Ammonia-fueled ship designs of tomorrow

Case study: Nordic Green Ammonia Powered Ships (NoGAPS)

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Mærsk Mc-Kinney Møller Center
for Zero Carbon Shipping

Introducing M/S NoGAPS

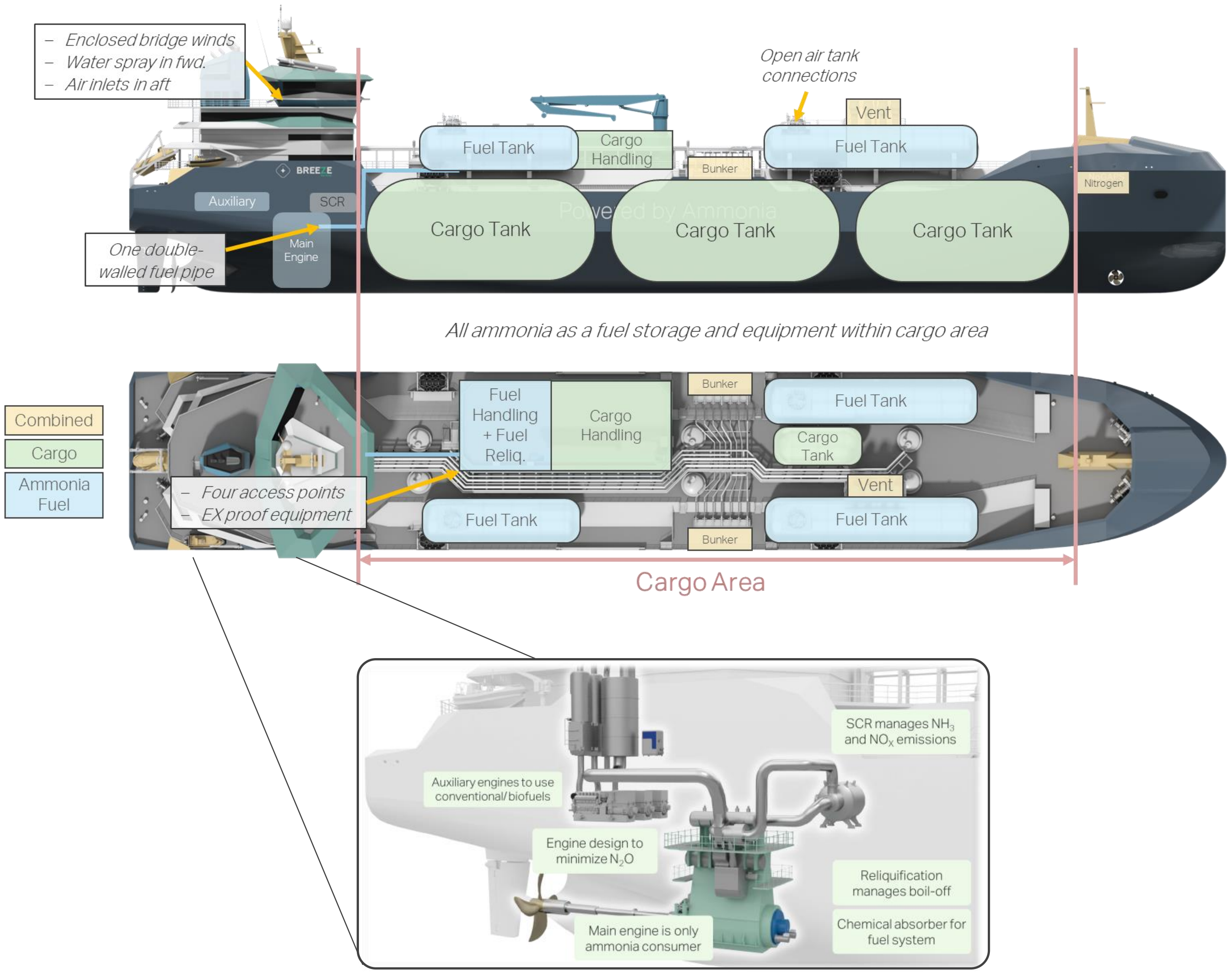
Design Objectives

- Confirm no major technical or regulatory obstacles are present to putting a vessel on the water
- Demonstrate a credible business model through meaningful risk and cost reductions

Design Requirements

- 22,000 m^3 gas carrier
- Semi-refrigerated cargo tanks (5.3 bar)
- Multi-gas, but main intended cargo commodity is ammonia
- Semi-refrigerated fuel tanks, 8 bar, -33.2C
- Intended route: Gulf of Mexico to Northern Europe (range on ammonia 12,000 nm)

