Global Centre for
MARITIME DECARBONISATION

Realising ammonia bunkering:
Insights from ammonia transfers in the Pilbara

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Global Centre for Maritime Decarbonisation (GCMD)

Ammonia transfers between the Green Pioneer and the Navigator Global at the outer anchorage of Port Dampier

4,000 m^3 (2,700 MT) of liquid ammonia was transferred at 700-800 m^3/h from the Green Pioneer to the Navigator Global and back

GCMD's mission

Our goal is to help international shipping decarbonise along a trajectory that meets or exceeds key targets, including reaching net zero around 2050.

We do this by:

Shaping standards	Financing projects	Deploying solutions	Fostering collaboration
We **share learnings** from our projects at relevant national and international technical committee meetings **to assist and accelerate the drafting of guidelines and standards.**	We **co-fund projects,** especially ones that lack immediate commercial viability or ones that may not lead to commercial returns, so learnings may lower the barrier for adoption.	We **rally partners** and **execute projects** to demonstrate the viability of decarbonisation solutions.	We provide **neutral ground** for stakeholders across the value chain to convene, ensuring a **diversity of inputs** to scope and operationalise pilots.

Partners support our mission

Global Centre for MARITIME DECARBONISATION

Founders/ Strategic partners

BHP · Rio Tinto · Eastern Pacific Shipping · DNV · MPA Singapore · ONE Ocean Network Express · Seatrium · bp · Hanwha Ocean · Hapag-Lloyd · NYK Line Nippon Yusen Kaisha · PSA

Impact partners

BCG · the human energy company (Chevron) · gard · MOL Mitsui O.S.K. Lines · msc · Olympic Shipping and Management S.A.

Coalition partners

IBIA · International Chamber of Shipping Established 1921 · IWSA International Windship Association · OGCI Oil and Gas Climate Initiative · SSA Singapore Shipping Association · SGMF

Knowledge partners

ADB · Global Maritime Forum · GSBN · KPLER · Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping · SINTEF

Enabling partners

KIRI Capital

And ~100 project partners

Enabling ammonia as a marine fuel*

ADVARIO · Asiatic Lloyd · BHP · bp · DNV · Eastern Pacific Shipping · Fratelli Cosulich · gard · Hong Lam Marine · James Fisher Fendercare · Jurong Port · Kenoil · MOL Mitsui O.S.K. Lines · National Metrology Centre · Navigator Gas · NYK Line · ONE Ocean Network Express · OSRL · Pavilion Energy · PIL · Pilbara Ports Authority · PSA · Rio Tinto · SeaTech Trusted Solutions · Seatrium · TCOMS · Viswa Group · Vopak · VPS · Yara

Assuring the quality, quantity and emissions abatement of drop-in green fuels*

Angelicoussis Group · AngloAmerican · Astomos Energy · Authentix The Authority in Authentication · AVL · BCG · BHP · bp · BunkerTrace · the human energy company (Chevron) · CMA CGM · Controlunion · Eastern Pacific Shipping · FincoEnergies · Hapag-Lloyd · 汇盛生物 HUISON · IDS Group · MAN Energy Solutions · MTM Maran Tankers Management Inc. · NYK Line Nippon Yusen Kaisha · ONE Ocean Network Express · PIL · Saybolt · Stena Bulk · Swire Bulk · TotalEnergies · Viswa Group · VPS

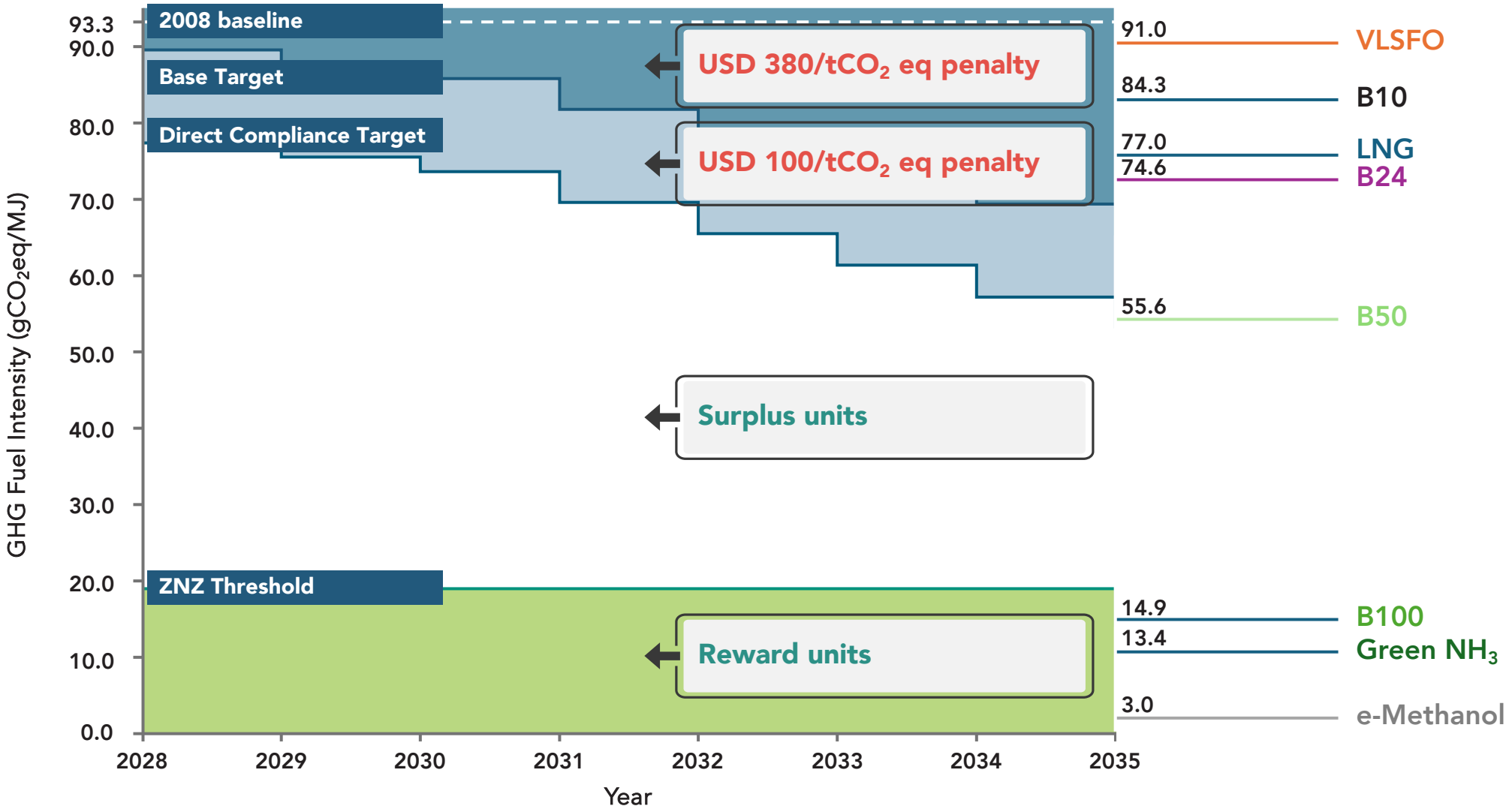
Unlocking the carbon value chain

ABS · ADVARIO · Alfa Laval · BCG · BHP · BW Epic Kosan · bp · the human energy company (Chevron) · DELTAMARIN · Eastern Pacific Shipping · Emerson · Endress+Hauser · gard · Hapag-Lloyd · Jurong Port · K Line Kawasaki Kisen Kaisha · Lloyd's Register · MPA Singapore · Navigator Gas · OGCI Oil and Gas Climate Initiative · Panasia · Pavilion Energy · Port of Rotterdam · PSA · SSA Singapore Shipping Association · SLNG Singapore LNG · Shell · SeaTech Trusted Solutions · Seatrium · Stena Bulk · TNO innovation for life · Woodside Energy

** Initiatives partially funded by MPA; partners for the initiative "Scaling the Adoption of Energy Efficiency Technologies" will be announced soon*

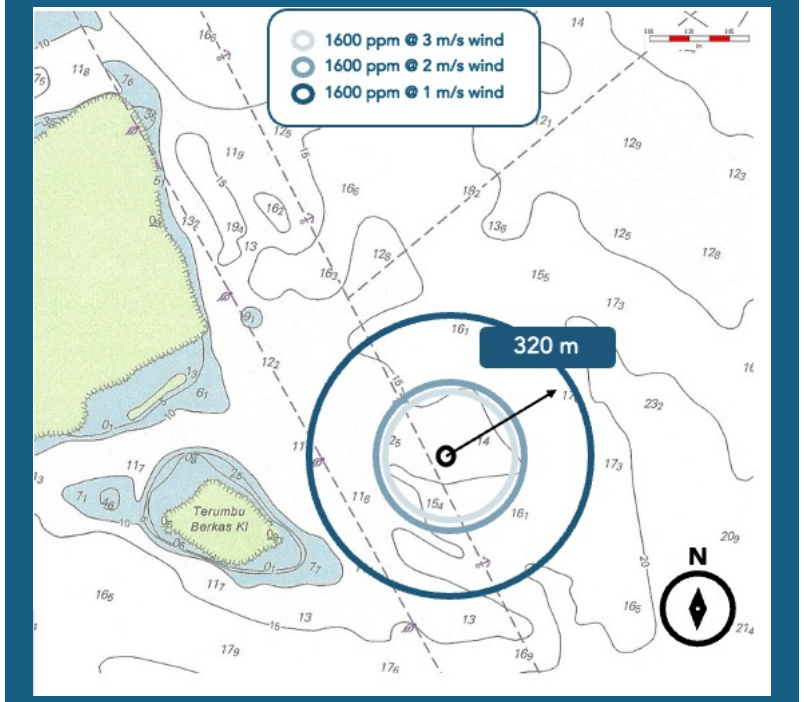
IMO's adopts landmark measure to price GHG emissions

Clearest signal yet: Switch fuels to minimise total operations cost



Mobilised ecosystem for ammonia bunkering safety study

With DNV, Surbana Jurong, Singapore Maritime Academy; in consultation with MPA



Singapore ammonia bunker demand

- Projected to take off in mid-2030's; around **2 MTPA by 2035**
- Can be supported by one **15,000 cbm** bunker vessel

Operational and location risks

- **400** operational and locational risks identified across 4 concept designs and 3 locations
- All considered **low** or **mitigable**

Industry development and training

- Guidebook incorporated into SMA's curriculum
- Learnings incorporated in SGMF's interim bunkering guidelines
- Collaborated with OSRL to develop emergency response plans

8 regulatory agencies consulted

Covering the following areas:

- Fire and chemical safety
- Major hazards assessment
- Industrial land utilisation
- National climate change

Project partners

Potential first mover in green ammonia

Bulk carriers delivering iron ore from point to point between Western Australia-Northeast Asia

