Global Centre for
MARITIME DECARBONISATION

Ammonia as marine fuel: Risk awareness vs risk adversity

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Chief Technology Officer

Mission statement

Our mission is to help the maritime industry eliminate GHG emissions by **shaping** standards, **deploying** solutions, **financing** projects, and **fostering** collaboration across sectors

Founding + strategic partners

BHP, bp, DNV, Eastern Pacific Shipping, Hapag-Lloyd, MPA Singapore, ONE Ocean Network Express, Seatrium*, NYK Line

Impact partners

BCG, gard, the human energy company, Olympic Shipping and Management S.A., msc, MOL Mitsui O.S.K. Lines

Coalition partners

International Chamber of Shipping, IBIA, SSA Singapore Shipping Association, IWSA International Windship Association, ashurst

Knowledge partners

Global Maritime Forum, KPLER, Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping, GSBN

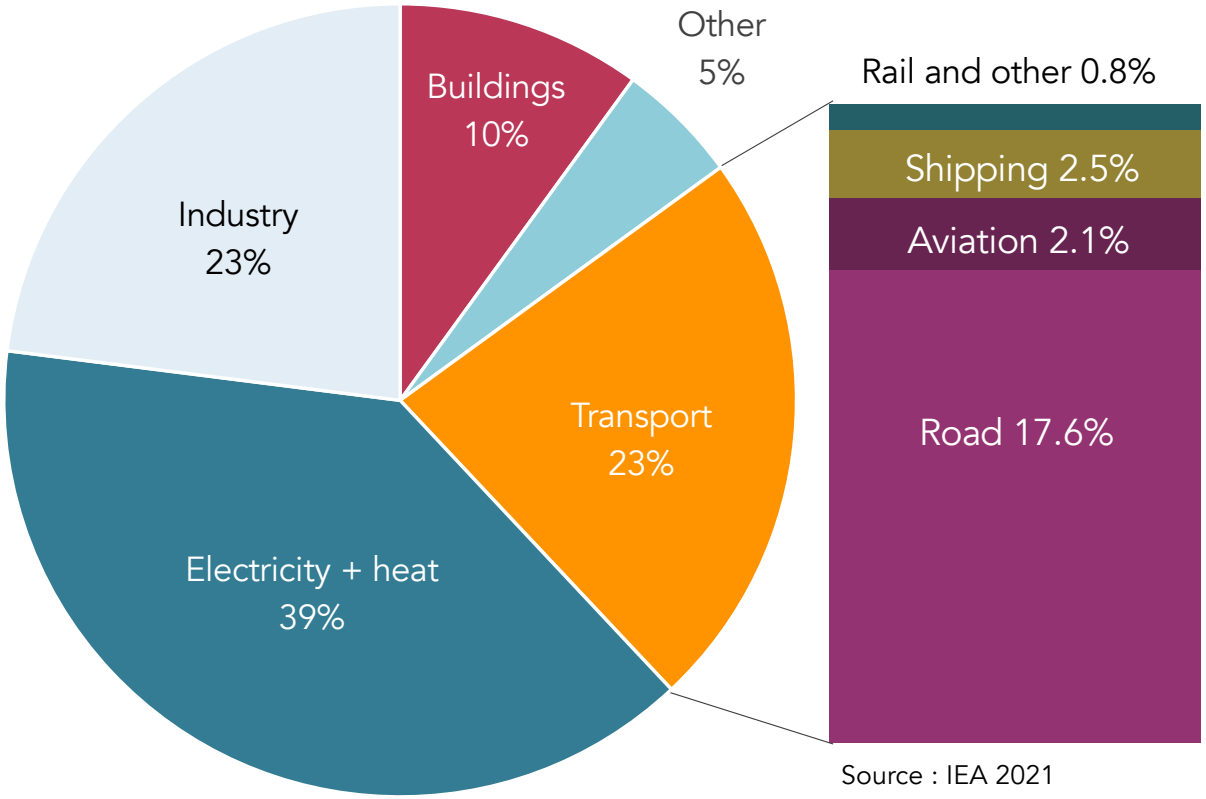
and >80 project partners

** Formerly Sembcorp Marine*

Shipping is a **global** industry

- Responsible for transporting **11B tons** of goods annually, or **90%** of global trade
- Regulated by International Maritime Organization (IMO)

Shipping contributes **2.5%** of global GHG emissions

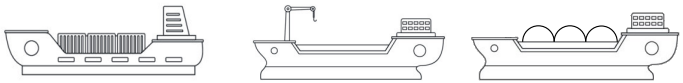


Source : IEA 2021

- Transport accounts for about **one quarter** of total GHG emissions
- Shipping contributes **2.5%,** greater than the emissions of the **sixth** largest emitter (Germany)
- IMO targets: **40%** reduction in carbon intensity by 2030 and **50%** total GHG emissions by 2050; targets to be revisited in summer 2023

Shipping's emissions are difficult to abate

Shipping is **heterogeneous,** requiring a heterogeneous set of solutions



5,307 container

12,258 bulk / cargo carriers

2,031 LNG

15,106 general cargo

7,350 crude oil tankers

5,664 chemical

7,027 roro / passenger

Statista.com, Merchant ships by type, 2021

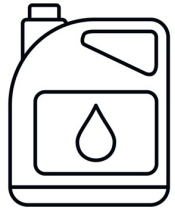
Ecosystem for maritime decarbonisation **not mature**