Preliminary safety concept



Key considerations: risk, cost, emissions

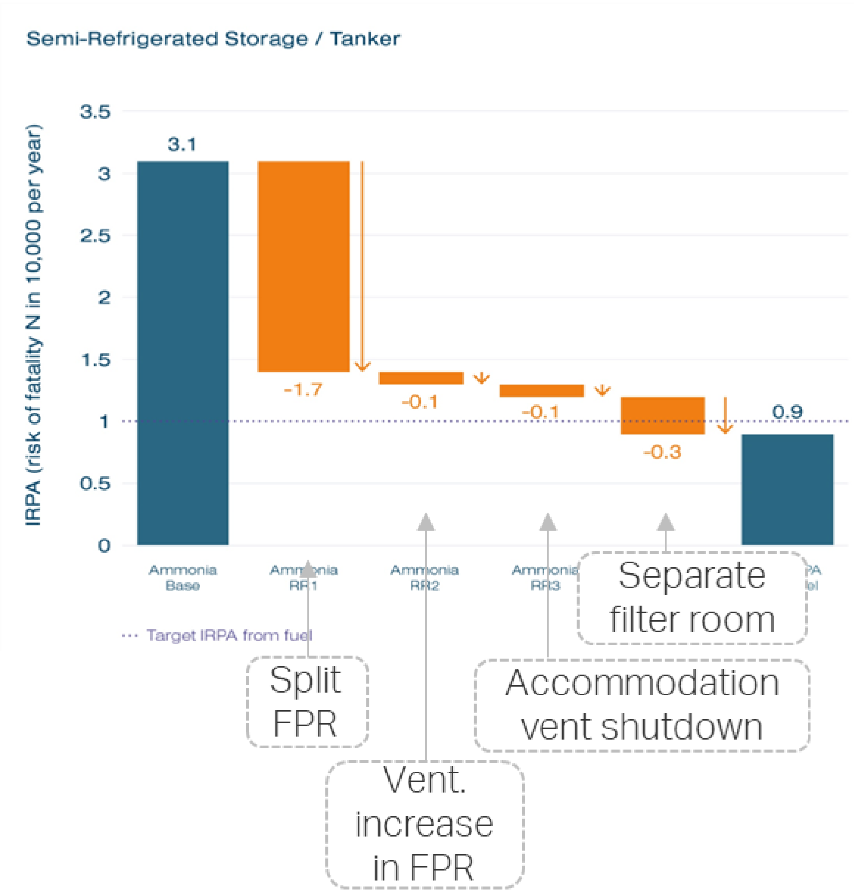
HAZID results

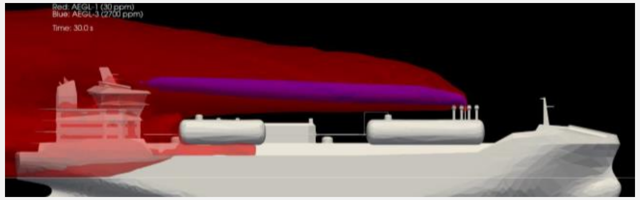
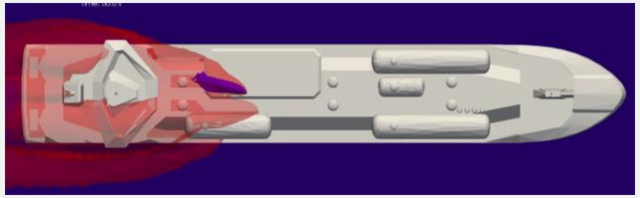
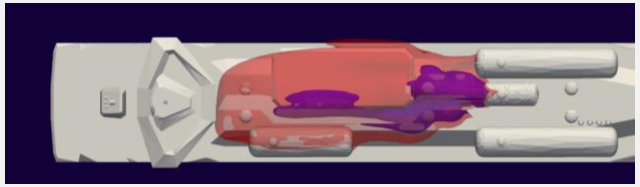
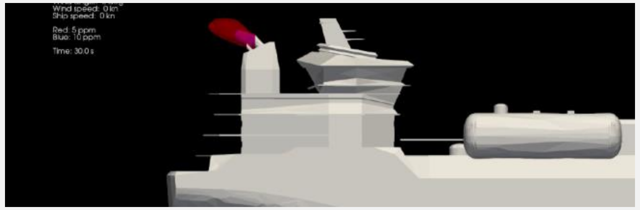
Frequency	Severity: 1 None	2 Minor	3 Significant	4 Severe	5 Catastrophic
5 Frequently					
4 Very likely					
3 Likely	1.3, 1.6, 3.8	1.2	1.4, 3.1, 3.3	6.1	
2 Unlikely		1.1, 1.5, 2.1, 2.3, 3.5, 3.6	2.2, 3.10, 6.[illegible]	3.2, 3.9	2.6, 4.1
1 Extremely remote					2.4, 2.5

Top Risks

- Fuel tanks: Loss of primary containment due to fire (2.4), explosion (2.5), impact or dropped object (2.6), connection failure
- Fuel handling room: leakage in valves/flanges (3.1), pipe rupture (3.2), heater/cooler leakage (3.3), trapped liquid (3.9)
- Rupture of high-pressure fuel piping on deck (6.1)
- Pipe rupture in engine room (4.1)

Projects should take advantage of new tools (QRA + gas dispersion)



Scenarios	Results
Vent mast	
Fuel preparation room ventilation outlet	
Pipe flange on deck	
Engine exhaust	

Further investigations needed to inform regulatory development

Ammonia releases/emissions

- Automated accommodation ventilation design with gas detection
- Water catcher/chemical absorber in fuel supply system and resulting ammonia water solution
- Ammonia slip from engines

Energy Efficiency

- Fuel cells, batteries, wind assisted propulsion, hullform optimization, …

Fuel Handling Room

- Automated ventilation design
- Fire fighting equipment
- Minimize crew time in fuel handling room

Emission Reduction

- NO_X and N_2O
- Pilot fuel: minimize amount and prepare for biofuel

Key considerations and lessons learned

- Gas carrier segment best to introduce ammonia as a fuel (with IGC Code update)
  - Ammonia-fueled gas carriers can also be designed as bunker vessels
- Early engagement with classification society and flag state critical
- Optimize the vessel's energy efficiency
- Take advantage of new tools to inform design decisions including QRA and gas dispersion
- Risk, cost and emissions were main drivers of design decisions
  - Main engine is only ammonia consumer with auxiliary engines using conventional/biofuels
  - Reduced number of fuel storage tanks
- We don't know everything yet
  - Close monitoring of the development and testing of ammonia dual-fuel engines and auxiliary technologies needed
- Follow-up and further develop risk mitigation measures identified in HAZID reviews

Thank you!