A Potential Port for Ammonia

- **5%** of all tradeable ammonia are currently supplied through Dampier
- Start of the busiest iron ore route
- About **7,700** vessel calls in the Pilbara Ports for 2023
- Potential demand of **1-1.5** million tonnes of bunker by 2035

Source: Kpler, 11 Oct 2024
Vessel traffic for iron-ore carrying capesize and newcastle max bulk carriers

Goal of our pilot in Pilbara

*To showcase **lightering** and simulate **bunkering** operations before ammonia-fuelled vessels are available*

Four areas of focus:

01 | Operational procedures

02 | Safety protocols

03 | Safety + risk assessments

04 | Emergency response protocols

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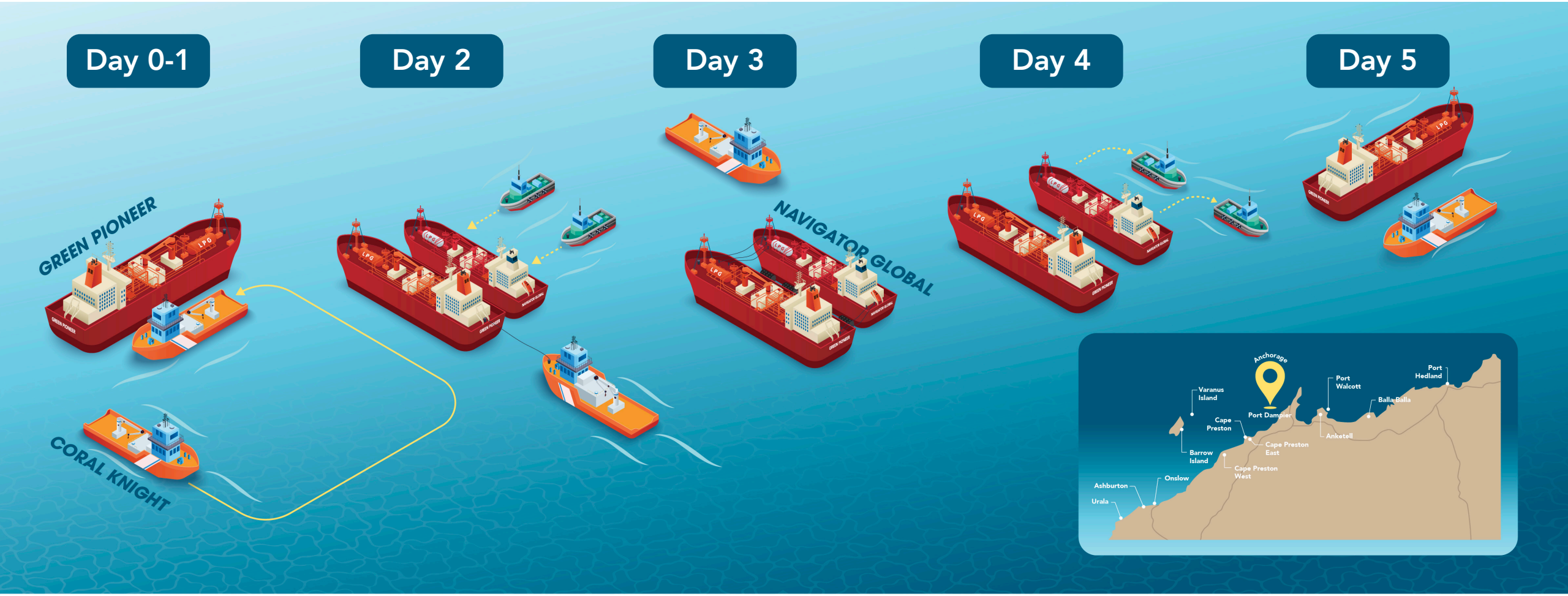
Five-day operations at the anchorage of Port Dampier

4,000 cbm (2,700 tonnes) of liquid ammonia was transferred at 700-800 cbm/h from the Green Pioneer to the Navigator Global and back

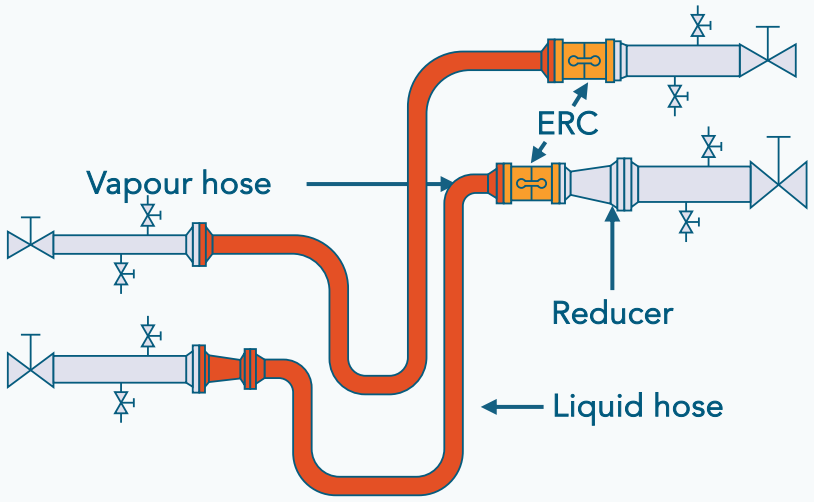


PILBARA PORTS · Yara Clean Ammonia · MOL Mitsui O.S.K. Lines · NAVIGATOR GAS · BHP · bp · DNV · EASTERN PACIFIC SHIPPING · gard · James Fisher Fendercare · OSRL · RioTinto · FCOMS

Transfer system arrangement

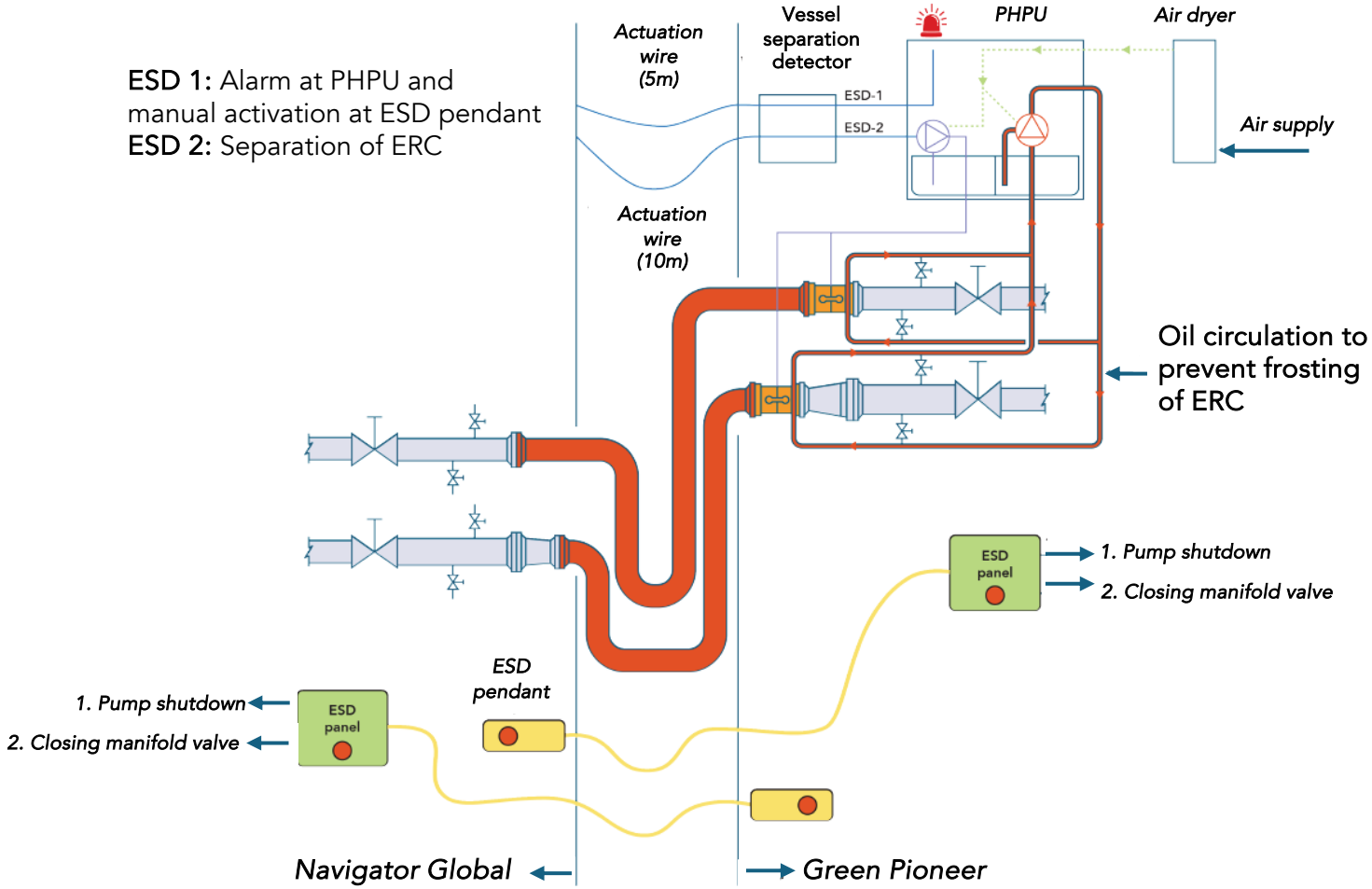
Equipped with emergency shutdown (ESD) and emergency release couplings (ERC)

