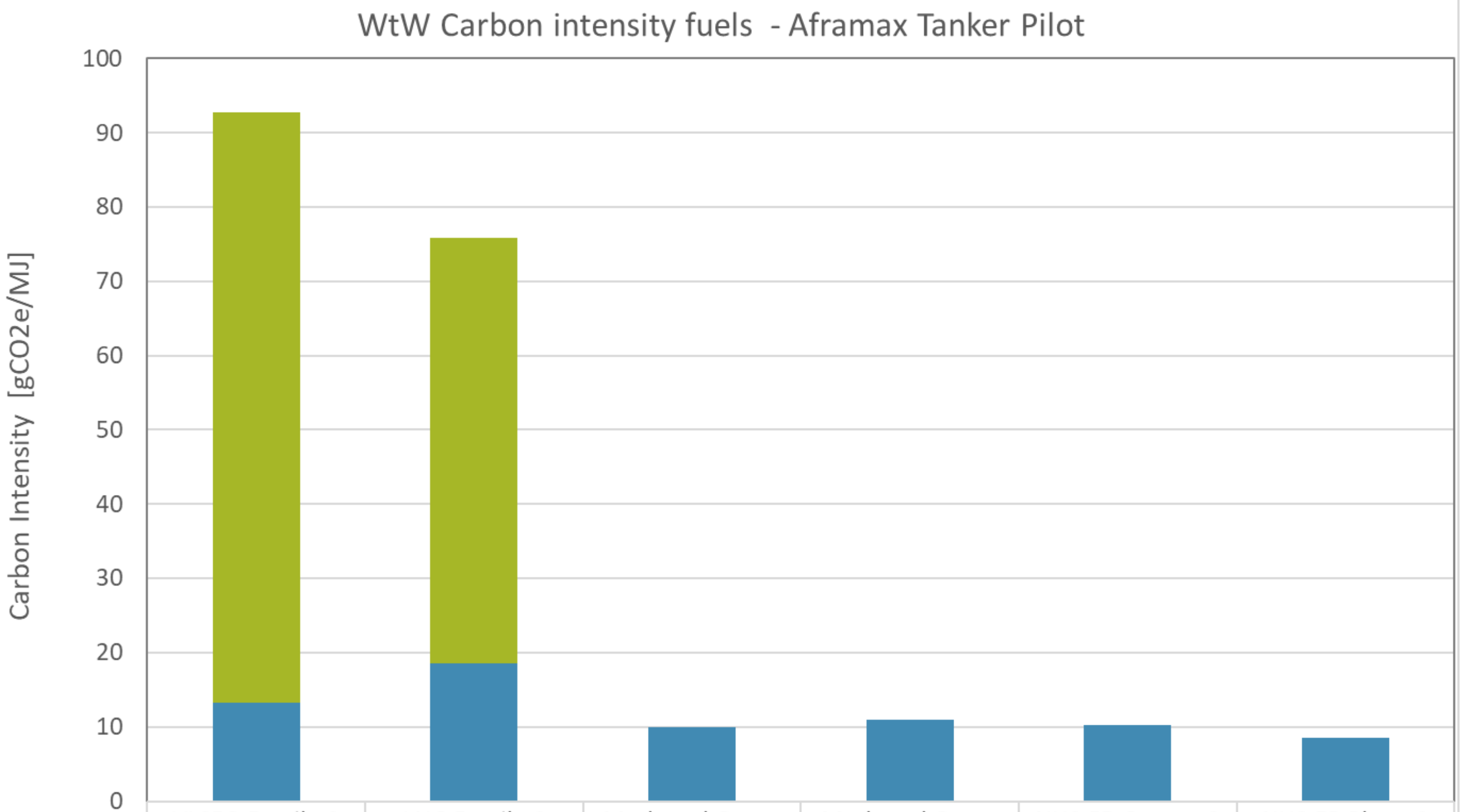


	MGO	LNG	VLSFO	HFO	Blue NH3	Green NH3	e-Methanol (PS)	e-Methanol (DAC)
Conventional fuels	14,4	18,5	13,2	13,5				
60% capture					44,9			
90% capture					16,2			
95% capture					8,5			
98% capture					5,2			
125 g CO2/kWh						73,3	72,9	79,5
17 g CO2/kWh						10,3	10,0	10,9
0 g CO2/kWh						0,4	0,1	0,1

WP2 - Carbon intensity – Well to Wake

Value Chain Footprint

- **Blue part** is upstream emissions
  - Well-to-tank (WtT)
- **Green part** is operational emissions from the ship
  - Tank-to-wake (TtW)
- Tank-to-wake footprint for NH_3 and Methanol is assumed to be 0
  - N_2O formation must be quanitified
  - CO_2 generated through methanol combustion not counting
- Total value chain emissions
  - Well-to-wake (WtW)
- Both green and blue fuels **can** reduce emissoins substantially (about 90% WTW)
- FuelEU Maritime 2050 ~18g/MJ



	VLSFO Fossil - 2 Stroke HP	LNG Fossil - 2 Stroke HP	Methanol Green PS - 2 Stroke HP	Methanol Green DAC - 2 Stroke HP	NH3 FR Green - 2 Stroke HP	NH3 FR Blue - 2 Stroke HP
WTW Carbon intensity	93	76	10	11	10	9
TtW Carbon Intensity	80	57	0	0	0	0
WtT Carbon Intensity	13	19	10	11	10	9

Grønt Skipsfartsprogram

WP2 - LCA and fuel cost levels

Ship Cost Model

Model for comparison of various fuel types' cost level, based on the following:

- Relevant ship parameters
- Operational profile
- Motor type / pilot fuel / efficiencies
- Fuel cost / footprint
- CAPEX and OPEX