Let's stay in touch

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for Zero Carbon Shipping

NoGAPS 2 Partners

Global Maritime Forum

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BW Epic Kosan

Yara

MAN Energy Solutions
Future in the making

Wärtsilä

DNV

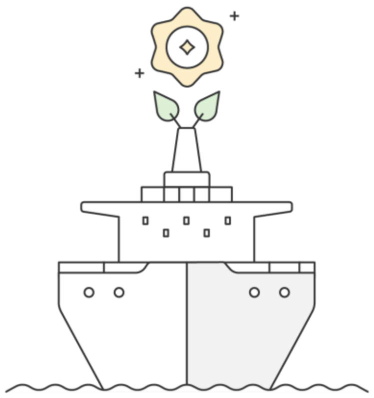
Co-funder
Nordic Innovation

Ship designer
Breeze

Flag state representative
Danish Maritime Authority

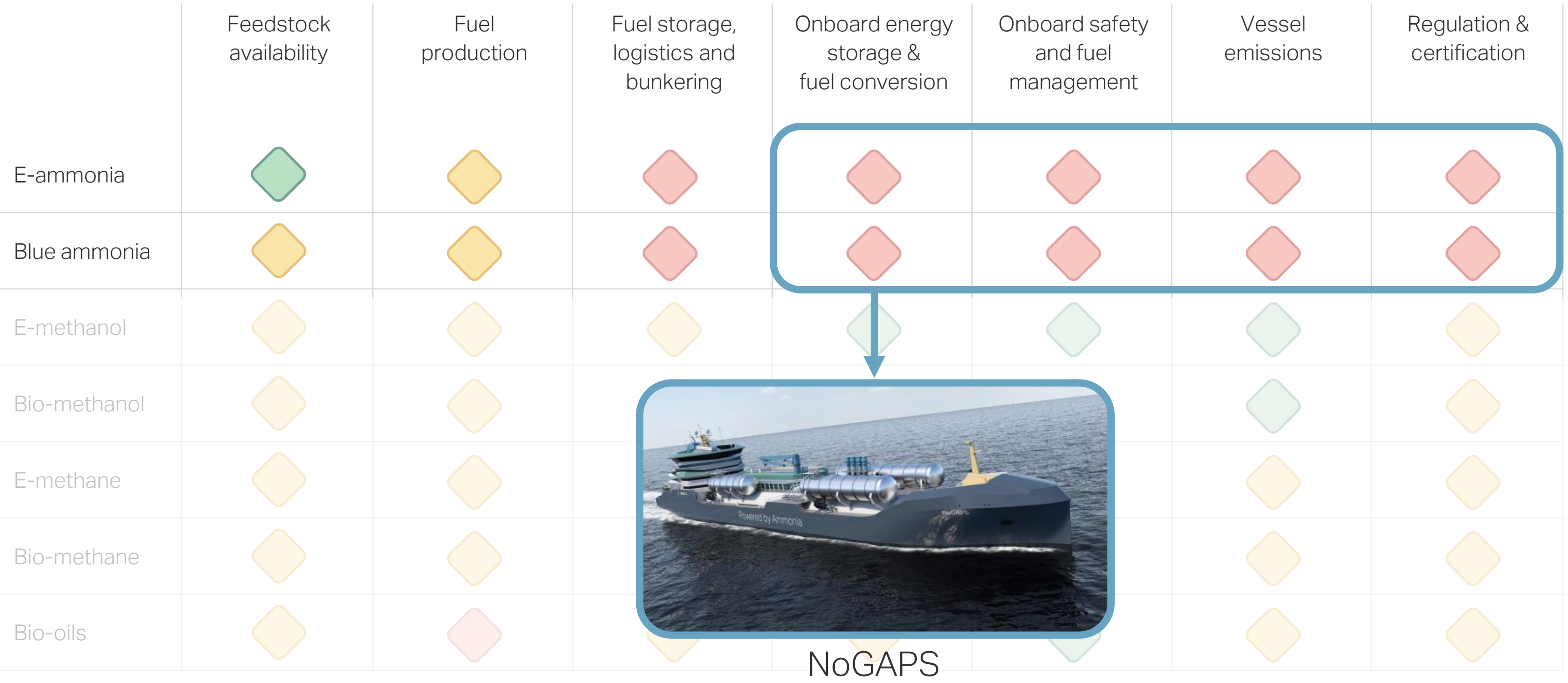
Critical challenges to onboard safety and operations

- Ammonia's toxic properties
- Absence of harmonized international rules
- Ammonia dispersion properties



- Development of novel system technologies (i.e., engines and fuel supply systems)
- Onboard risks to crew and needed upskilling
- Unknown emissions profile (N_2O, NO_X)

Developing integrated ship designs



MATURE

Solutions are available, none or marginal barriers identified.

