Global Centre for
MARITIME DECARBONISATION

Ammonia bunkering safety study in Singapore

Dr Sanjay C Kuttan, Chief Strategy Officer

Green Fuels Transition for International Shipping Workshop

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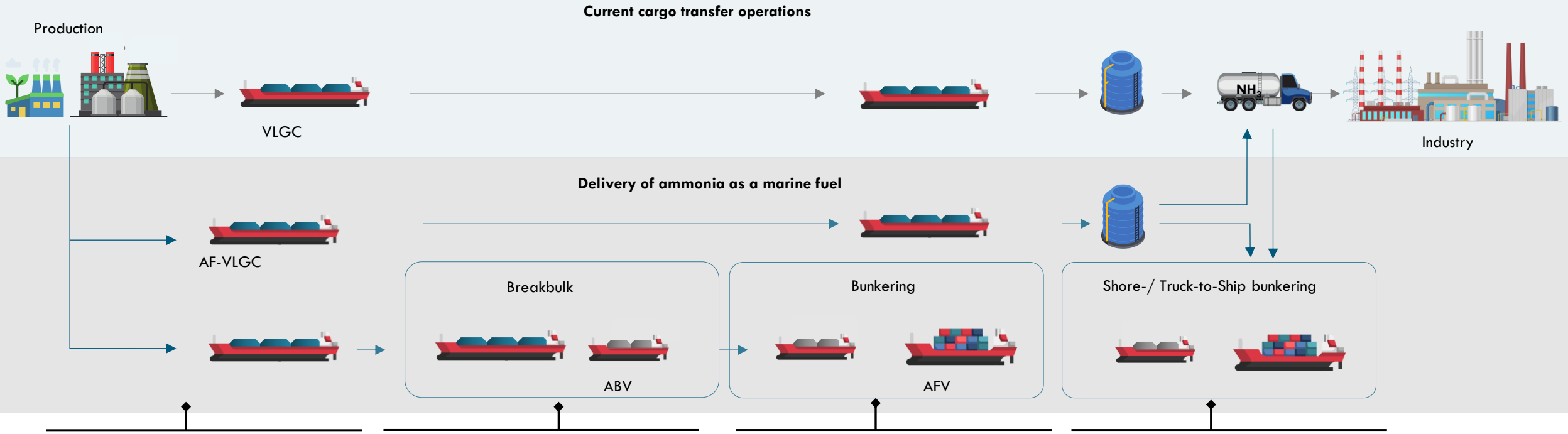
Paving the way for an eventual ammonia bunkering pilot

At the outset, we did not know **whether, where, or how** ammonia bunkering can be carried out safely.

Key considerations for ammonia bunkering	State of play before we embarked on pilot
Projections for ammonia bunker demand or storage capacity requirements	✗
Technical reference for ammonia bunkering	✗
Competency framework to support training	✗
Site(s) identified for a pilot	✗
Appreciation of CAPEX needed to ready bunkering sites	✗
Risk identification or assessment for different bunkering concepts	✗
Guidelines for custody transfer to assure quality and quantity	✗
Regulatory guidelines or sandbox for conducting a pilot	✗

Delivery of ammonia as a marine fuel will be more complex than current cargo transfer operations



- Existing cargo loading procedures can be used
- New AF-VLGC with NH_3 engines
- Engine room
  - New designs e.g., isolation/ segmentation of fuel preparation rooms
  - Additional safety designs & procedures, remote engine monitoring

- NH_3 transfer procedures do not exist
- New ABV designs with or without NH_3 engines with additional safety guidelines
- STS procedures between AF-VLGC and ABV to be established
- Emergency response plans to be developed and refined using STS cargo transfer as a proxy – interim step to build confidence in safety procedures

- NH_3 related bunkering procedures do not exist
- New AFV with NH_3 engines
- New AFV engine room with additional safety designs & procedures, remote engine monitoring
- Bunkering procedures and emergency response plans to be refined when vessels are available

- NH_3 related bunkering procedures do not exist
- Existing storage to truck procedures are applicable
- Bunkering procedures and emergency response plans to be refined when vessels are available

AF-VLGC: Ammonia-Fueled Very Large Gas Carrier
VLGC: Very Large Gas Carrier
ABV: Ammonia Bunkering Vessel
AFV: Ammonia-Fueled Vessel

Ammonia bunkering safety study

In Jan 2022, GCMD commissioned a study to define the **safety and operational** envelopes under which **ammonia bunkering pilots can be carried out in the port waters of Singapore**, the world's largest bunkering hub and second-largest container port.