Fuel production cost model

- Comparing fuel production cost with consistent assumptions

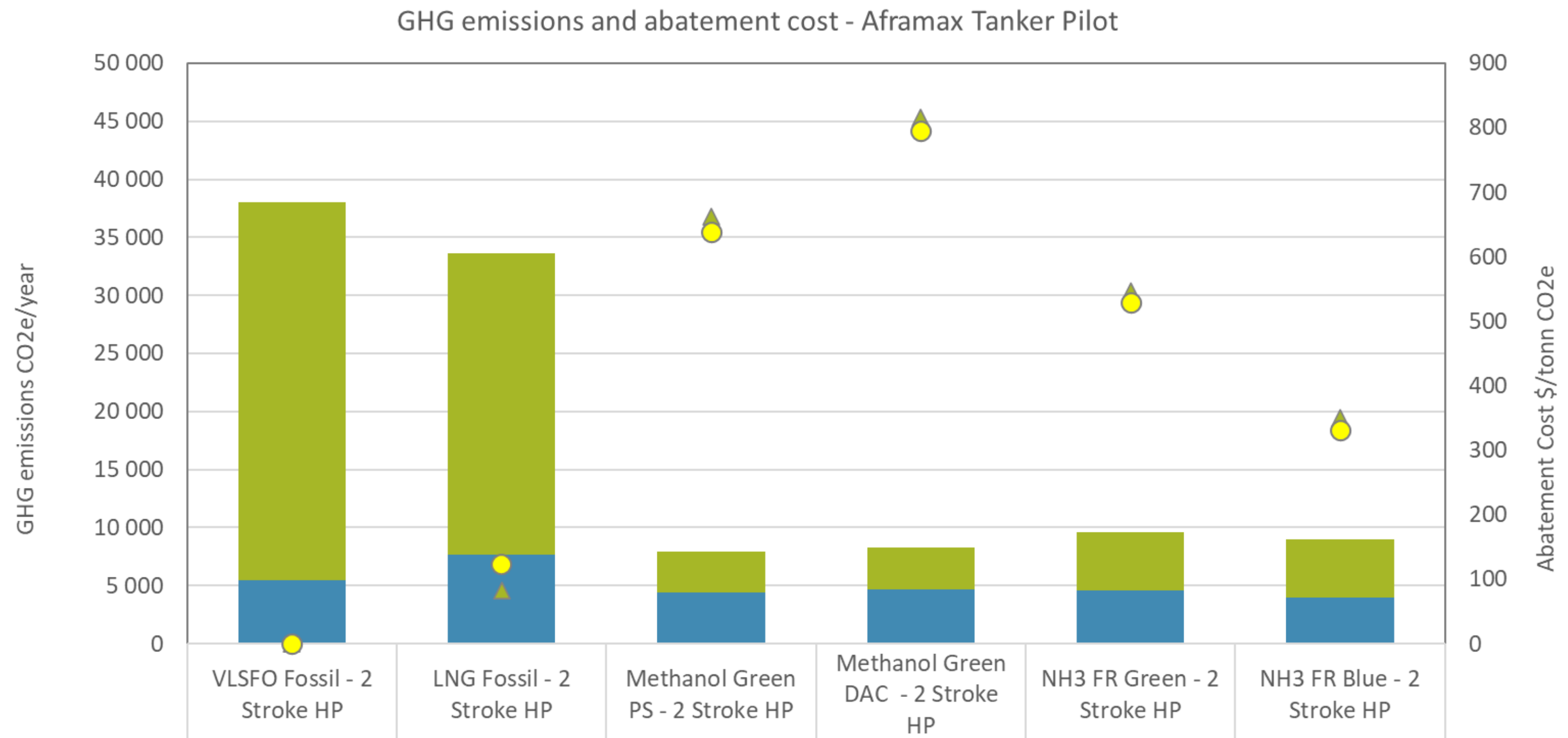
Ship case	Contract price / delta cost [MUSD]
Conventional Aframax VLSFO	68
DF Aframax LNG	+13
DF Aframax NH3	+13
DF Aframax MeOH	+ 4

Fuel Cost	$/ton
VLSFO	350
LNG	300
Blue NH3	593
Green NH3	878
Point source Methanol	1178
Direct Air capture Methanol	1416

WP2 - LCA and fuel cost levels

Emissions and abatement cost from the Ship Cost Model

- Abatement cost is based on ship cost model
- Pilot fuel / auxiliary engines increase total emissions
- Blue ammonia – lowest abatement cost
- CAPEX – limited impact on abatement cost
- Cost of energy is crucial
  - Reduce consumption!
- CO2e tax or ETS needs to be 350-660 \$/ton CO2e (not included in numbers)
- Contracts for difference??



	VLSFO Fossil - 2 Stroke HP	LNG Fossil - 2 Stroke HP	Methanol Green PS - 2 Stroke HP	Methanol Green DAC - 2 Stroke HP	NH3 FR Green - 2 Stroke HP	NH3 FR Blue - 2 Stroke HP
WTW	38 050	33 619	7 973	8 301	9 621	8 999
TTW	32 568	25 967	3 587	3 587	5 031	5 031
WTT	5 482	7 651	4 385	4 713	4 590	3 968
Abatement cost TW	0	82	662	816	547	350
Abatement cost WTW	0	122	638	795	530	332

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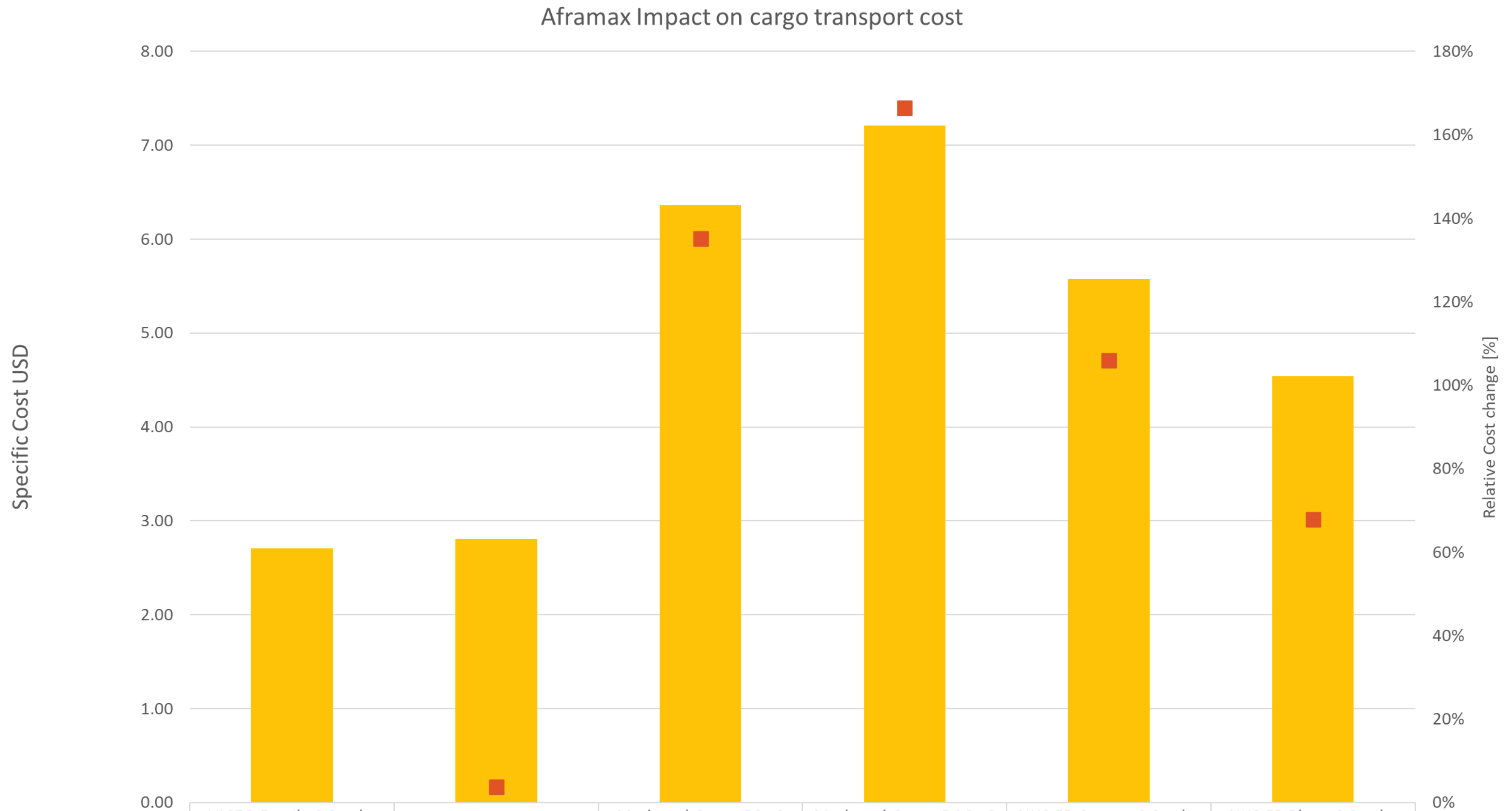
WP2 – Impact on Cargo transport unit cost