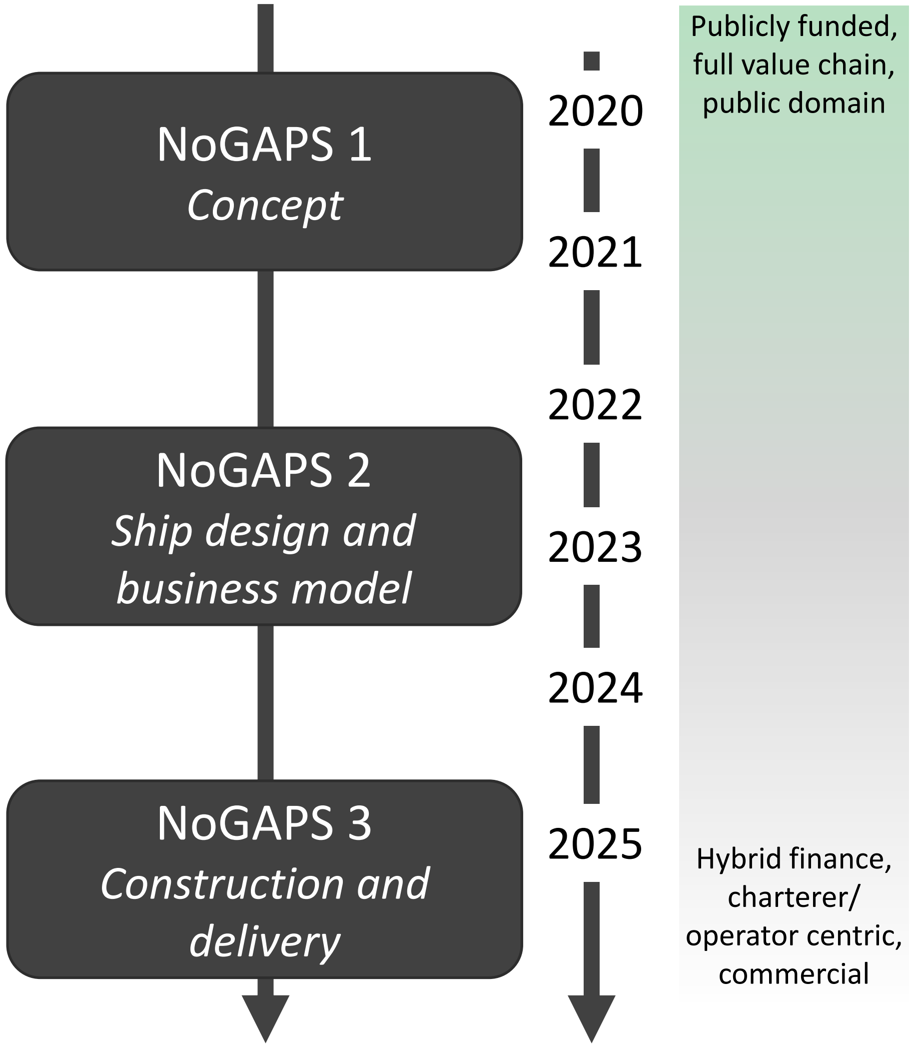
SOLUTIONS IDENTIFIED

Solutions exist, but some challenges on e.g., maturity and availability.

MAJOR CHALLENGES

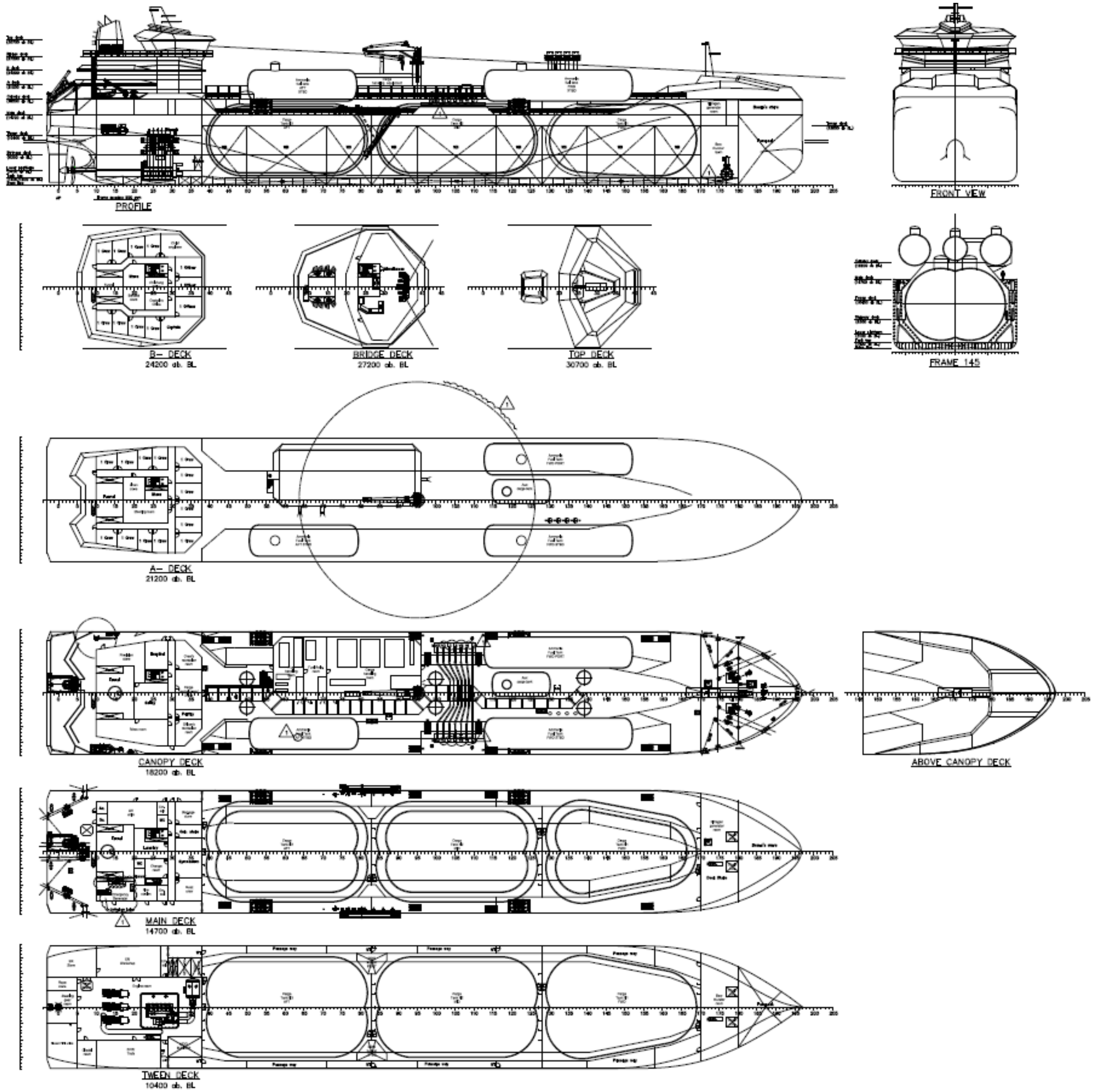
Solutions are not developed or lack specification.