Transfer system arrangement



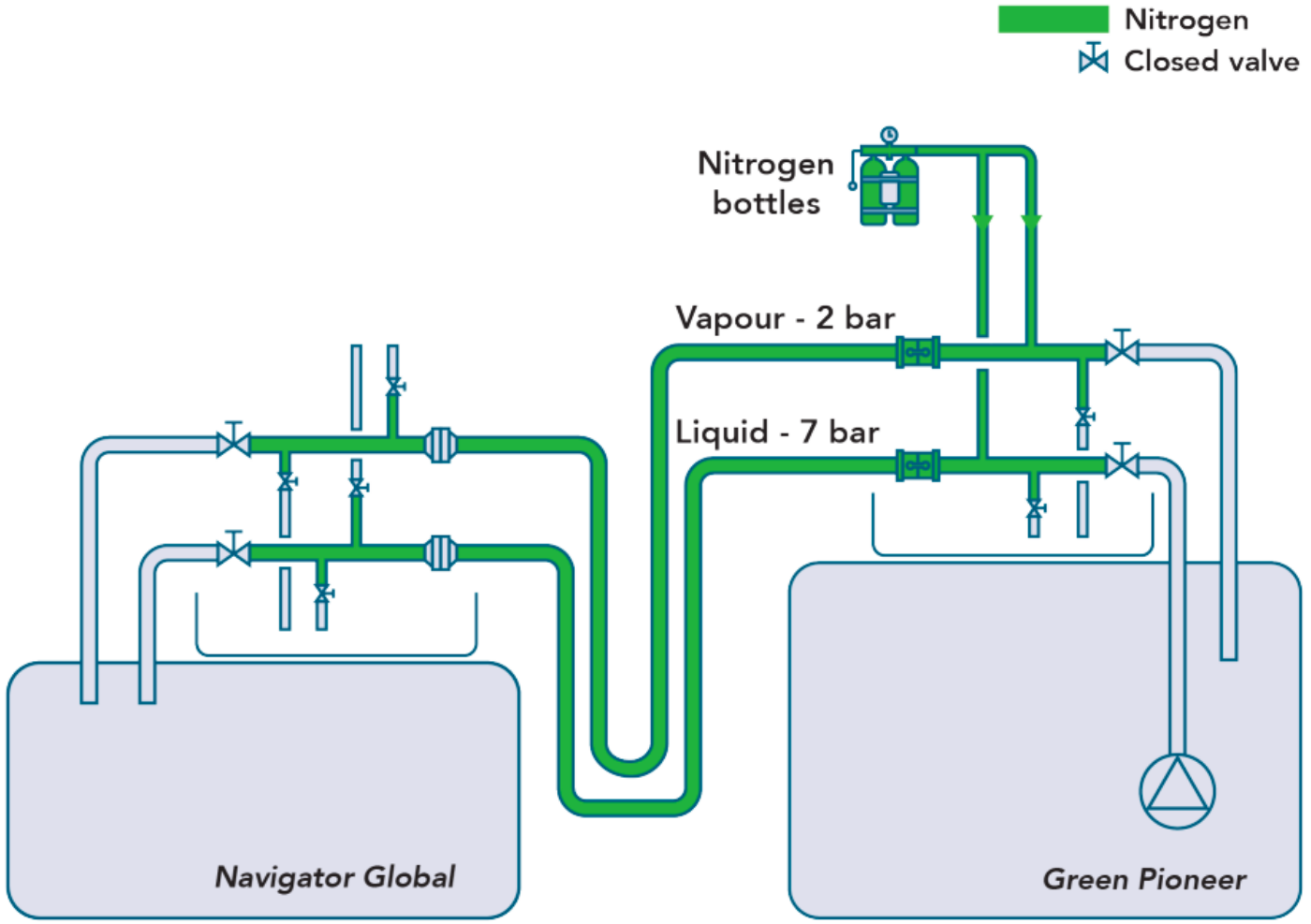
Procedures	Proxy bunkering
Manifold connection	Emergency release coupling on the receiving vessel
Vapour line	Vapour return line connected
Lines connection	One liquid line connected

ESD and ERC arrangements



Leak test

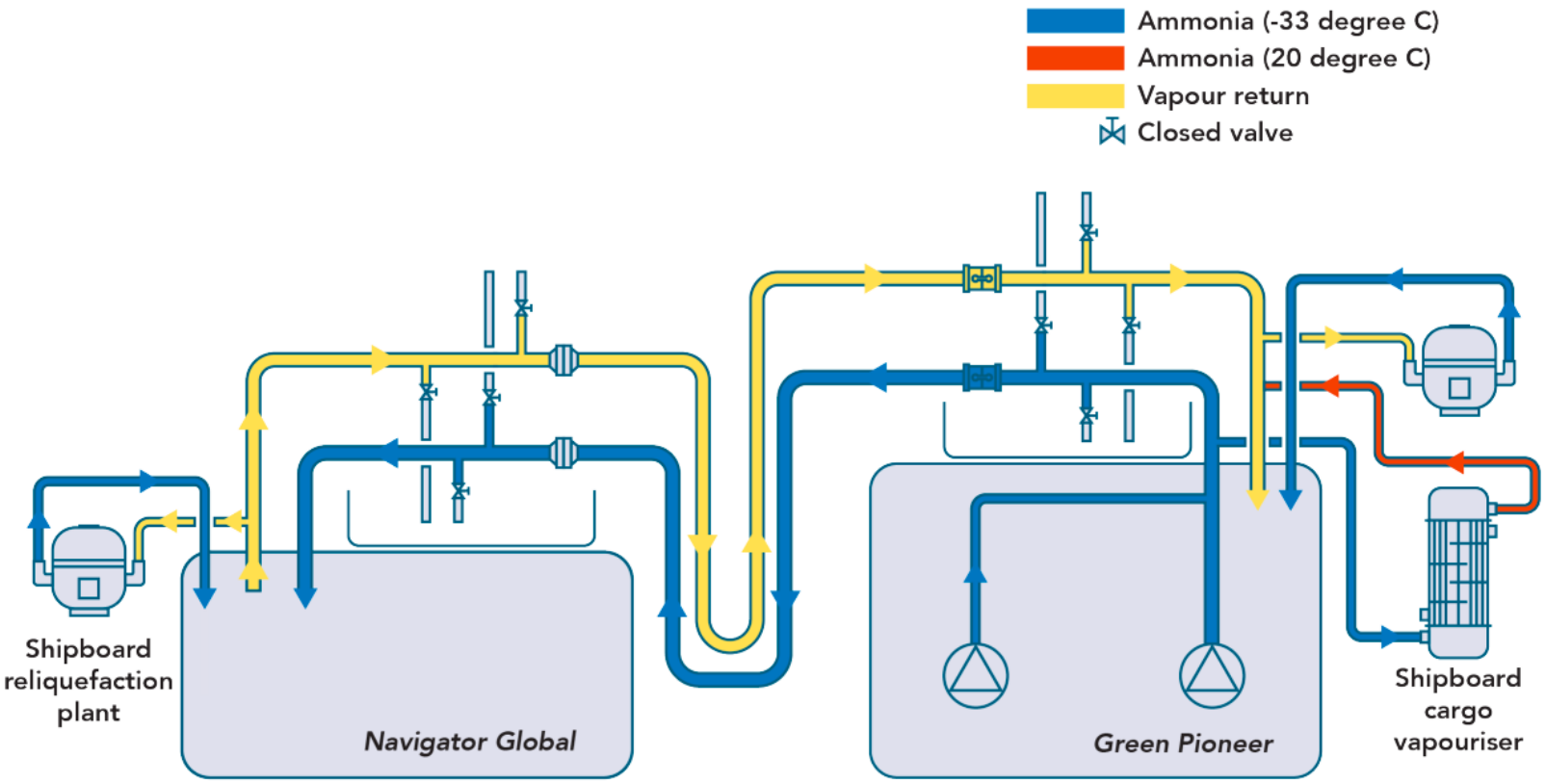
- Nitrogen introduced through the *Green Pioneer*'s manifold vent
- Liquid line tested at 7 bar; vapour return line tested at 2 bar
- Hose connections were checked for leaks using a soap solution.
- Nitrogen was released through the *Navigator Global's* manifold drain.



Ammonia transfer #1

From the Green Pioneer to the Navigator Global

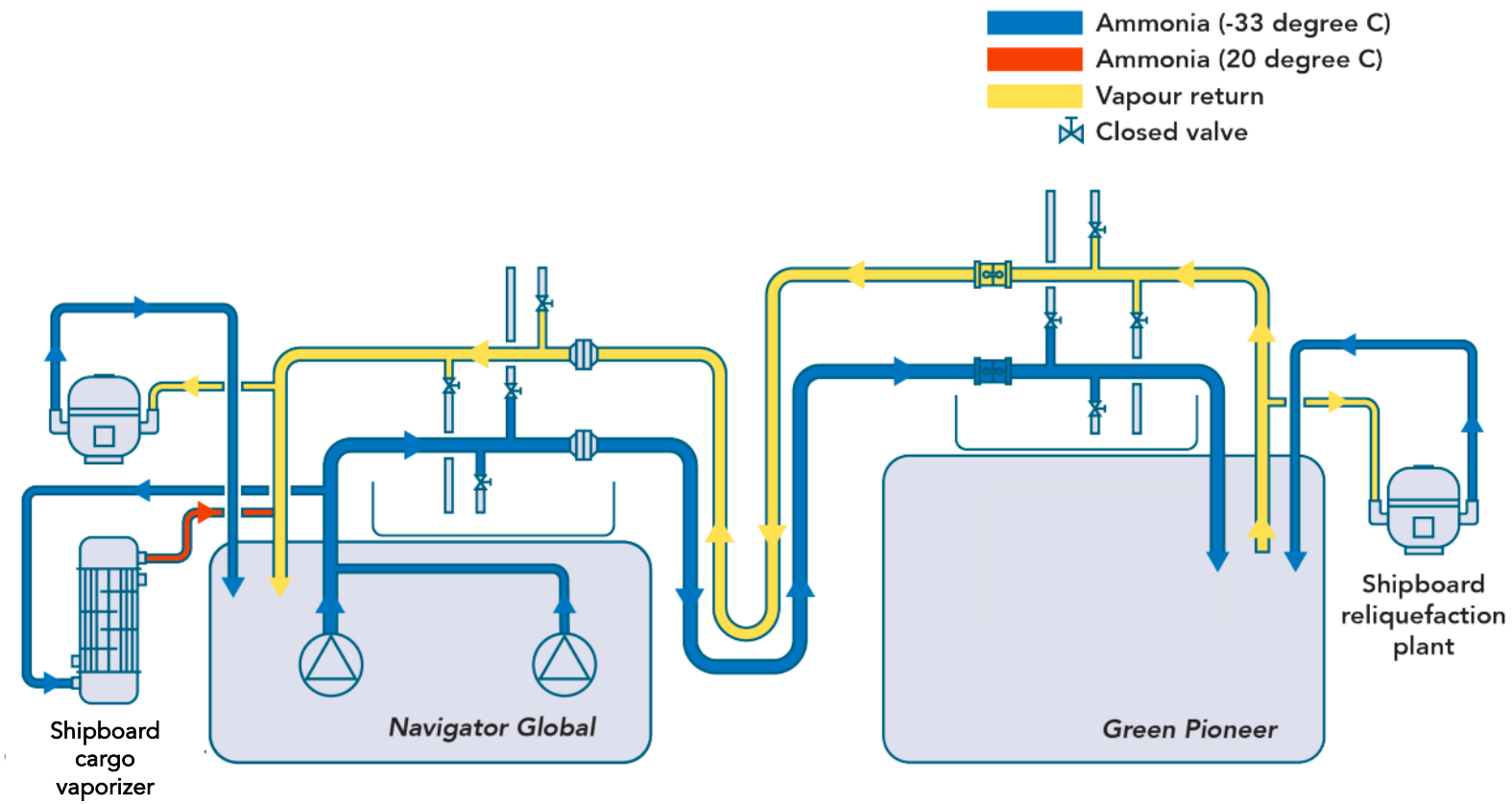
- 4,000 m³ of liquid ammonia transferred
- Initial flow rate: 100 m³/hr (15 min)
- Maximum flow rate: 700 m³/hr
- The *Green Pioneer* maintained positive tank pressure using its cargo vaporiser.
- Vapour generated during transfer primarily processed by *Navigator Global's reliquefaction plant*