Expected outcomes will help to support the establishment of a regulatory sandbox for pilots.

01	02	03	04	05	06
Identify + make recommendations to address regulatory gaps	Recommend up to two sites for ammonia bunkering	Draft Technical Guidelines and Procedures	Generate CAPEX model for ammonia bunkering infrastructure	Develop competency standards for bunkering operations	Validate + finalise findings with industry stakeholders

Source: GCMD

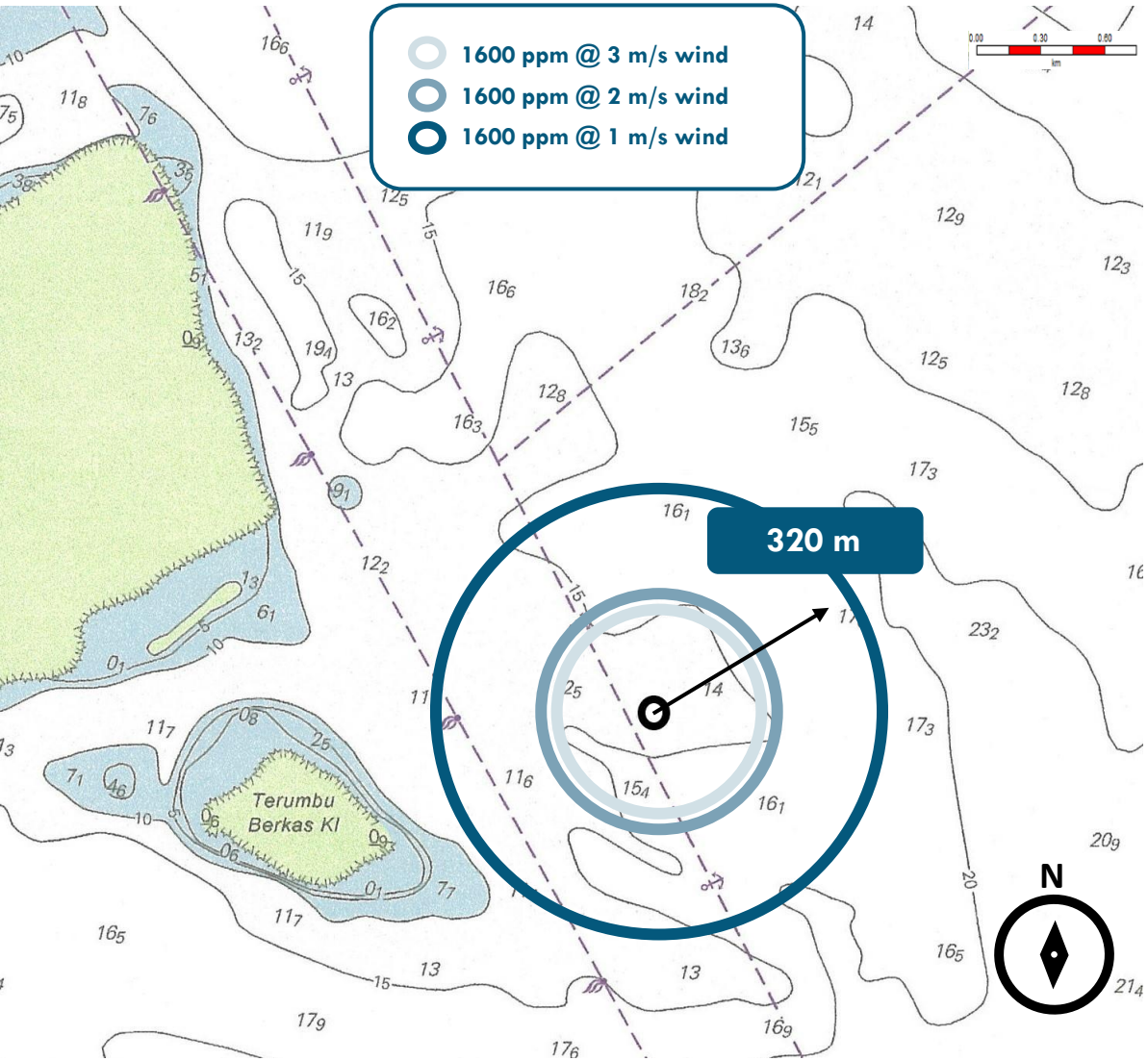
Mobilised all-of-ecosystem for the study