From concept to reality



- The NoGAPS journey started by agreeing on a shared overall concept and identifying key issues to be addressed when developing specific solutions
- NoGAPS 2 sees some narrowing of focus toward the vessel and its design, operation, and economics, but a broader interaction with the ecosystem was still important to build support for the model and exchange knowledge
- NoGAPS 3 is now narrowing in on commercialization with a small group including ship owner, charterer and shipyards focused on constructing and delivering a vessel that will operate using ammonia as a fuel

Arrangement and main characteristics



MAIN DIMENSIONS

Length over all .... 160.00 m
Length PP .... 157.60 m
Breadth moulded .... 26.00 m
Depth, moulded .... 14.70 m
Design draft, moulded .... 9.28 m
Scantling draft, moulded .... 9.50 m
Deadweight, des. draught.......... 18.400 t
Deadweight, max. draught......... 19.820 t

SPEED & ENDURANCE

Service speed, ... 15.0 kn
Max. speed ....16.7 kn

Endurance (service speed)... 12.000 nm

CAPACITIES (100%)

Cargo tanks .... 22.200 m^3
MGO .... 929 m^3
BW .... 10.063 m^3
FW.. 452 m^3

CARGO EQUIPMENT

Segregations .... 2 (3 cargo tanks)
Cargo pumps (submerged) 6 x 400 m^3/h
Cargo pumps type .... Deep-well, electric
Discharge rate (6 simult.).......2 400 m^3/h

NH_3 FUEL TANKS

NH_3 ....2.669 m^3
Pressure .... 8.0 barg

FUEL CONSUMPTION

(Service speed, design draft, 15% SM, no PTO engaged)

Fuel consumption, NH_3 .... 48.8 t/d
Fuel consumption, MGO (pilot) .. 1.87 t/d

ACCOMMODATION

- 27 + 6 Suez Crew all in single cabins

PROPULSION / MACHINERY

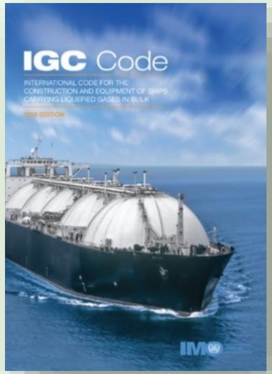
- 2-stroke 6G50ME-C9.6-Ammonia HL main engine
  1 x 7,200 kW at 93.0 r/min
- 4 stroke Wärtsilä Generating sets
  3 x 1,255 kWe 6L20
- Shaft generator (PTO) 1,000 kWe
- 1 CP Propeller, dia. 5.8 m
- 1 x Emergency diesel generator 129kW
- 1 x Bow thruster 1500 kW
- 1 x Ballast water treatment system 1000m3/h

CLASSIFICATION

✠1A Tanker for Liquefied Gas, Ship type 2G(-48C, 700kg/m3, 5.3bar) GF NH3, Clean design, E0, NAUT(OC), BNOM, BIS, TNOM, BWM (T), Recyclable, DNV Ice Class 1A

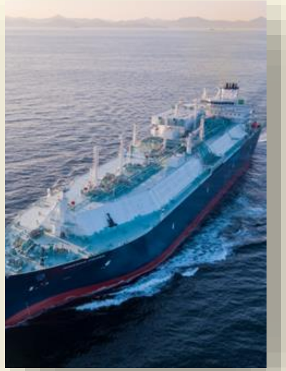
Regulatory approach

IGC Code and DNV Rules as a basis



- Ch.16 of the IGC Code covers cargo as fuel
- IGC Code is mainly written for methane (LNG) cargo as fuel, but §16.9 in the IGC Code allows for alternative fuel products
- Unlike IGF Code, IGC Code prohibits toxic products as fuel
- DNV Rules for Liquified Gas Carriers can accept use of ammonia subject to agreement with flag administration