Ammonia transfer #2

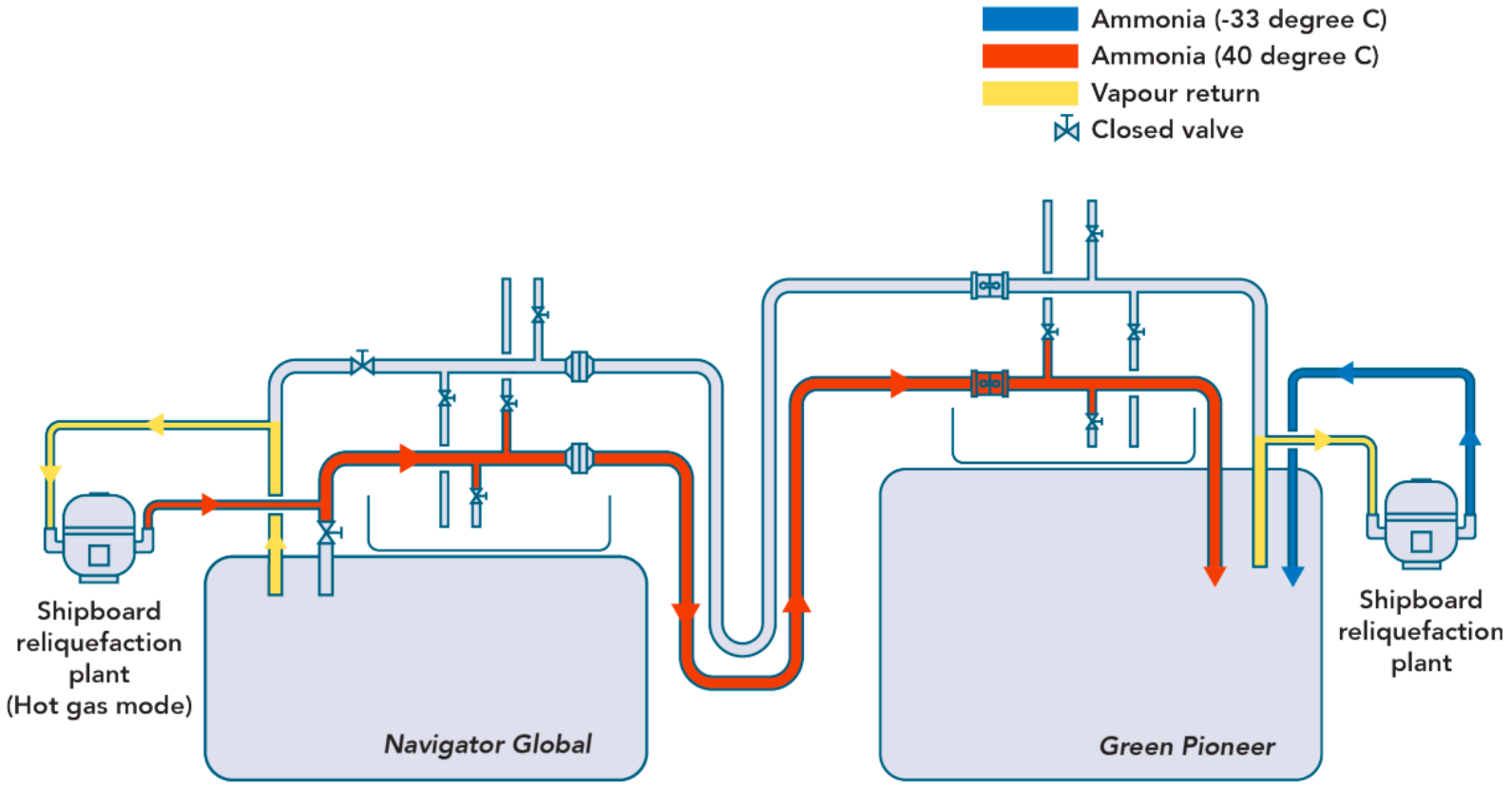
From the Navigator Global to the Green Pioneer

- 4,000 m³ liquid ammonia transferred back to the *Green Pioneer*
- Initial flow rate: 100 m³/hr (15 min) to cool down lines and monitor any abnormal conditions
- Maximum flow rate: 700 m³/hr
- The *Navigator Global* maintained positive tank pressure using its cargo vaporizer.
- Vapour generated during transfer primarily processed by the *Green Pioneer's reliquefaction plant* and/ or sent back to the *Navigator Global*



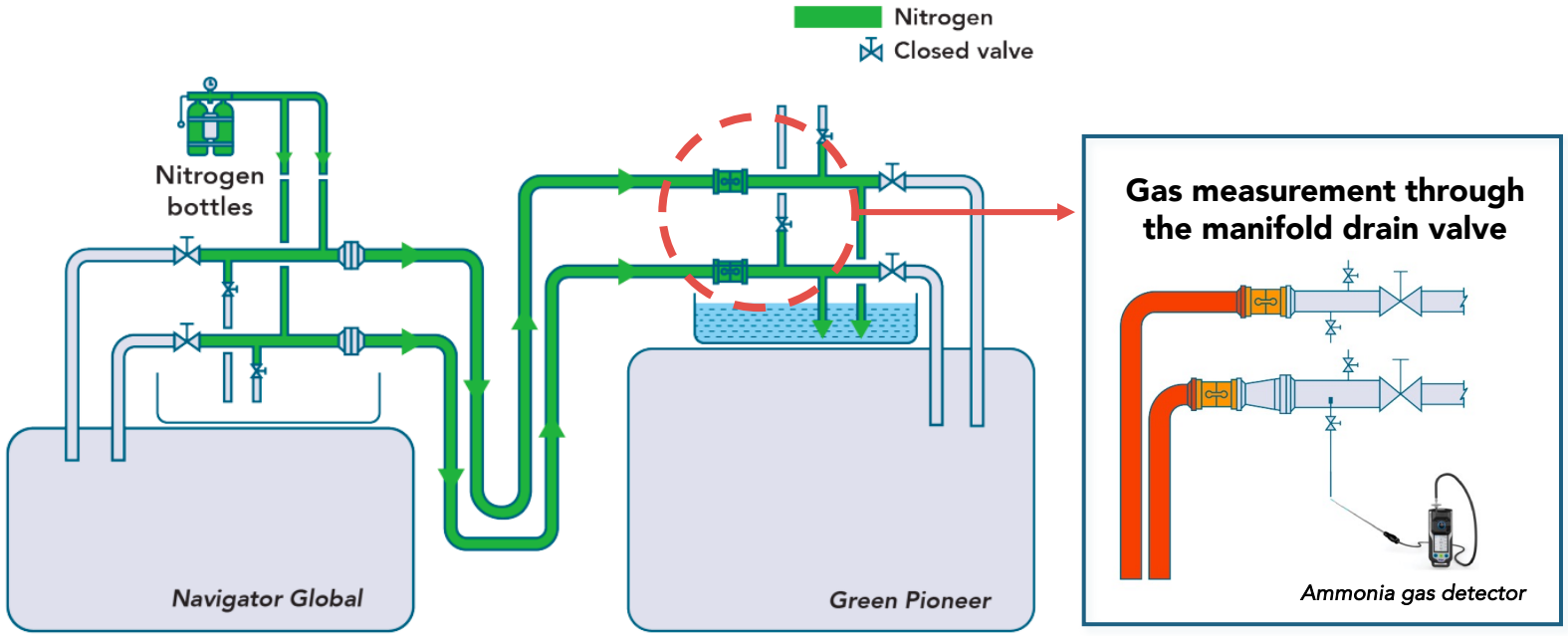
Hot gassing

- Warm ammonia at 40°C is introduced into the liquid line.
- Fire hose from each vessel supplied a continuous seawater spray at ambient temperature onto the 'U' bend section of the liquid line.
- This process continued for ~ two hours until the lines warmed to ambient temperature.
- As the vapour return line did not contain liquid ammonia, hot gassing was not required for this line.

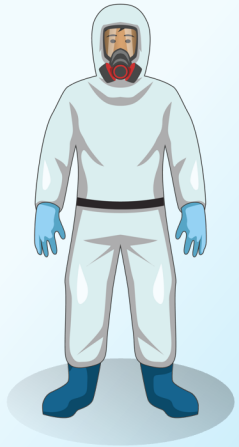


Nitrogen purging

- Nitrogen cylinders were connected to the *Navigator Global's* manifold vent.
- First blow through was directed to the *Green Pioneer's* cargo tank
- Lines were purged for ~10 min; nitrogen released into manifold drip tray filled with water on the *Green Pioneer*
- Before disconnection, gas measurements ensured an ammonia concentration below 300 ppm
- Ammonia detector recorded a concentration of 7 ppm; well within the safety limits



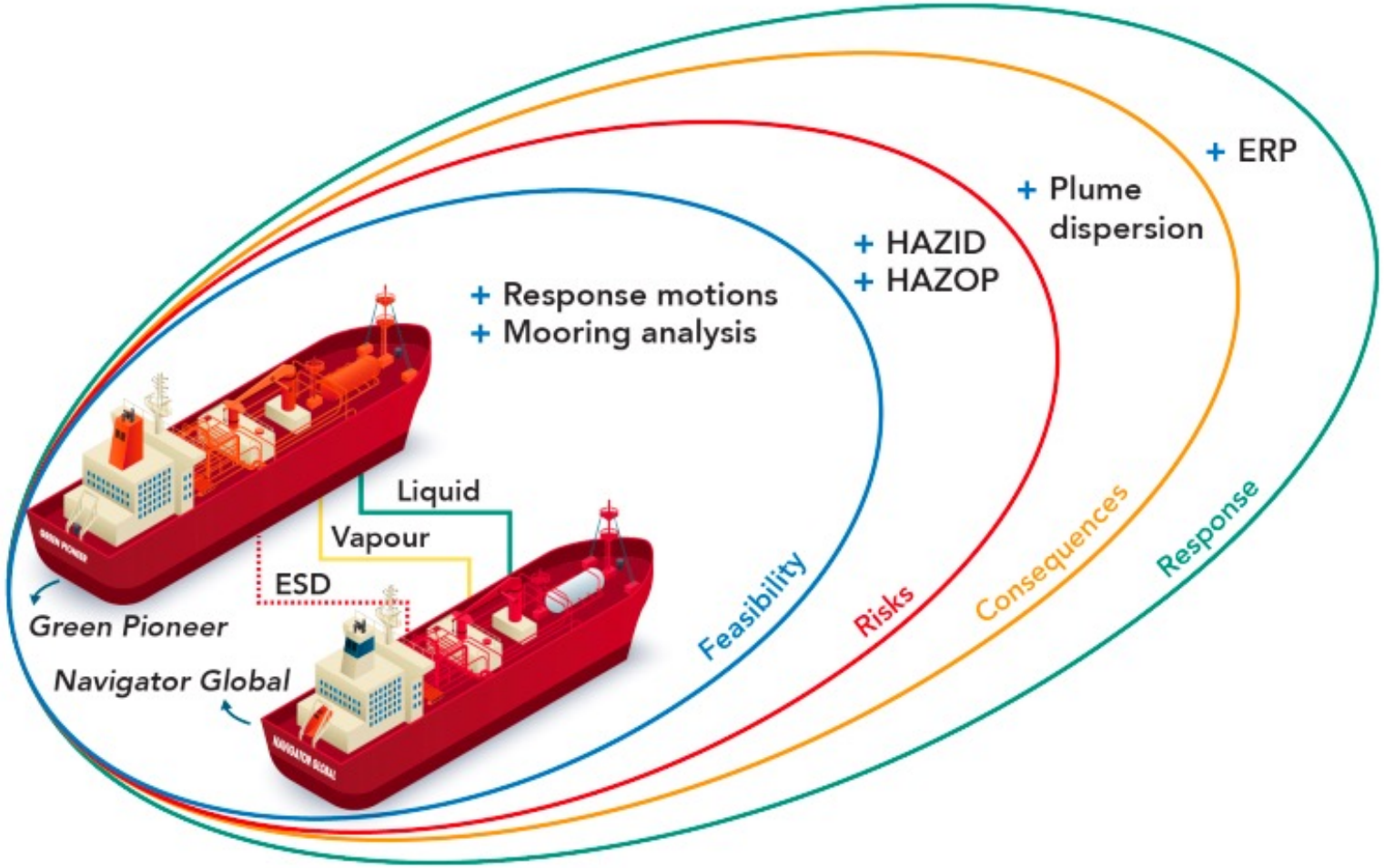
Personal Protection Equipment (PPE): Balancing safety with practicality