Study conducted by DNV, Surbana Jurong and Singapore Maritime Academy

Fuel producers	Fuel storage terminal operators	Bunker suppliers + barge operators	Port terminal operators	Vessel owners + operators	Shipyards + vessel design + consultancy	Fuel (quality + quantity) testing service providers
YARA	ADNARIO Vopak	Fratelli Cosulich PAVILION Energy KENOIL HONG LAM MARINE	Jurong Port PSA	Asiatic Lloyd EASTERN PACIFIC SHIPPING PIL MOL NAVIGATOR GAS NYK LINE ONE	SEATECH Trusted Solutions Seatrium	National Metrology Centre NMC VISWA GROUP VPS

+ With **22** study partners
+ And **>130** members on the industry consultation and alignment panel
+ **8** regulatory agencies consulted

Ammonia bunkering pilot safety study released Apr 2023



Singapore ammonia bunker demand

- Projected to take off in mid-2030's; estimated to be 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

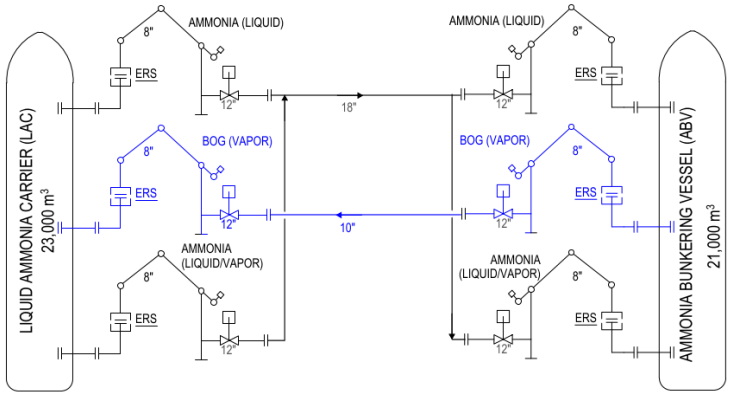
- Guidebook incorporated into curriculum at SMA; first course offered in March 2023
- Learnings incorporated in SGMF interim bunkering guidelines
- Collaborating with OSRL to develop emergency response plans

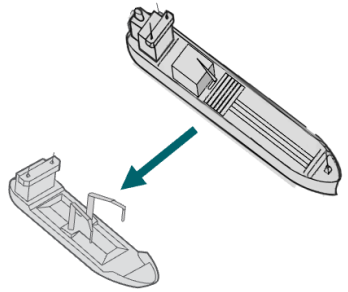
Readying for STS transfers as proxy to bunkering

- In Singapore anchorage and ports elsewhere
- To build confidence and competence