Equivalent safety as methane (LNG) cargo as a fuel

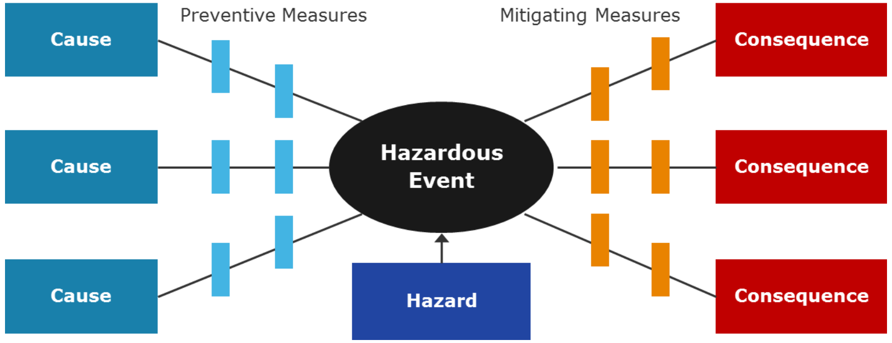


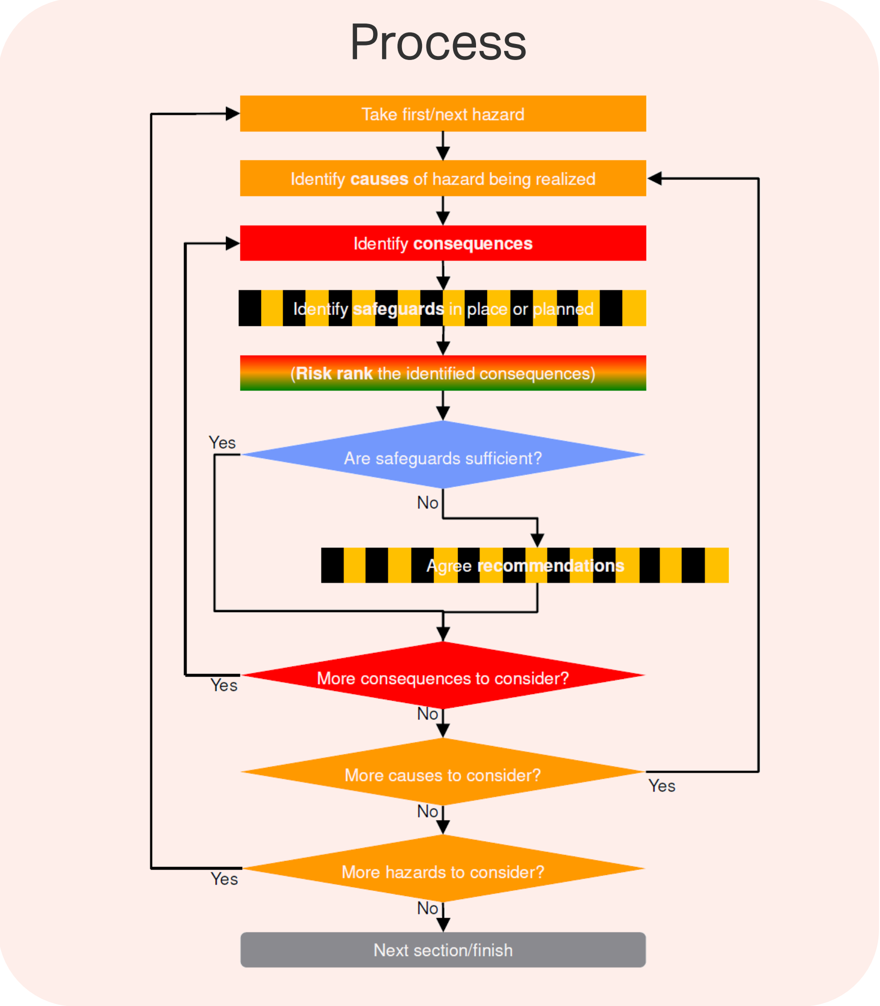
- NoGAPS project and planned AIP is only a high-level review of relevant early design documentation
- A hazard-based on ALARP principle is found to be appropriate level to document similar safety for NH3 as fuel compared to Methane (LNG)
- When potential vessel is made, then full compliance with rules must be done

HAZID methodology

– **HAZID** is a structured team-based review technique to identify hazards associated with a particular concept, design, operation or activity

– **HAZID** is one of the most effective approaches to identify major accident hazards with the expertise and knowledge of a competent and experienced workshop team represented by people from design, construction and operation





Source: DNV

HAZID results and top risks

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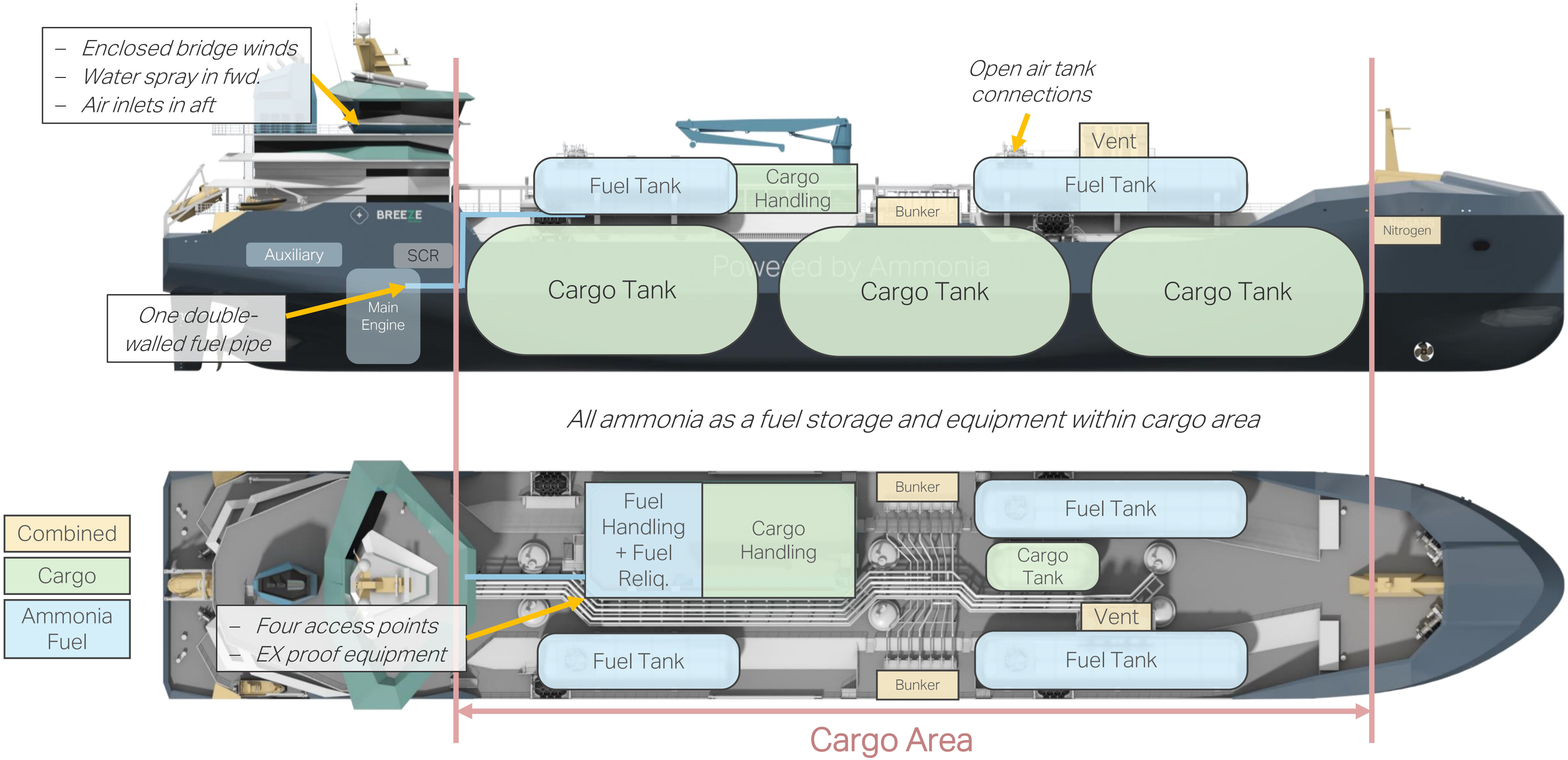
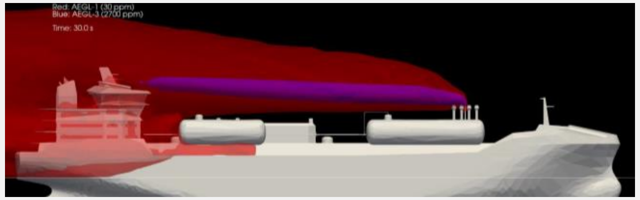