- The transport cost is significantly higher
- ETS price and contracts for difference will reduce cost difference
- What is the value of a lower-footprint product transport?



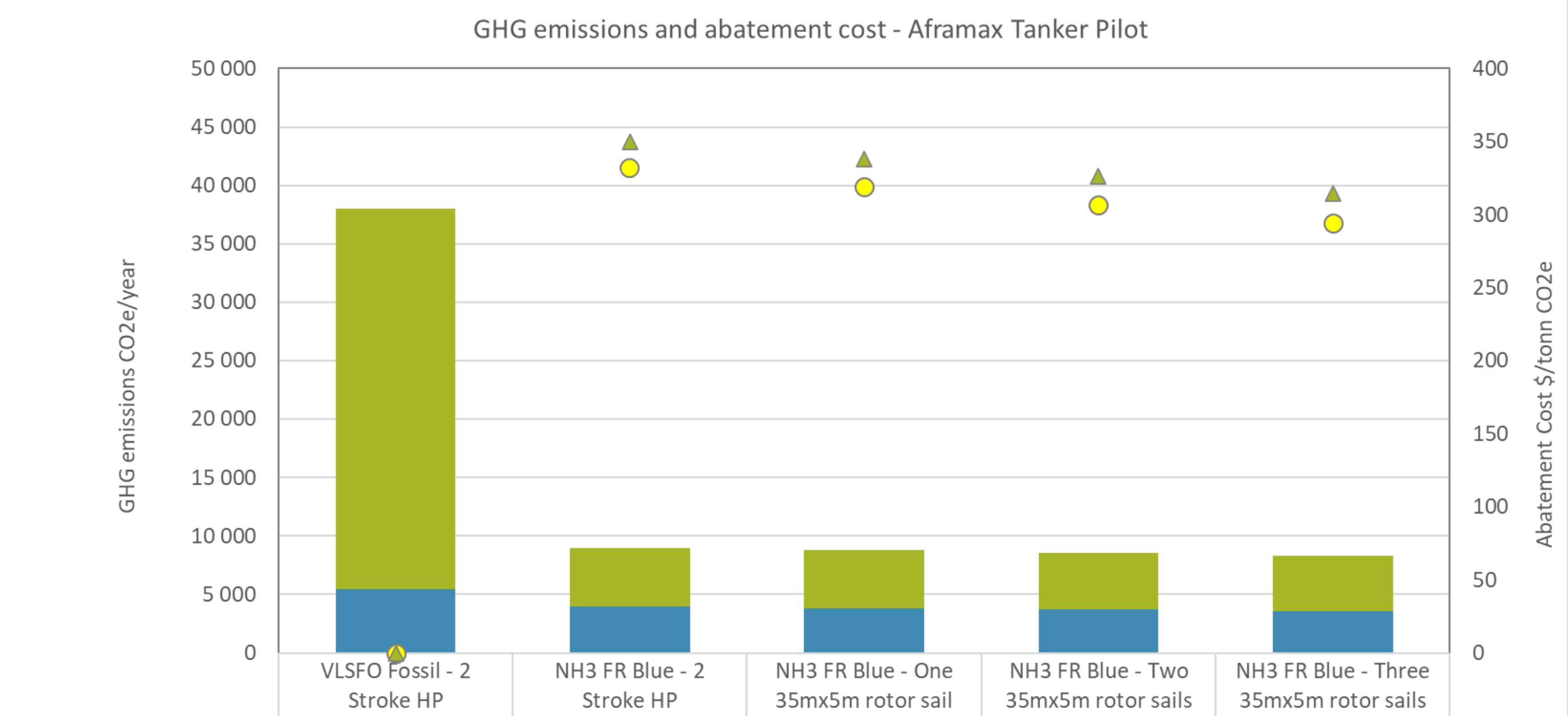
	VLSFO Fossil - 2 Stroke HP	LNG Fossil - 2 Stroke HP	Methanol Green PS - 2 Stroke HP	Methanol Green DAC - 2 Stroke HP	NH3 FR Green - 2 Stroke HP	NH3 FR Blue - 2 Stroke HP
$ / barrel	2.71	2.81	6.37	7.21	5.58	4.54
Relative Change cost		4 %	135 %	166 %	106 %	68 %

Green Shipping Programme

WP2 – Impact of energy efficiency technology

Energy efficiency technology

- Rotor sail technology can generate a significant reduction in fuel consumption ~ -11% (3 sails).
- The investment is profitable, particularly with clean fuels.
- Evaluation of possible energy saving measures is important for a cost efficient decarbonisation.
- Technologies not possible to defend with conventional fuels – often possible to defend in light of increased energy prices.