Watchkeeping	Hot gassing + nitrogen purging + gas measurement + Hose disconnection	Emergency response
Regular PPE set with personal gas detector	Light duty chemical suit with gas mask	HAZMAT suit with Self Contained Breathing Apparatus (SCBA)
		
✓ **5 ppm:** All crew members equipped with personal ammonia monitors, set to detect levels as low as 5 ppm. ✓ **25 ppm:** Alarm goes off; crew would don gas masks and evacuate to the accommodation block.	**<300 ppm:** Gas measurement taken to ensure < 300 ppm before disconnection. **Pilbara trial: 7 ppm after hot-gassing and purging, well within safety limits.*	Emergency shutdown devices automatically halt transfer and isolate manifold when ammonia concentrations exceed 250 ppm.

IMO draft interim guidelines and SGMF bunkering guidelines for ammonia detection thresholds

25 ppm for enclosed spaces, 110 ppm for secondary containments, 220 ppm for alarms and shutdowns

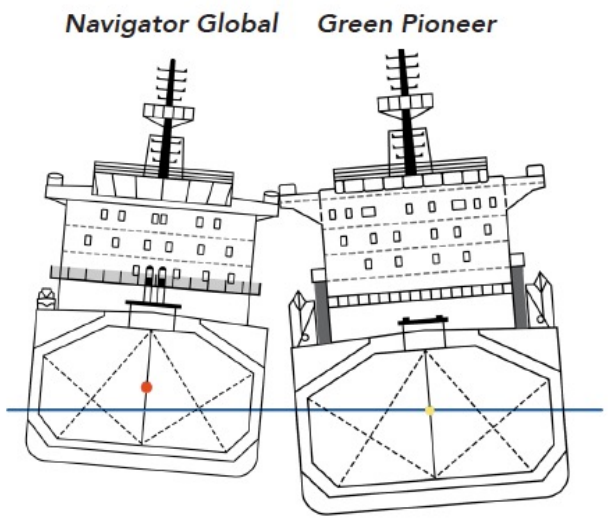
Safety studies overview



Feasibility: Response motions

Roll motions analysis overview

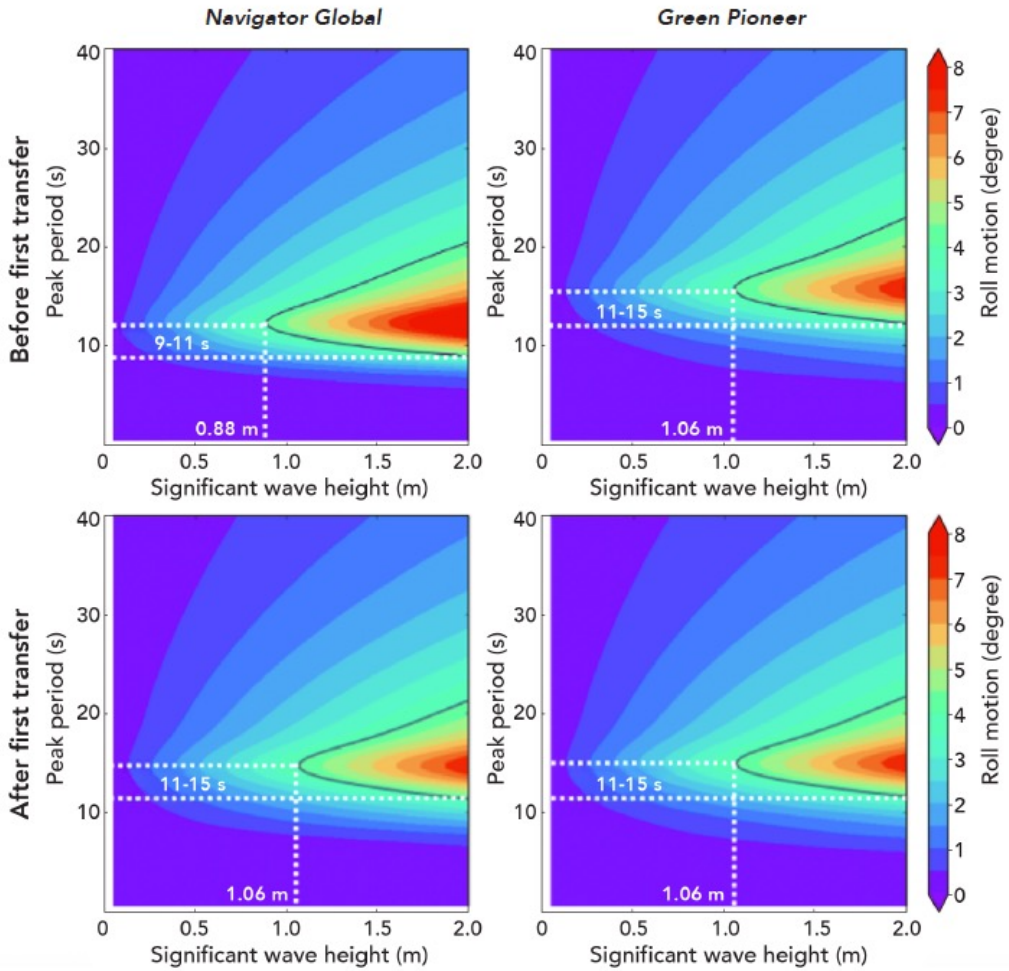
Historical metocean data was used to run the roll motions analysis



Operation limits

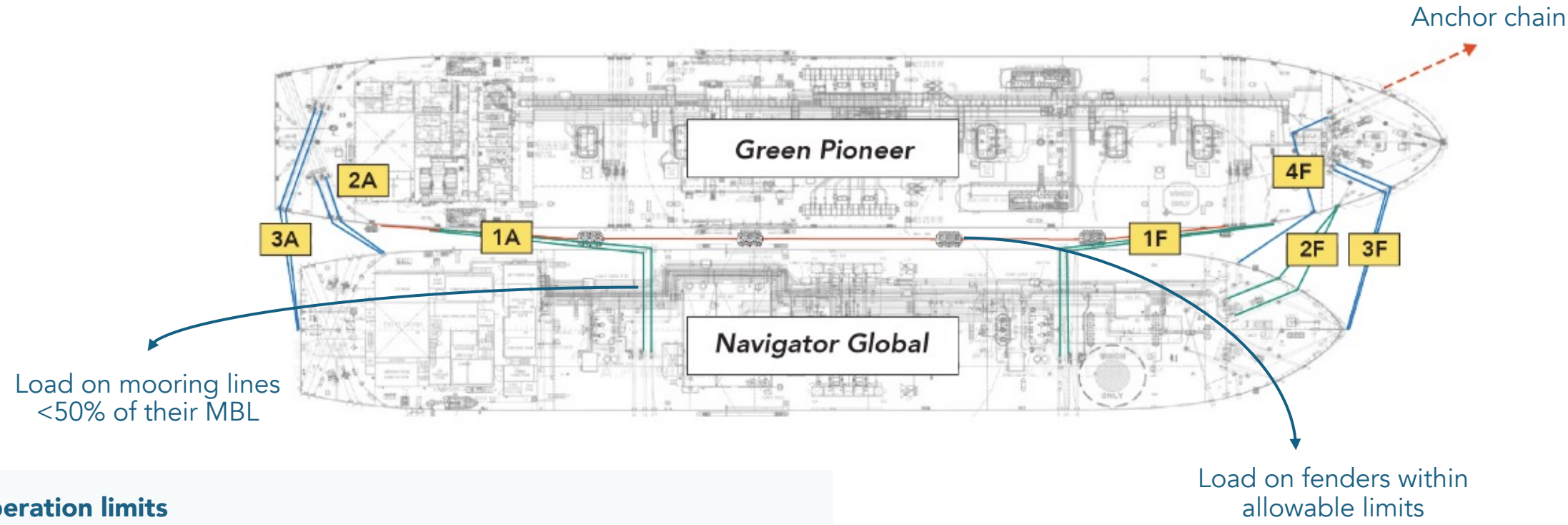
- Bridge wings will collide > 4° roll
- Roll motions <4° based on metocean data
- Critical roll motions occur at 0.88 m wave height with a peak period between 9 to 11 sec.