Gas dispersion scenarios and analysis

Classification	10 min	30 min	1 h	4 h	8 h	End Point (Reference)
AEGL-1 (nondisabling)	30 ppm (21 mg/m^3)	30 ppm (21 mg/m^3)	30 ppm (21 mg/m^3)	30 ppm (21 mg/m^3)	30 ppm (21 mg/m^3)	Mild irritation (MacEwen *et al.*,1970)
AEGL-2 (disabling)	220 ppm (154 mg/m^3)	220 ppm (154 mg/m^3)	160 ppm (112 mg/m^3)	110 ppm (77 mg/m^3)	110 ppm (77 mg/m^3)	Irritation: eyes and throat; urge to cough (Verberk, 1977)
AEGL-3 (lethal)	2,700 ppm (1,888 mg/m^3)	1,600 ppm (1,119 mg/m^3)	1,100 ppm (769 mg/m^3)	550 ppm (385 mg/m^3)	390 ppm (273 mg/m^3)	Lethality (Kapeghian *et al.*, 1982; MacEwen & Vernot, 1972)

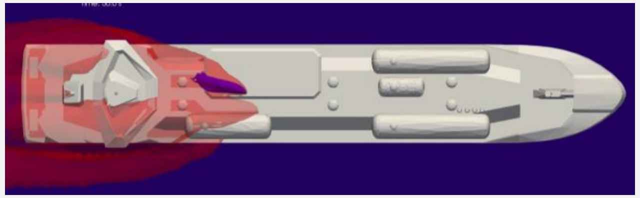
Scenarios | Results | Findings

Vent mast



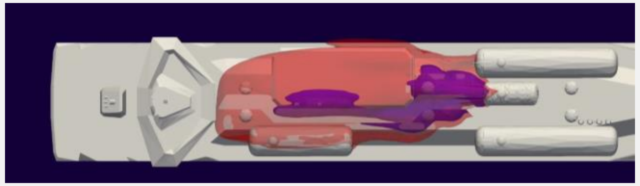
- 30ppm gas cloud will cover accommodation
- 2,700ppm gas cloud avoids accommodation and deck level
- Slightly changing vessel direction can reduce risk

Fuel preparation room ventilation outlet



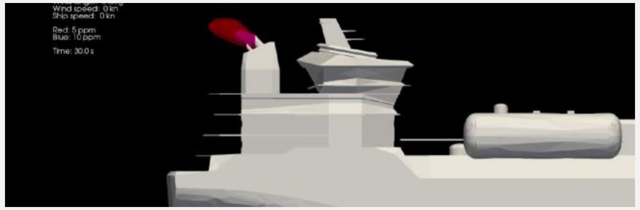
- 30ppm gas cloud will cover accommodation
- 2,700ppm gas cloud closer to deck area and accommodation
- Assumed leakage rate impacts final hazardous zones

Pipe flange on deck



- Highest risk identified from the analysis; risk mitigation measures needed
- 2,700ppm gas cloud covers deck area