	VLSFO Fossil - 2 Stroke HP	NH3 FR Blue - 2 Stroke HP	NH3 FR Blue - One 35mx5m rotor sail	NH3 FR Blue - Two 35mx5m rotor sails	NH3 FR Blue - Three 35mx5m rotor sails
WTW	38 050	8 999	8 767	8 535	8 304
TTW	32 568	5 031	4 925	4 820	4 714
WTT	5 482	3 968	3 842	3 716	3 590
Abatement cost WTW	0	332	319	307	294
Abatement cost TW	0	350	338	326	314

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Safety Moment

Ammonia risks

H221 Flammable gas
H280 Contains gas under pressure; may explode if heated
H331 Toxic if inhaled
H314 Causes severe skin burns and eye damage
H400 Very toxic to aquatic life
H411 Toxic to aquatic life with long lasting effects

Hazards of anhydrous ammonia (YARA)

Ammonia cloud – heavy gas experiment from INERIS leak tests 1996-97

Ammonia Concentration (parts per million)	Health Effect
1-5	Range of odour threshold
50	Irritation to eyes, nose and throat after 2 hours exposure
100	Rapid eye and respiratory tract irritation
250	For most persons, 30-60 minutes exposure is tolerable
700	Immediately irritating to eyes and throat
>1500	Pulmonary edema, coughing
2500 – 4500	Fatal (30 minutes)
5,000 – 10,000	Rapidly fatal due to airway obstruction

CH027- Chemical Hazards Revised August 2010 "Ammonia at the Work site", Workplace Health and Safety

Visibility	Invisible in gaseous form. Two phase cloud looks like fog
Dispersion	Heavy gas, if released from pressurized liquefied conditions. Otherwise light or passive. NH3 liquid reacts violently with water
Very cold	Very cold (T < - 65 °C) if released from liquid conditions Freezing, cryogenic burns, *equipment integrity*
Toxic	Main risk to life and health. Classified as toxic. Very strong pungent panic-inducing odor at non hazardous concentration
Aquatic life	Very toxic to aquatic life
Corrosive	Corrosive. Risk for stress corrosion cracking. Forms an alkali which "burns" skin and damages the respiratory system
Flammability	Less flammable than hydrocarbons, lower fire and explosion hazard, indoor explosions have occurred

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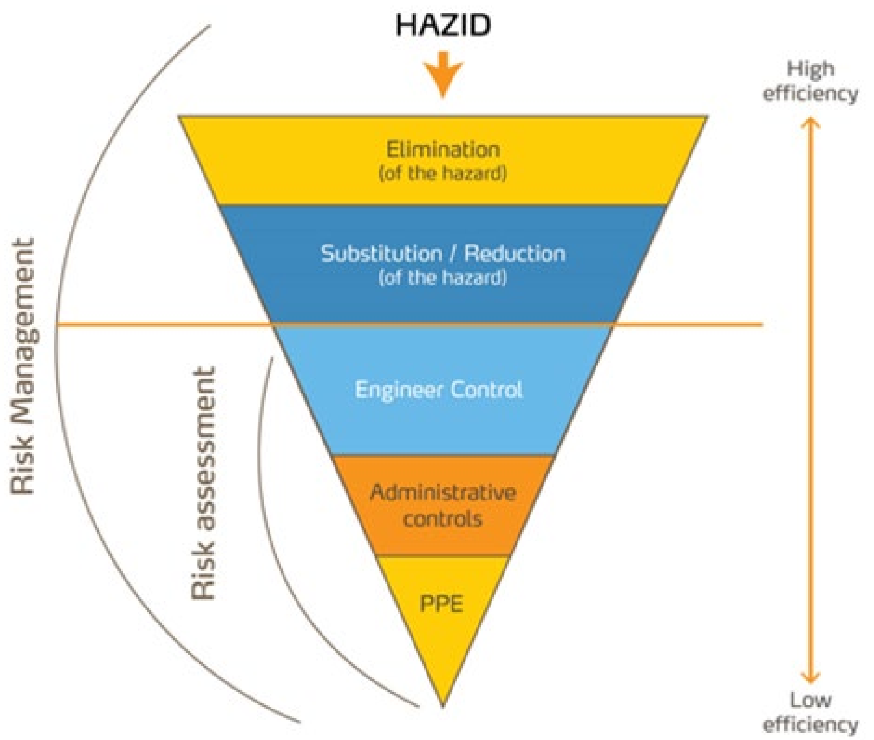
Ammonia Safety

Hazard isolation:

- Ammonia storage and associated equipment used for bunkering activity shall, as much as possible, be kept away from possible external impacts.
- Secondary confinement, for example a pipe in pipe system, associated with specific safety zones are very efficient in mitigating many possible leak consequences.

Hazard reduction:

- Liquid ammonia stored and handled in its' refrigerated and atmospheric form is inherently safer than warm and pressurized ammonia.



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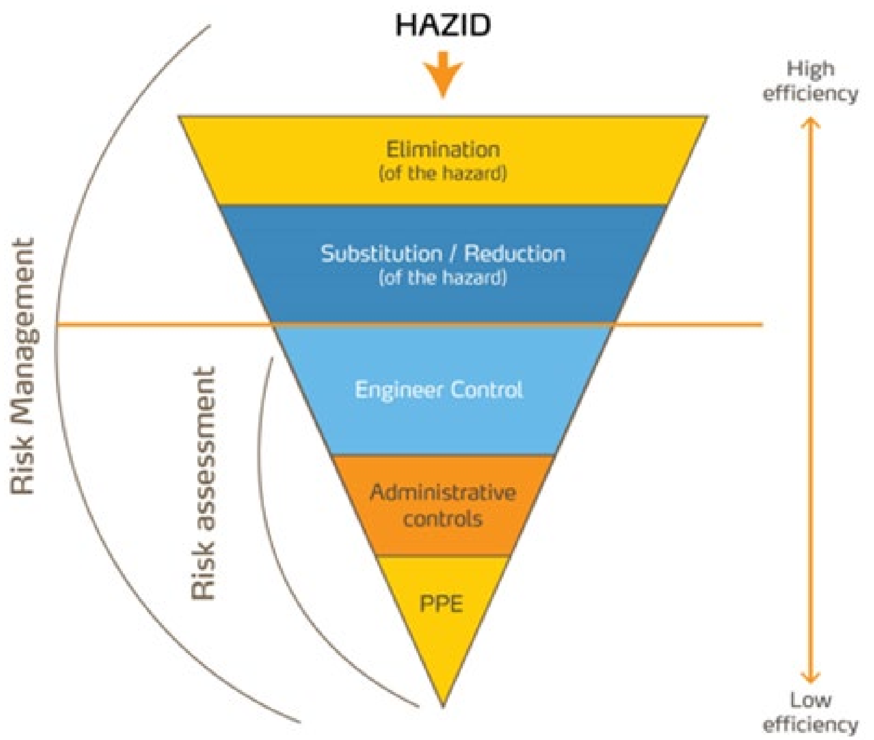
Ammonia Safety

Engineering Controls:

1. Material selection
2. Piping design pressure
3. Avoid and/or remove any operational release
4. Barriers to detect and handle unexpected loss of containment
5. Avoid human errors and manual connections with automated sequences

Administrative controls

- Operational procedures
- Emergency response etc.
- Training and safety culture!