Four concepts and three sites were identified

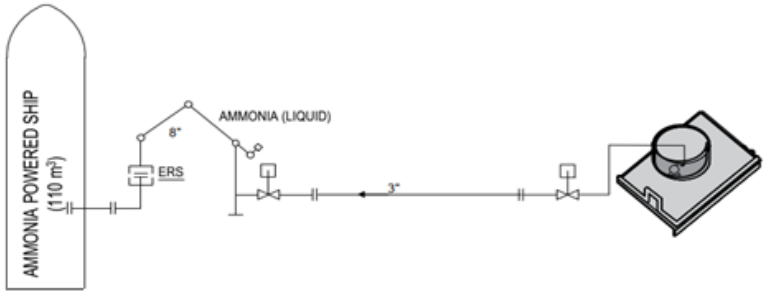
1

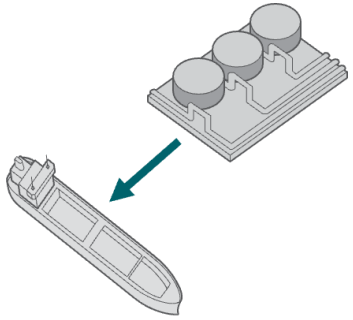




Cross-dock breakbulk @
Advario Helios Terminal
750 m^3/hr x 2

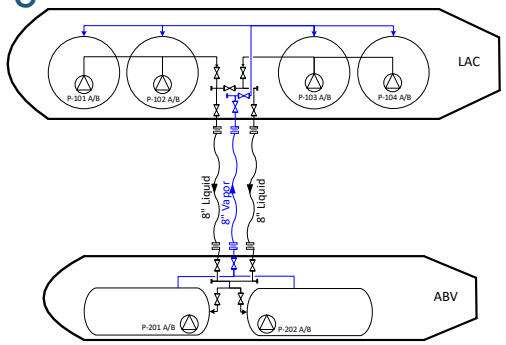
2





Shore-to-ship bunkering @
Vopak Terminal
9 m^3/hr

3



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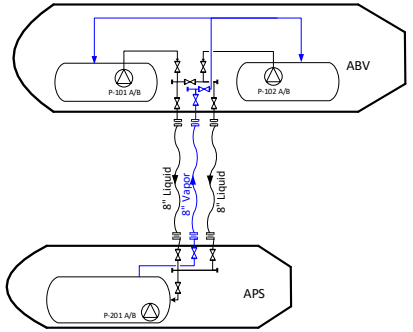
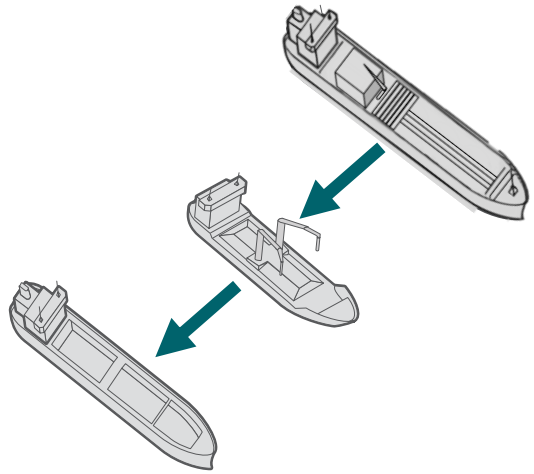
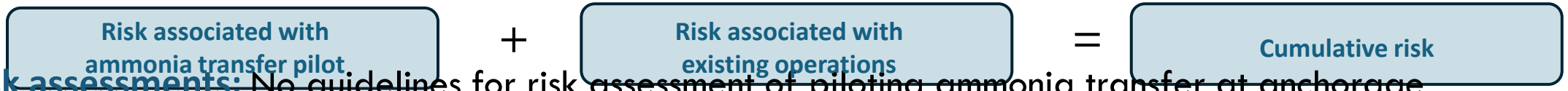




Breakbulk and bunkering
@ **Raffles Reserve Anchorage**
350 m^3/hr x 2; 350 m^3/hr; 175 m^3/hr x 2

Safety zone determination

- **Safety zones:** Determined probabilistically and added to risk from existing operations
  - cumulative risk for pilots was lower than the criteria in the Major Hazards Department (MHD) guidelines[1].



- **Risk assessments:** No guidelines for risk assessment of piloting ammonia transfer at anchorage
  - assumed Technical Reference 56 guidelines developed for LNG bunkering for determining safety zone at anchorage

- **Safety zones for breakbulk and bunkering pilots** at anchorage determined deterministically and probabilistically

- **Sensitivity analyses** carried out with varying flow rates and transfer frequencies

* Based on a "most credible" loss scenario of a small leak (10 mm diameter) in pipe/ hose

[1]National Environment Agency of Singapore (2016) "QRA Criteria Guidance," Rev. No. 3, 9 Nov 2016

Safety radius is not directly proportional to inventory release

Case no. and description	Hole size (mm)	Pressure (barg)	Temp. (deg. C)	Flow rate (m^3/hr)	Inventory released (kg)	Maximum radius (m)*
Case 1: This case modelled a release at the manifold location	10	4	-32.9	350	259	205
Case 2: This case modelled a release at the piping from the tank to the header on the ABV	10	4	-32.9	350	476	320

Concentration tracked (AEGL-3, 1,600 ppm), 1F wind condition

- 1 m/s with stability class F (1F)
- 2 m/s with stability class B (2B)
- 3 m/s with stability class C (3C)

Maximum safety radius still subjected to ALARP considerations

ABV: Ammonia bunkering vessel
AEGL: Acute Exposure Guideline Levels
ALARP: As Low as Reasonably Practicable

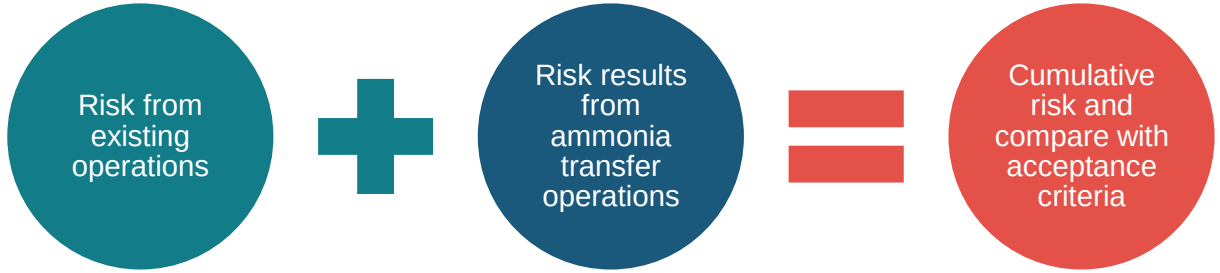
Local regulatory guidelines were considered