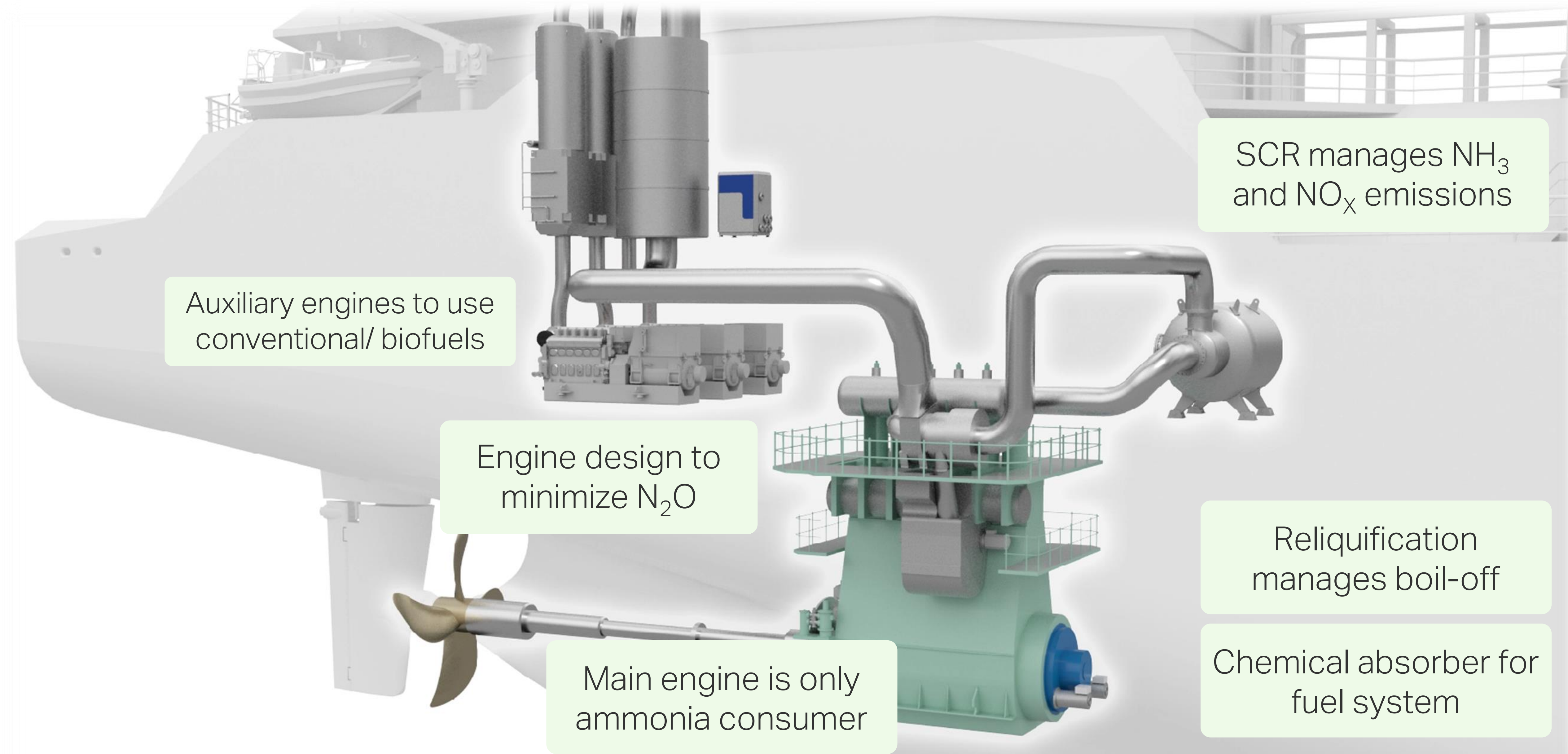
Engine exhaust



- Ammonia slip in engine exhaust is quickly diluted to sufficiently safe levels (<5ppm)
- Same applies for 10ppm and 30ppm cases, which can inform current Class guideline updates and regulation development

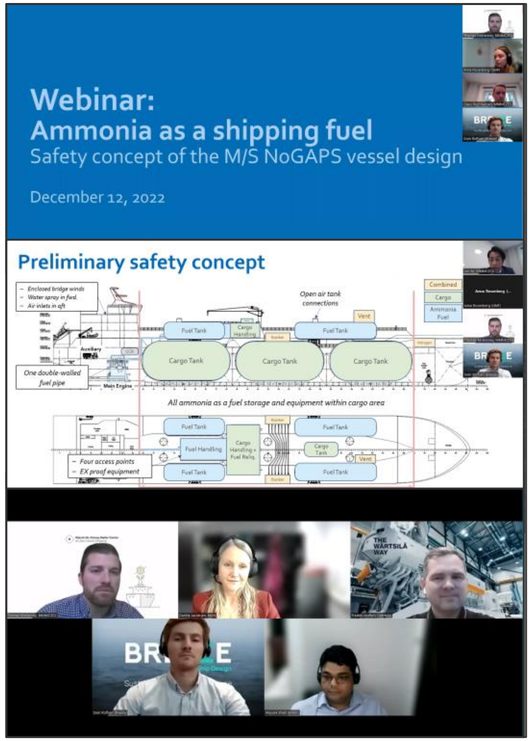
AGEL Table: Danasa, A & Soesilo, Tri & Martono, Dwi & Sodri, A & Hadi, A & Chandrasa, Ganesha. (2019). The ammonia release hazard and risk assessment: A case study of urea fertilizer industry in Indonesia. IOP Conference Series: Earth and Environmental Science. 399. 012087. 10.1088/1755-1315/399/1/012087.

Key considerations: risk, cost, emissions

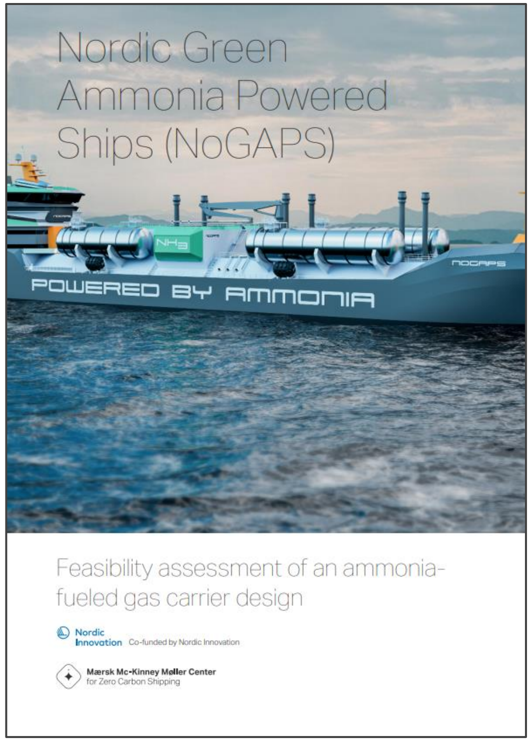


Project deliverables = actionable industry guidance

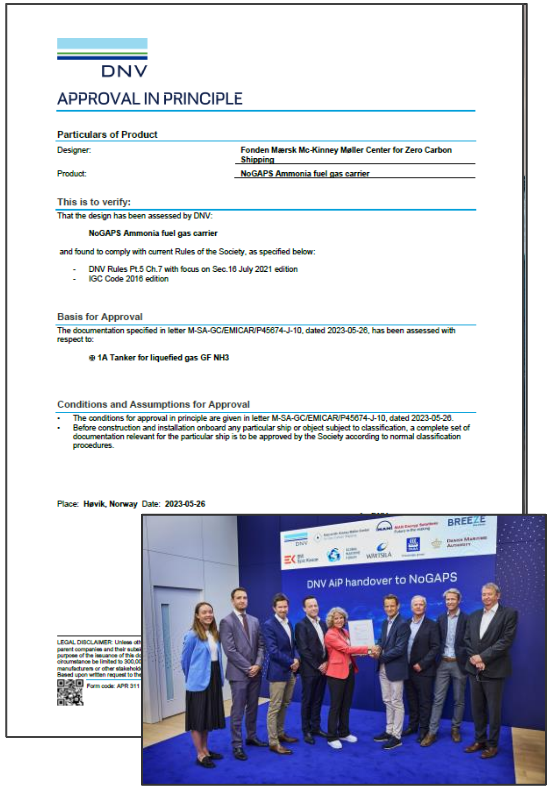
Webinar (Dec. 12th)



Feasibility report (Mar. 29th)



Approval in Principle (Jun. 7th)



Final report (Aug. 31st)