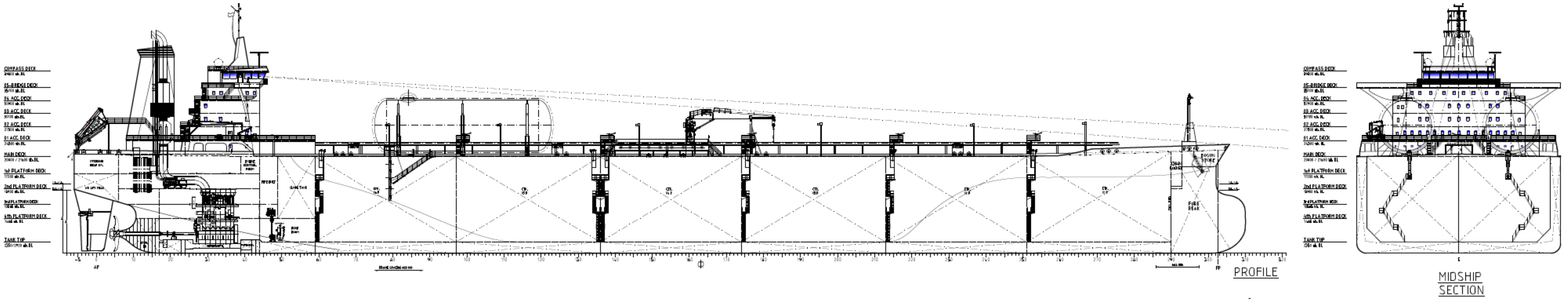


WP3 – Onboard Implementation

- Reliquefaction plant
- Fuel gas supply system
- Vent system
- ARMS system/boiler /inert gas

BREEZE Ship Design

Z 9501 111k
AFRAMAX TANKER FOR OIL & PRODUCTS



- Main engine
- Ammonia storage
- Stability
- Bunkering interface

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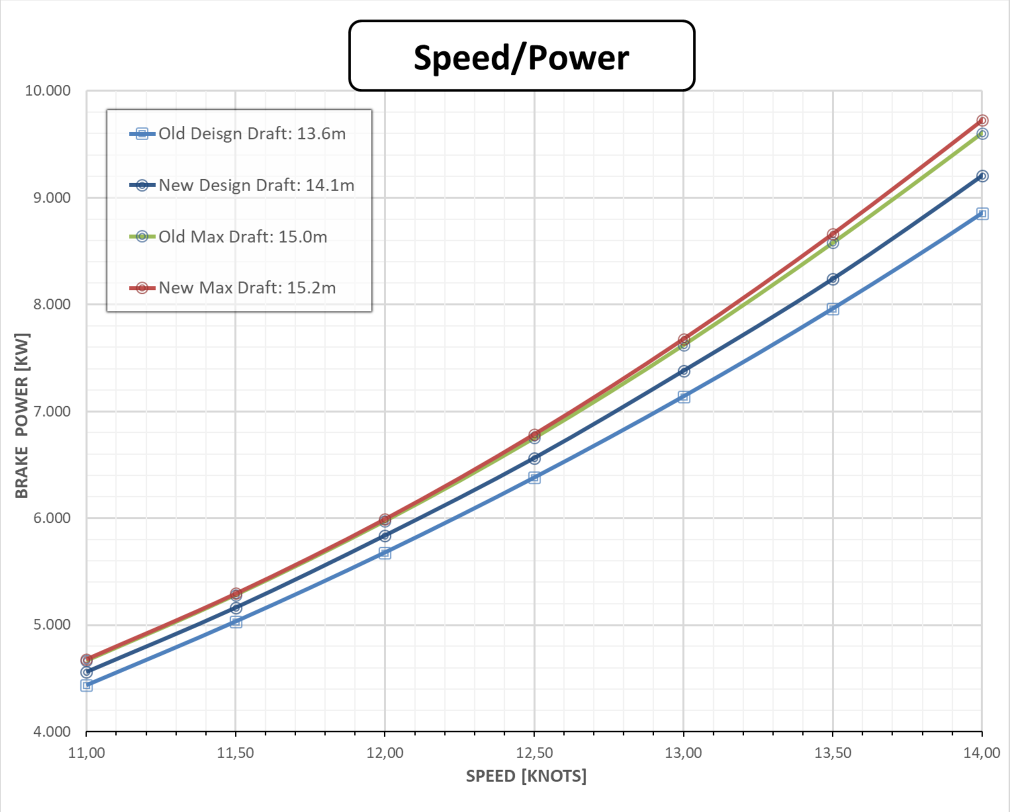
WP3 - Ship fuel consumption and stability

- Existing ship design and hull shape from Breeze
- Fuel tanks and gas equipment placed on deck
- Stability was verified accaptable, but trim was not optimal
- About 3% increased consumption due to new draft
- Ship design should be optimised for added equipment!
- 4 x fuel tanks could be possible (Færder Tankers)



Net fuel volume (m^3)					
Speed	Sailing Distance (NM)				
(knots)	5 000	7 500	10 000	12 500	15 000
13	2 170	3 151	4 131	5112	6092
12.5	2 075	3 003	3 931	4859	5787
12.	1 987	2 867	3 747	4627	5507
11.5	1902	2 735	3 568	4402	5235

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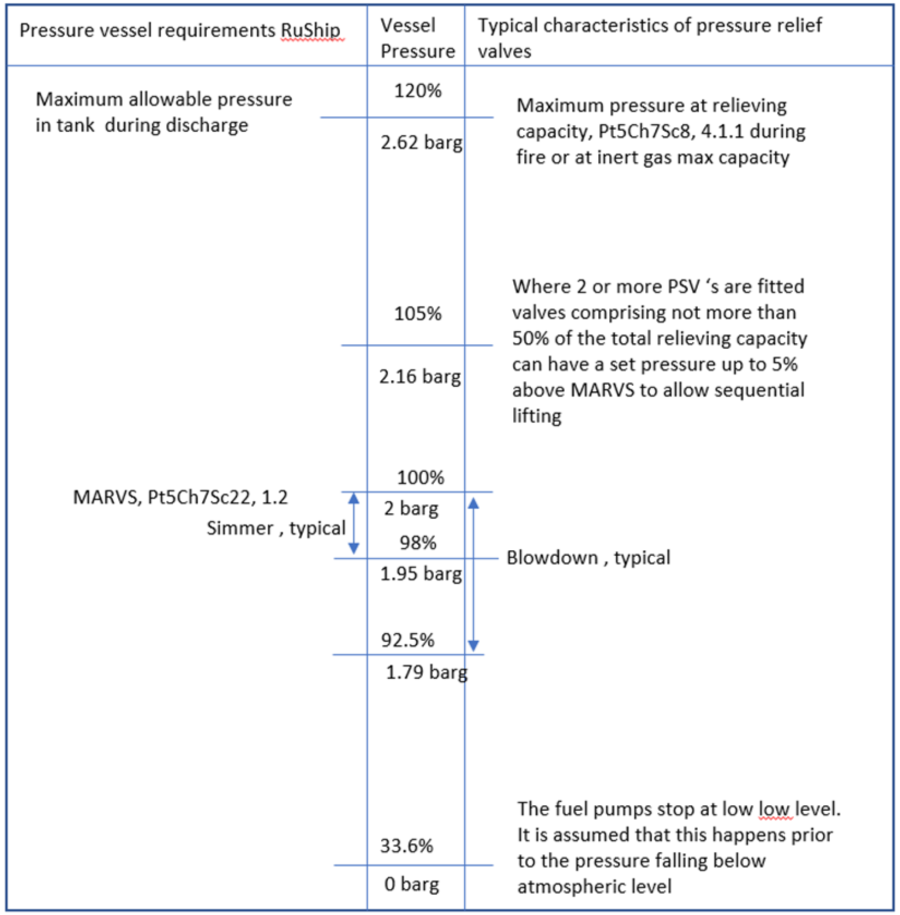
WP3 – Fuel Tank design