Roll motions for different loading conditions



Feasibility: Mooring configuration

Historical metocean data was used to run the mooring analysis



Operation limits

+ Wind: <20 knots
+ Swell: ≤0.3 m

Risk assessments

No high-risk items across risk nodes identified

Risk nodes

+ **Hazard Identification (HAZID)** was conducted from approach of vessel to mooring, transfer and unmooring
+ **Hazard and Operability (HAZOP)** was carried out for the transfer process from pressure testing to post-transfer purging

Risk summary

Risk ranking	Risks identified (HAZID)	Risks identified (HAZOP)
High	0	0
Medium	15	8
Low	8	3

Key recommendations for trials

+ No simultaneous operations (SIMOPS)
+ Tugs for mooring/ unmooring
+ Standby Anchor Handling Tug Supply (AHTS)
  - To assist with equipment transfer
  - To assist with perimeter patrol
  - To standby with fire fighting capability
+ Conduct drills closer to operation date

Computational Fluid Dynamics (CFD) plume dispersion study

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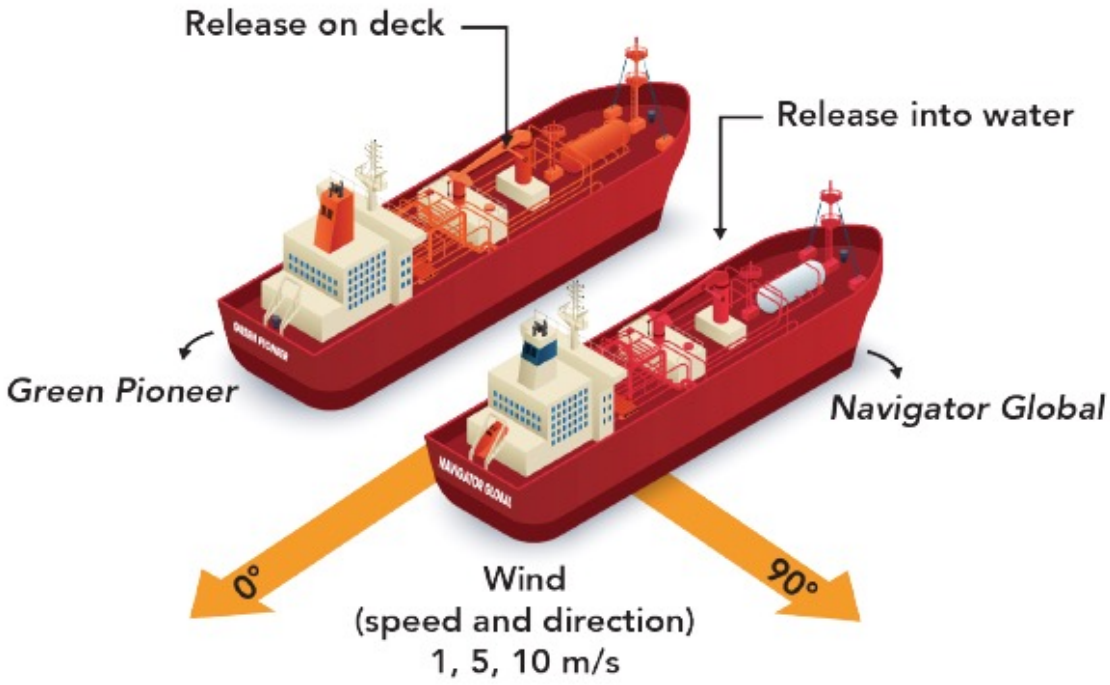
Model variants

+ **Release locations:** On deck and into water
+ **Release volume for 2 min**[(a)]: 33m^3 (4X the volume of a worst-case release scenario of a pipe rupture)

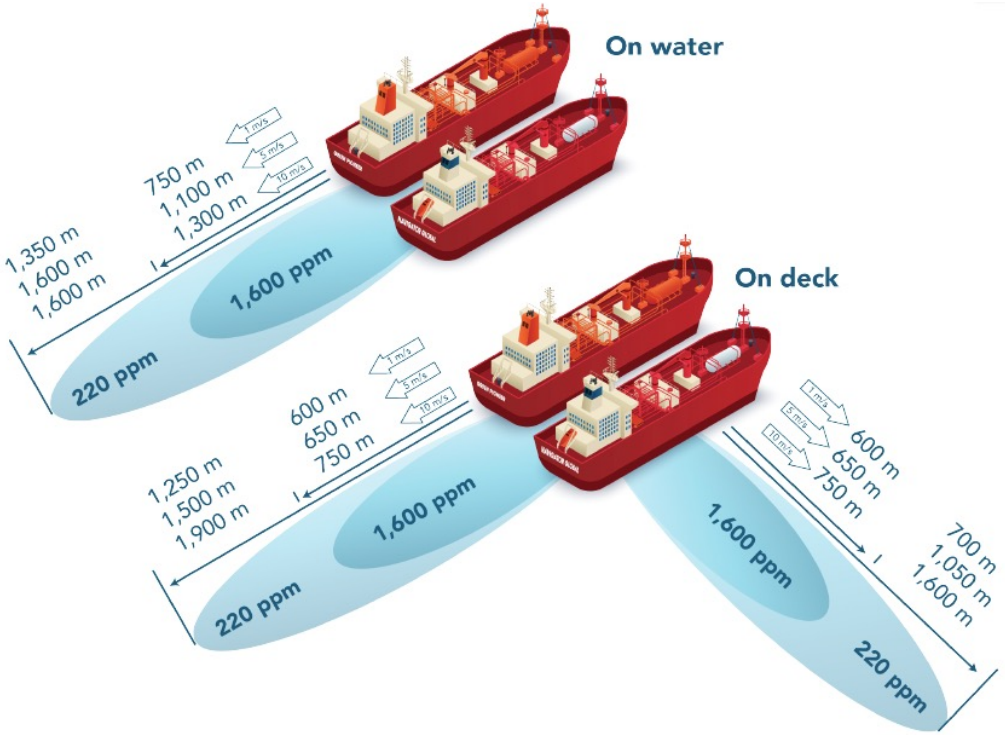


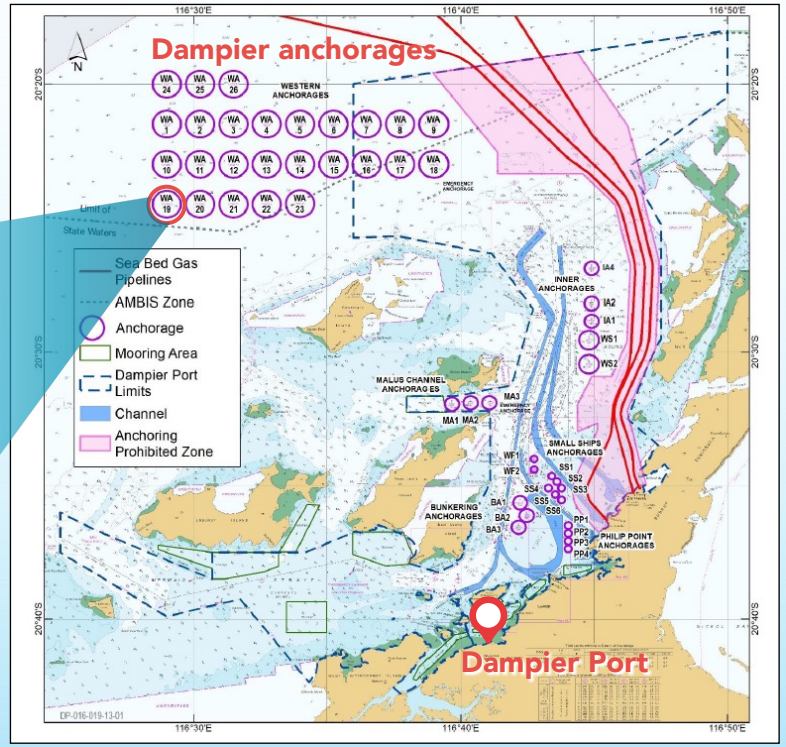
[(a)]Actual ESD actuation in 30 sec

Maximum plume length is less than 1 NM

At four times the volume of the most credible worst-case scenario of a pipe rupture (AEGL-3), the plume length is **1.3 km,** or **0.7 nautical miles**.

This maximum plume length is **within** the WA19 anchorage.

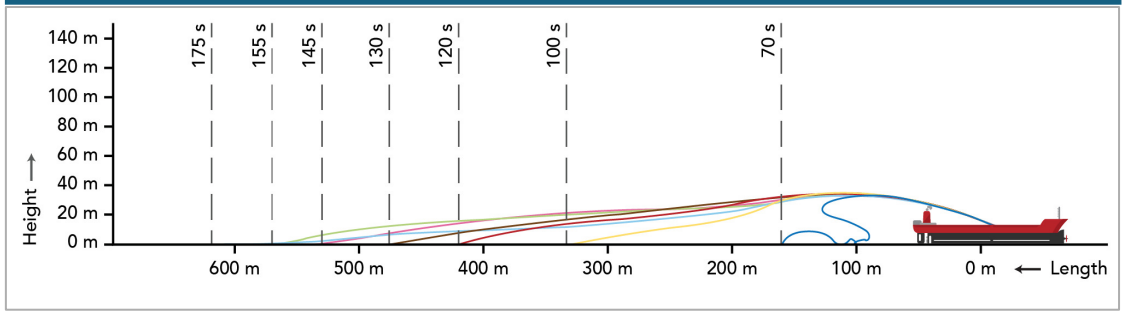
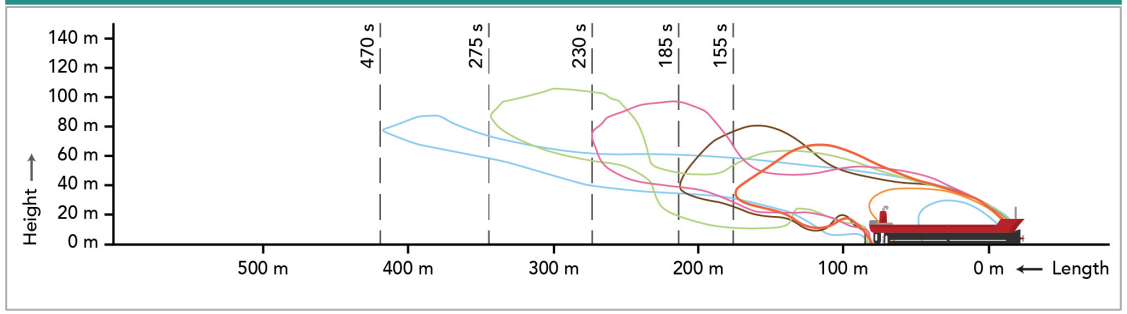
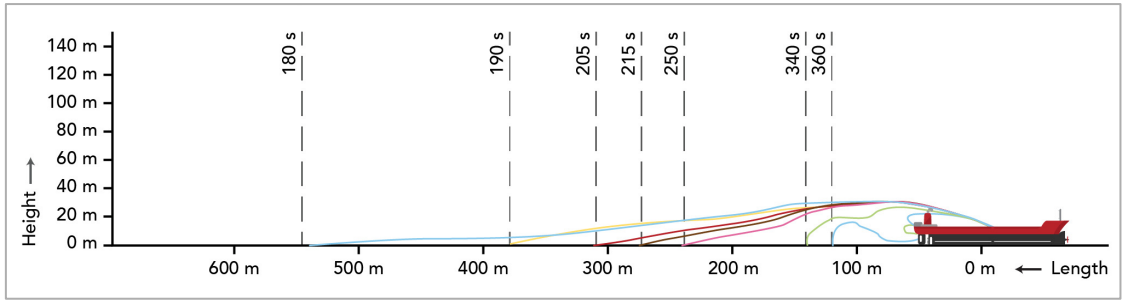
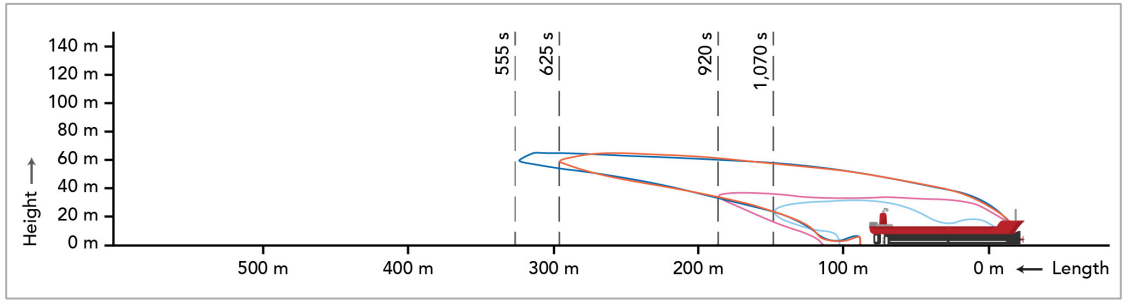