IR (fatality) (Cumulative risk of fatality/year)	Criteria
5E-05	Confined within boundary
5E-06	Confined to industrial developments only

IR (injury) (Cumulative risk of injury/year)	Criteria
3E-07	Confined to industrial and commercial developments only and shall not reach sensitive receptors

IR (fatality) for On-site Occupied Buildings (Cumulative risk of fatality/year)	Criteria
1E-03	Shall not exceed

- According to the QRA guidelines for any land site, the cumulative risk shall be estimated and compared with the acceptance criteria
- DNV estimated the cumulative risk after qualitatively combining risk results from existing operations (i.e., excluding ammonia transfer operations) with the proposed ammonia transfer operations



Learnings from study prepare us for STS pilots

Use **deterministic** safety zones to scope pilots

Mitigate risks further by **reducing inventory** transferred and/ or transfer **duration**

Substantially **lower flow rates** than specification can result in two-phase flow with larger dispersion zones during a leak.

Leverage **experienced personnel**, e.g., those who have sailed on ammonia-carrier vessels, for pilot

Install **automatic** emergency shutdown devices and emergency release couplings to minimise reaction time, and inventory loss during a leak

Deploy other **precautionary measures,** like double-walled pipes and secondary containment

Integrate **water curtains** for small leaks (water curtains are less effective for large leaks)

All personnel involved with pilot should use **appropriate PPE.**

STS ammonia transfer to build confidence + competence

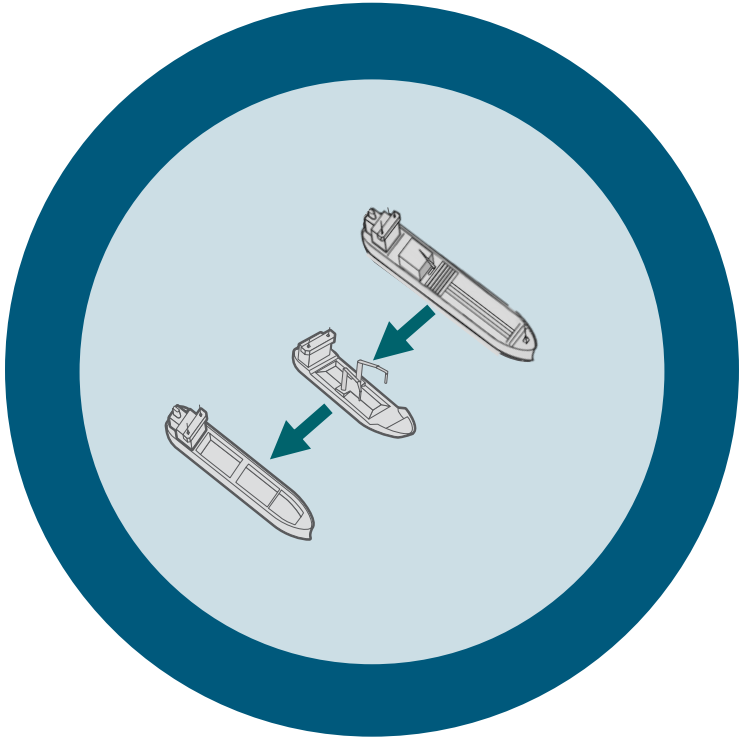
Exercise paves the way for an eventual bunkering pilot when ammonia-fueled vessels become available

Emergency response procedures to be developed

Ongoing conversations with regulatory agencies

Discussions ongoing to develop process for cargo integrity assurance

"Learning by doing" to build confidence, competence and capability



Ammonia transfer pilots to take place in port water

Identified two ammonia carriers; transfers will mimic breakbulk and bunkering

Detailed safety assessment, including HAZID, HAZOP, QRA being conducted

Validate requirements for crew competency syllabus for bunkering

Global Centre for
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8 Robinson Road #06-01 | Singapore 048544

www.gcformd.org

projects@gcformd.org

+65 6979 7660