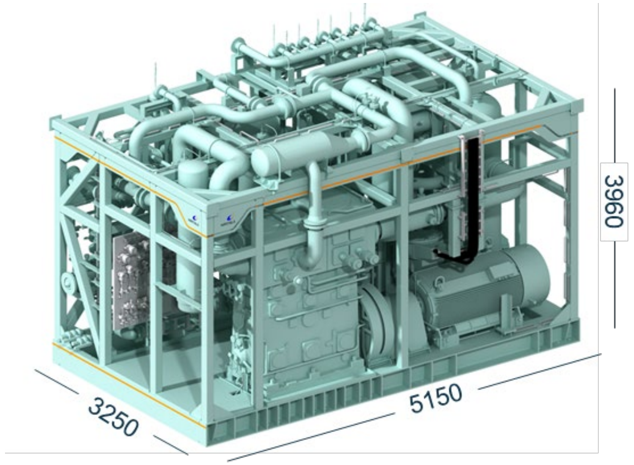
- Type C tanks selected
  - 2 x 3000m^3
  - 11m diameter, 38m long
  - Low cost material
- Fully refrigerated storage
  - Insulated tank
  - Boil off gas management
- Design pressure as low as possible
  - ~2.0 barg PSV setpoint
  - Increased loading limit (working volume of tank)

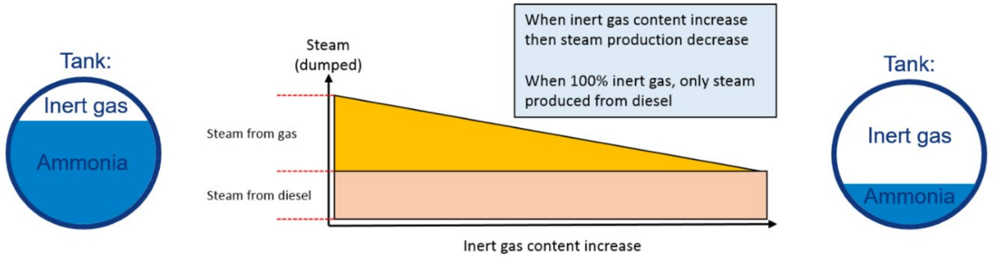


Loading conditions			Loading limit at T&P as a function of PSV setpoint					
Temperature	Pressure	Density	2 barg	3 barg	4 barg	5 barg	6 barg	7 barg
(C)	(barg)	(kg/m^3)	[%]	[%]	[%]	[%]	[%]	[%]
-33.326	0	681.97	93.53%	92.12%	90.93%	89.89%	88.97%	88.13%

WP3 - Reliquefaction plant / Oxidation / Burner

- Fuel tank BOG handling
  - Low pressure C-type tanks require redundant system for pressure control (in addition to insulation)
- Reliquefaction plant
  - Enables pressure control for fuel tanks
  - Conventional technology for gas carriers
  - Standard units oversized for BOG handling.
- Boilers and inert gas generators
  - Alfa Laval starts testing in small scale with NH_3
  - Based on LNG DF boiler principle
  - Can it potentially replace the ARMS??
  - Can it be used for inert gas generation (Cargo) and gas freeing (fuel tanks)??





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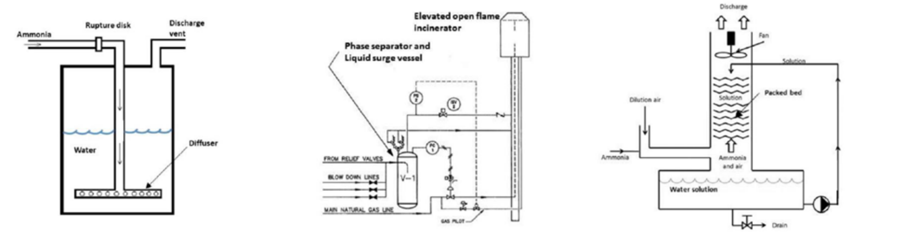
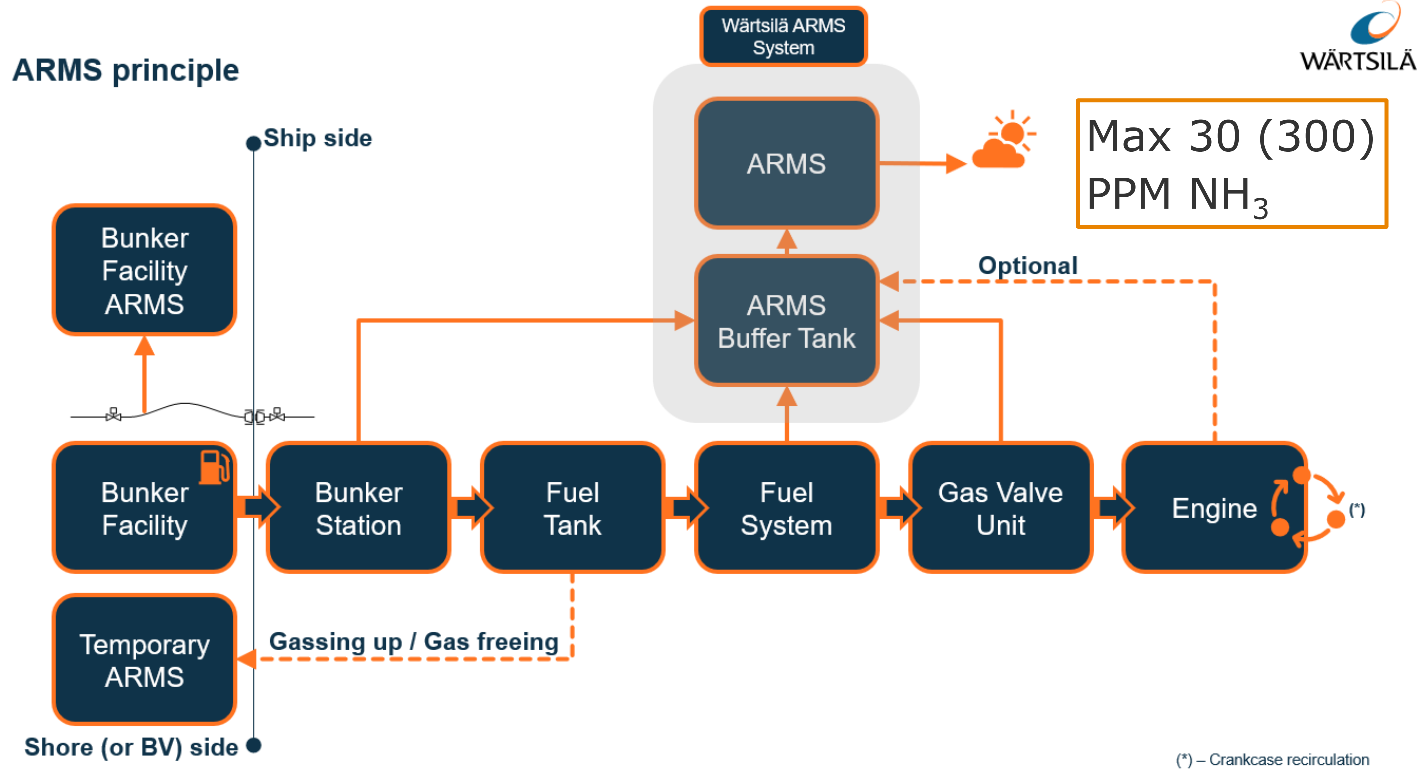
WP3 - Ammonia Release and Mitigation System (ARMS)