+ **AEGL-3 (1,600 ppm)** *basis for establishing monitoring zone*
+ **AEGL-2 (220 ppm)** *for reference*

Plume dispersion behaviour

At AEGL-3 concentration (1,600 ppm), and variable wind speeds

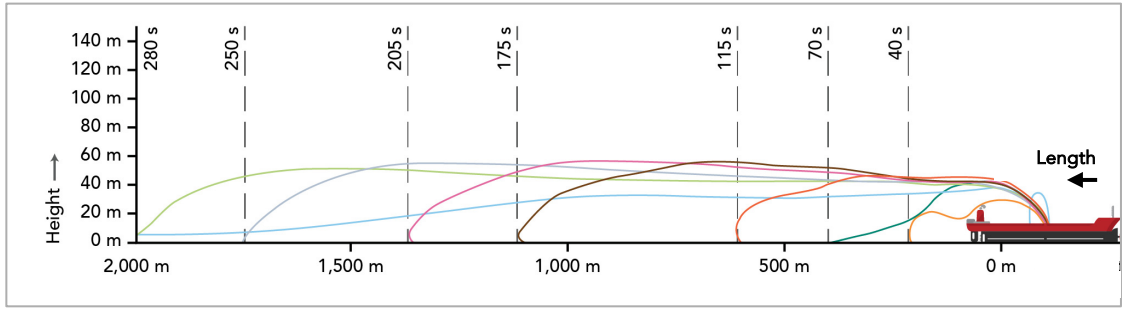
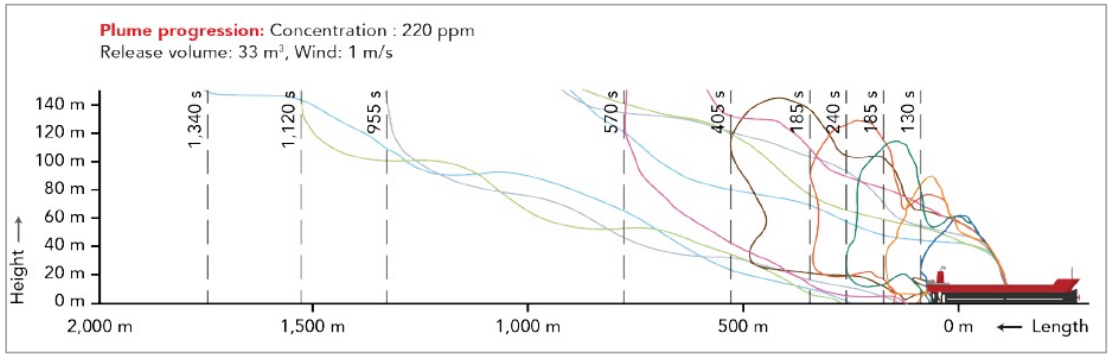
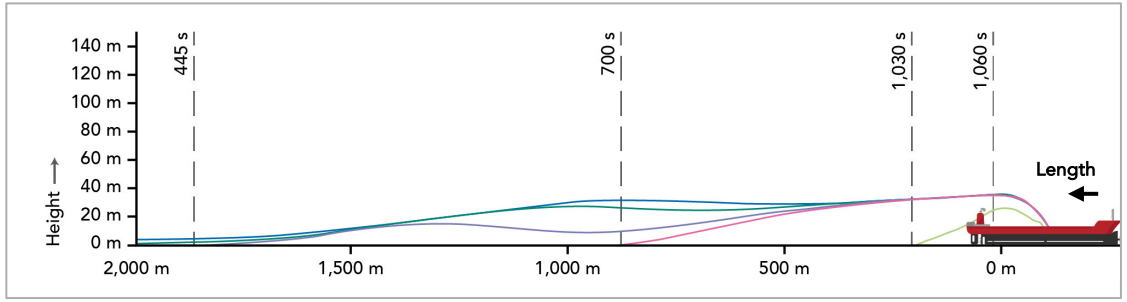
	Wind speed: 10 m/s	**Wind speed:** 1 m/s
Plume progression		
Plume dispersion		

Progression-dispersion rate	~5-4 m/s
Dispersion duration	Fully dispersed after 30 mins
Max length	>600 m in 175 s (~3 min)
Max height	40 m
Max width	60 m (largely within width of the vessels)

Progression-dispersion rate	~1.2-1 m/s
Dispersion duration	Fully dispersed after 60 mins
Max length	>400 m in 470 s (~8 min)
Max height	100 m
Max width	100 m

Plume dispersion behaviour

At AEGL-2 concentration (200 ppm), and variable wind speeds

	Wind speed: 10 m/s	**Wind speed:** 1 m/s
Plume progression		
Plume dispersion		

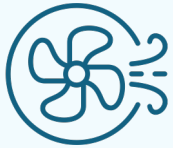
Progression-dispersion rate	~7-2.5 m/s
Dispersion duration	< 30 min
Max length	>2,000m in 280s (~5 min)
Max height	60 m
Max width	100 m

Progression-dispersion rate	~1.3 m/s
Dispersion duration	>120 min
Max length	~1,700
Max height	>140 m
Max width	100 m

Key recommendations from CFD analysis

01

Plume exposure & crew protection



- AEGL-3 plume may persist for 30–60 minutes, at low-wind conditions.
- Crew should remain inside accommodation block with ventilation set to recirculation and positive pressure maintained.

02

Deck safety measures

- Designate safe zones on deck for higher-severity incidents
- Align vessel with prevailing winds to aid plume dispersion
- Minimise deck activity during transfer—only essential personnel allowed
- Provide HAZMAT suits, SCBA, and gas masks at designated deck locations

03

Emergency equipment readiness

- Verify emergency showers and eye wash stations are functional before operations.

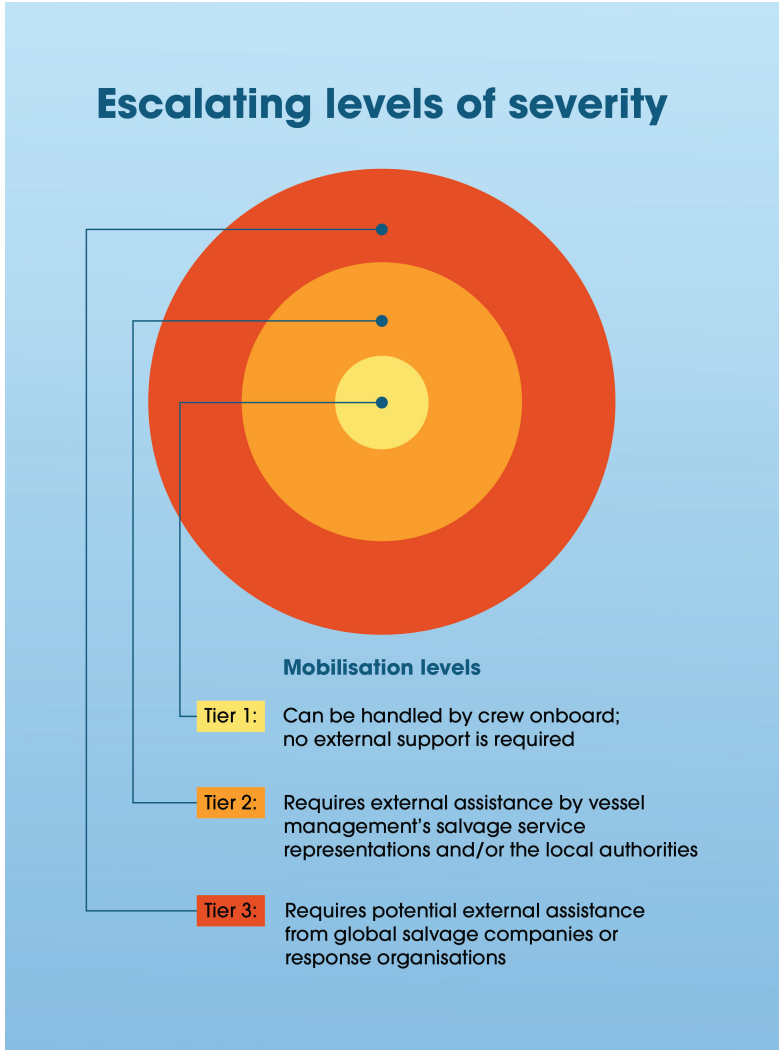
04

Response & evacuation planning

- Trained crew in full PPE to perform mitigative actions if safe
- Update ERP with staged evacuation timelines based on plume duration
- Define clear re-entry criteria for affected areas

Emergency response procedures were developed

Tailored to ammonia's physical characteristics



Ammonia's physical characteristics

- Harder to vapourise (needs 2.5 times more heat than LNG)
- Harder to ignite in open environments
- Can be recondensed using shields and covers (Required by IMO interim guidelines for bunker stations)

ERP primary objectives (SGMF's recommendations)

- Minimise liquid and vapour ammonia release
- Contain any released liquid
- Minimise vaporisation of released liquid
- Minimise crew exposure to released ammonia

Resources required according to severity release

Tier 1

Required by IMO

- Shipboard monitoring
- Emergency shutdown devices
- Relevant PPEs
- FiFi systems
- Shipboard Marine Pollution Emergency Plan (SMPEP) kits

Tier 2

- Stability support
- Lightering support
- Towing and recovery
- Salvage and emergency response

Additional elements incorporated in our trial:

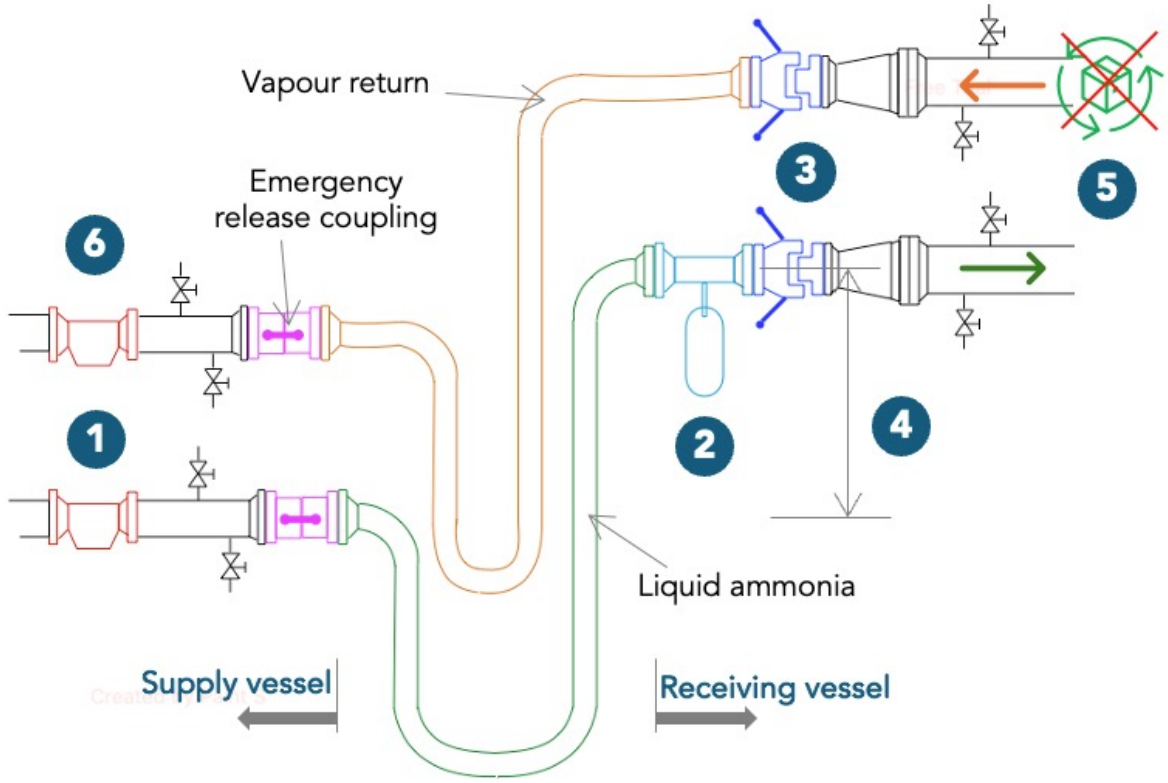
- Optical Gas Imaging camera onboard
- Standby vessel capable of firefighting and towing
- Standby certified incident handler for guidance on local resources

Tier 3

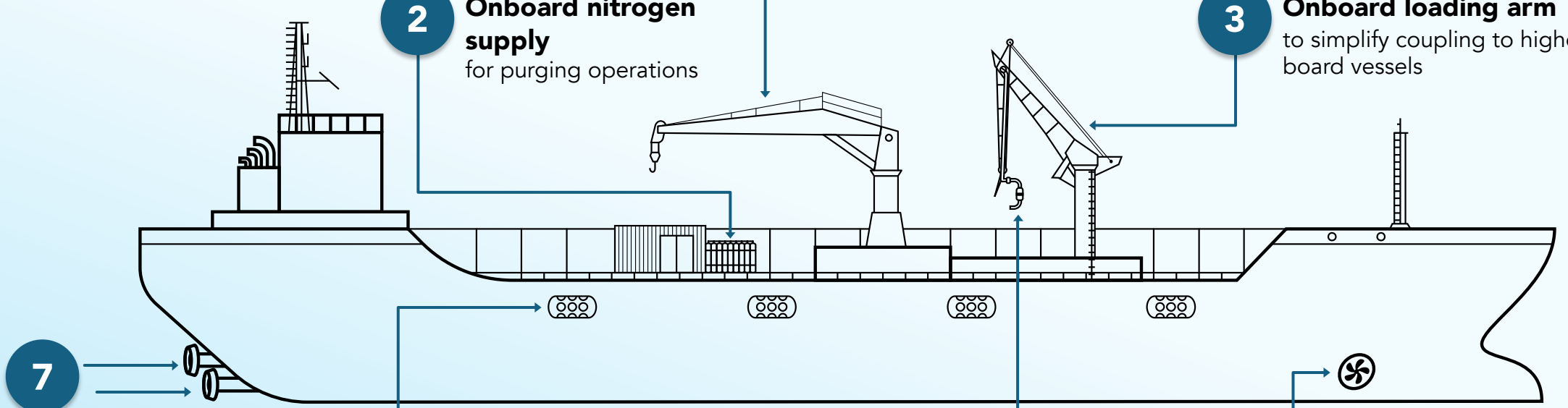
Future trials

Operational adjustments to further represent bunkering

1. In-line quantity measurement using mass flow meter
2. In-line intermittent or continuous sampling
3. Dry disconnect coupling for hose disconnection
4. Higher freeboard difference using VLGC as a receiving vessel
5. Receiving vessel reliquefaction plant is turned off to allow vapour return to supply vessel
6. Vapour return quantity measurement



Informing future ABV designs with pilot learnings



1 Service crane with higher capacity and longer reach
to facilitate deployment of bunkering equipment

2 Onboard nitrogen supply
for purging operations

3 Onboard loading arm
to simplify coupling to higher free-board vessels

4 Bow thruster
for better manoeuvrability

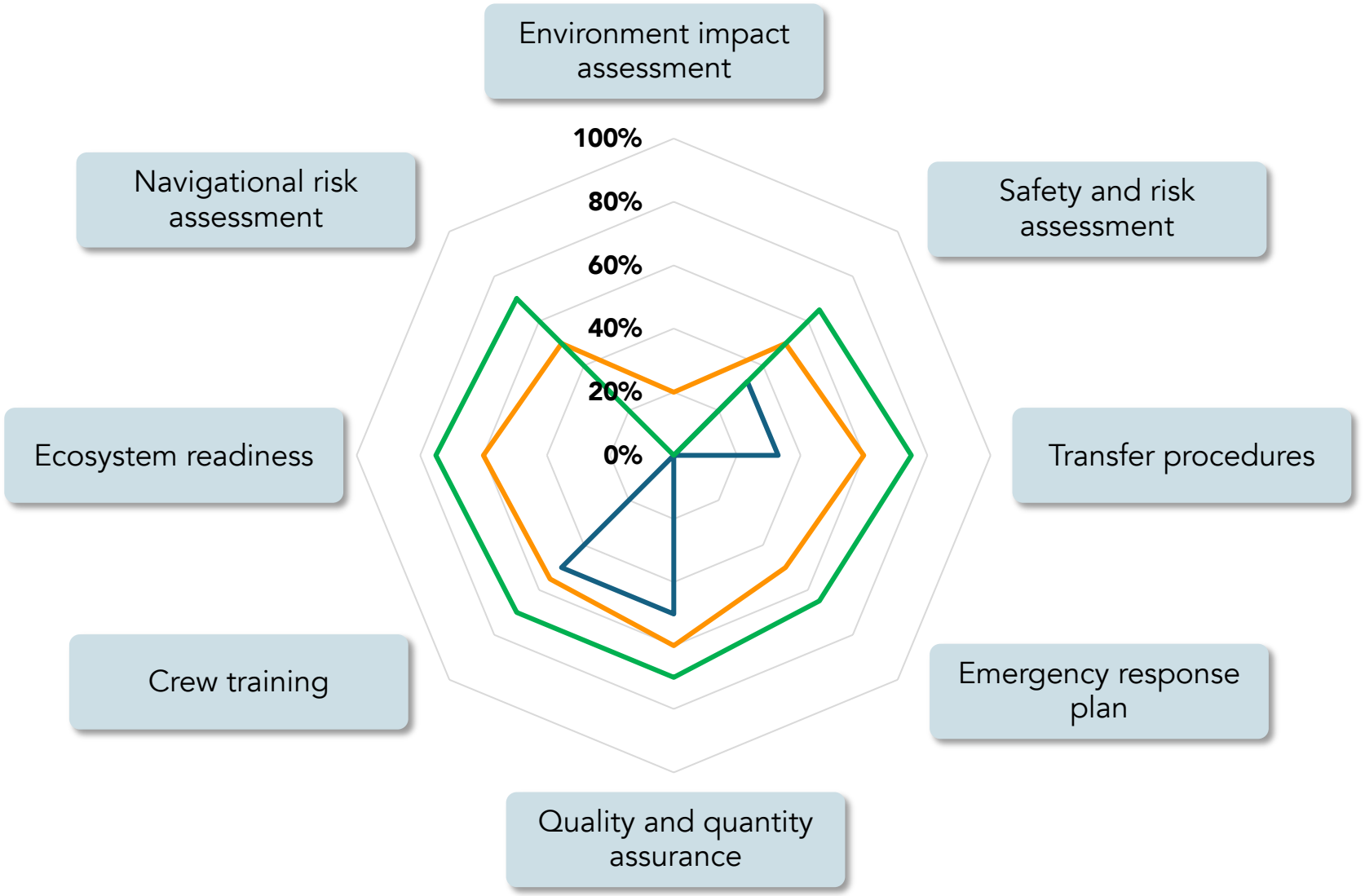
5 Emergency Release Couplings (ERC) on liquid and vapour hoses
that auto-shut during an emergency to limit release quantity

6 Onboard fender
to reduce deployment time for fendering

7 Twin propellers/ Azimuth propulsion
to allow better manoeuvrability

All images used are for illustrative purposes only. Individual features, as well as sizes and fittings, are not drawn to scale and will vary.

Enabling port readiness for ammonia bunkering



+ Singapore Phase 1
(generic safety study)

+ Singapore Phase 2a
(vessel-specific safety study)

+ Pilbara transfer
(vessel-specific safety study and trials)

Thank you!

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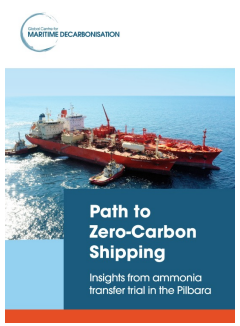

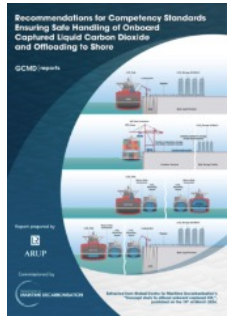

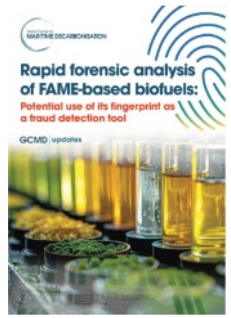

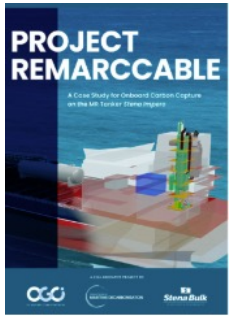

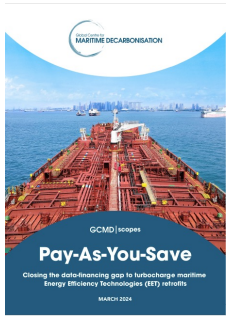

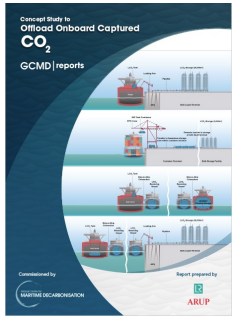

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