The ARMS regardless of its principles shall collect ammonia from piping and engine during purging or draining operations, handle releases from safety valves on piping system (not safety valves on fuel tanks) and any other operational releases.

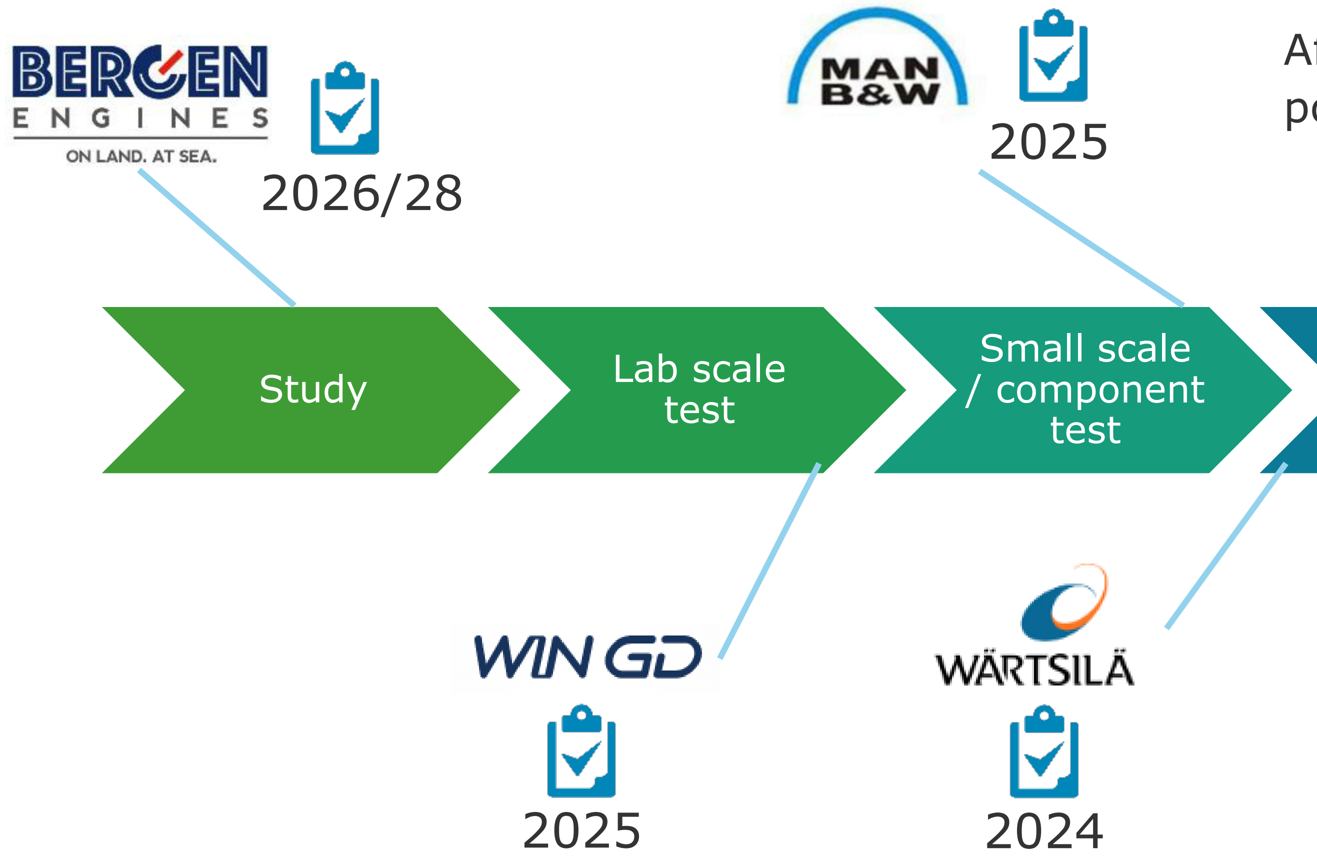
- ARMS system is key safety technology
  - GCU technology (Wartsila)
  - No operational emissions of NH_3
  - 0-100% ammonia capability
  - Available in 2023
- Other technologies exist:



Water diffusion tank | Ammonia Flare | Ammonia scrubber



WP3 - Ammonia engine technology development status



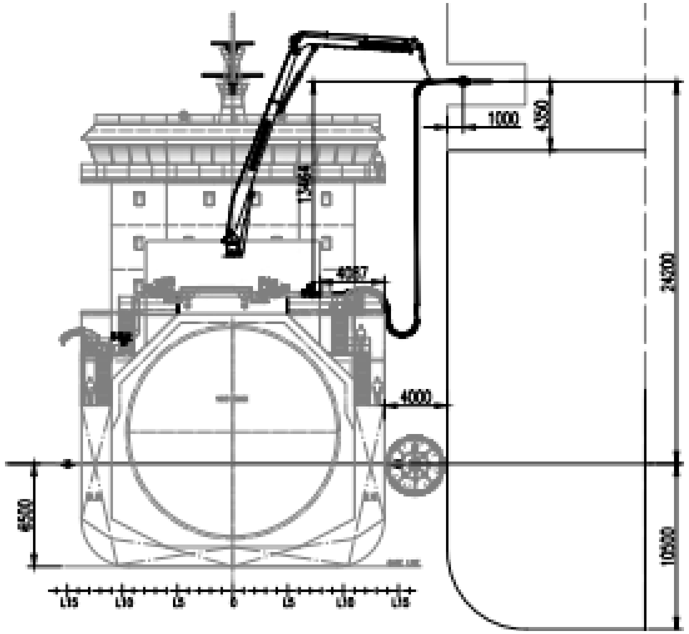
Aframax 2-stroke engine (60 bore) potentially available at Yard in 2025/2026

Important follow up points:

- Pilot fuel requirement (<5%?)
- N_2O formation, NOx and NH_3 slip (exhaust and engine internal)
- Impact on efficiency

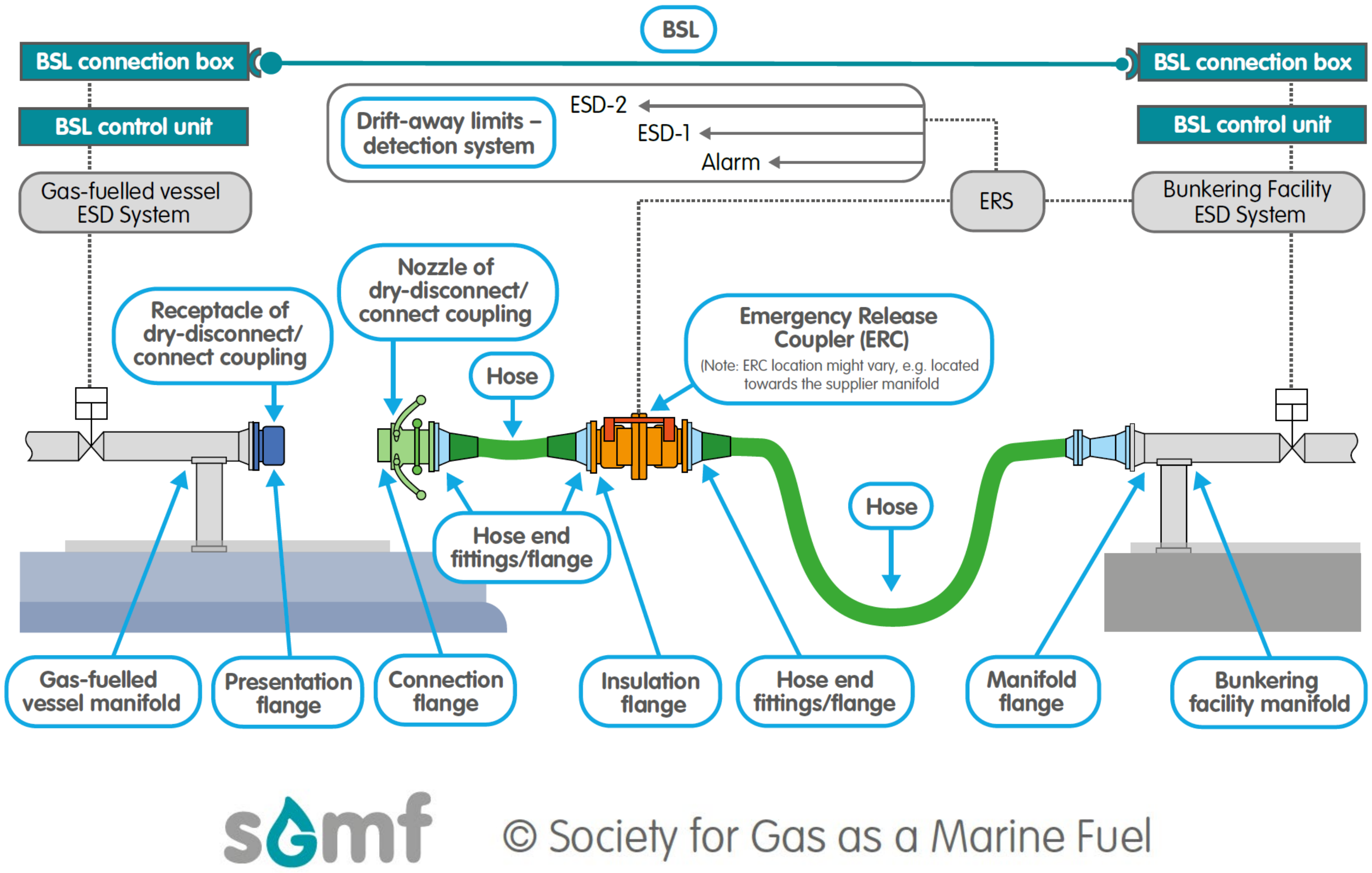
WP4 – Bunkering risks and mitigations for tankers

- Bunkering options for Ammonia Tanker
  - Base case: Ship to Ship bunkering, fully Refrigerated based on the Grieg Edge StS
- Bunkering of LNG vs. Ammonia and Ammonia cargo operations
  - Compare specific safety barriers related to ammonia versus LNG
  - Fire and Explosion risk vs Toxicity risk
- Bunkering of Ammonia – general development needs
  - Dedicated Ammonia Bunkering best practice / rules
  - Standardization and improved automated design and operation



WP4 – Bunkering arrangement

- Risk assessment and QRA
- Ammonia leak detection
- Automated operations
- Water spray system (water curtain)
- Contain liquid spills
- ESD response time
- Draining and inerting (ARMS)
- Safety zones
- PPE specific for NH_3
- Training program
- Safety leadership



Green Shipping Programme

Main Results for the Aframax pilot study

What we have learned:

- Clean ammonia can significantly reduce GHG emissions
- Clean ammonia have lower abatement cost than e-methanol
- ETS is currently too low;) - contracts for difference
- Feasible to integrate a DF ammonia system on an Aframax tanker (CAPEX comparable to LNG)
- Sufficient range for deepsea trade
- Safe cargo operations are proven on gas carriers
- Framework for safe design of fuel systems is maturing
- Ammonia technology is under development
- Ship to Ship is a flexible bunkering option for first movers
- Energy efficiency and reduction of fuel consumption is key in newbuild design utilizing clean fuels
- Tanker specific requirements (Inert gas and cargo pumps)

Whats next?

- Optimized ship concept development
  - Optimize energy efficiency and reduce fuel consumption
  - Layout and ship arrangement
  - Cargo operations (inert gas and pumps)
  - Shore power
- Ammonia specific equipment development
- Further derisking of ammonia fuel handling
  - Operators and crew training
  - Water curtain barrier efficiency
  - Liquid spill / spill to sea
  - Risk analysis of bunkering process (StS)
  - Synergy with Equinor ammonia PSV retrofit projects

Together with industry bring use of ammonia to required safety levels for cost efficient decarbonization of shipping!

Thanks to all contributors!