Existing solutions cannot get shipping to net-zero

Alternative fuels not available at cost or scale

5% of shipping's **fuel** must have zero emissions by 2030

15.8M tons heavy fuel oil



must be replaced with

≈ 36.5M tons ammonia / methanol

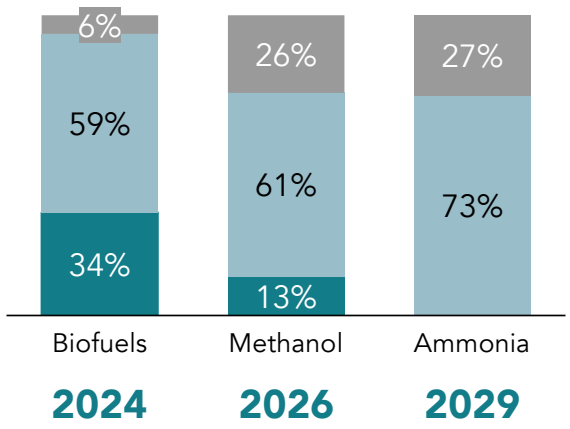
https://www.globalmaritimeforum.org/content/2021/03/Getting-to-Zero-Coalition_Five-percent-zero-emission-fuels-by-2030.pdf

Survey respondents plan to adopt ammonia as early as **2029**

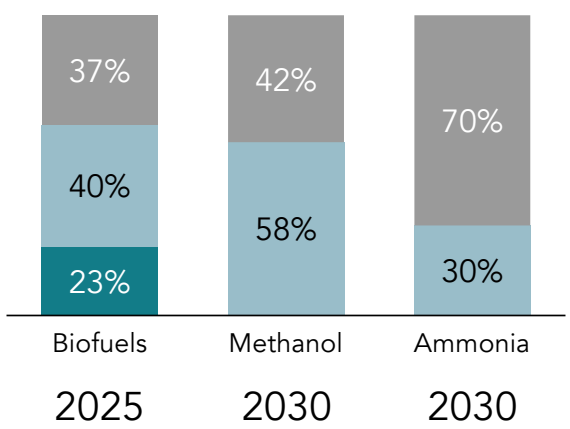
Global Centre for MARITIME DECARBONISATION

Current and planned adoption of future fuels

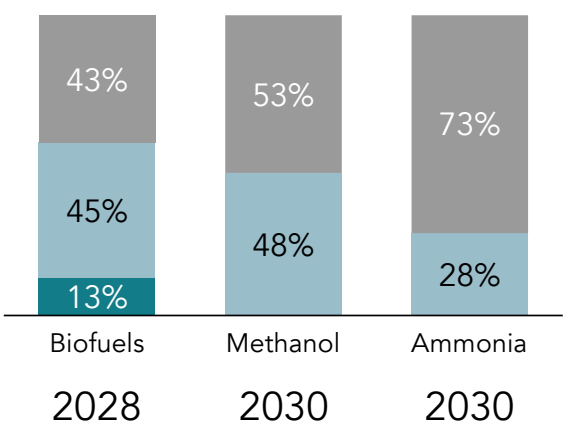
Frontrunners



Followers



Conservatives

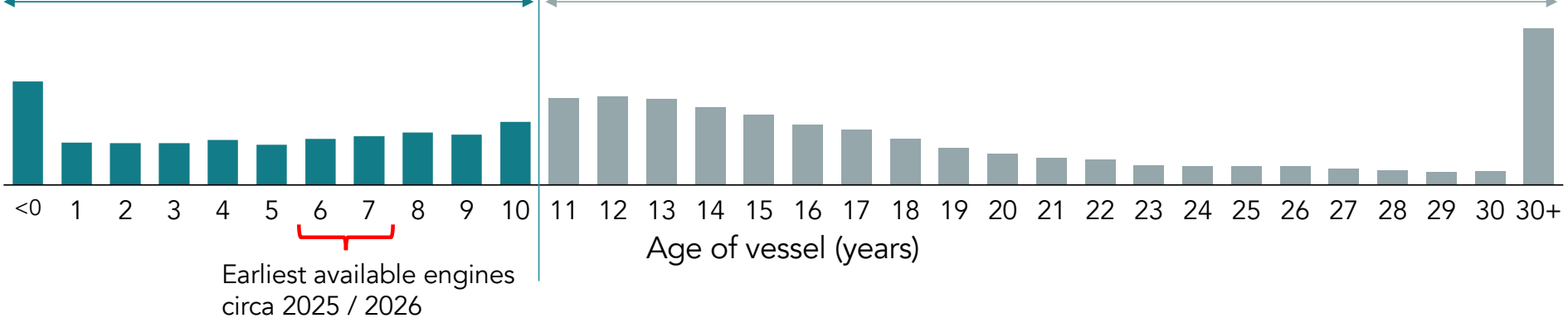


Already adopted | Plans to adopt | Not sure/no plans | xxx Median year of adoption

Source: GCMD-BCG Industry Survey on Maritime Decarbonisation (N = 128), BCG analysis

Fuel transition will take time; new builds will most likely drive demand

Most survey respondents would **not** equip vessels **>10 years old** with future fuel capabilities

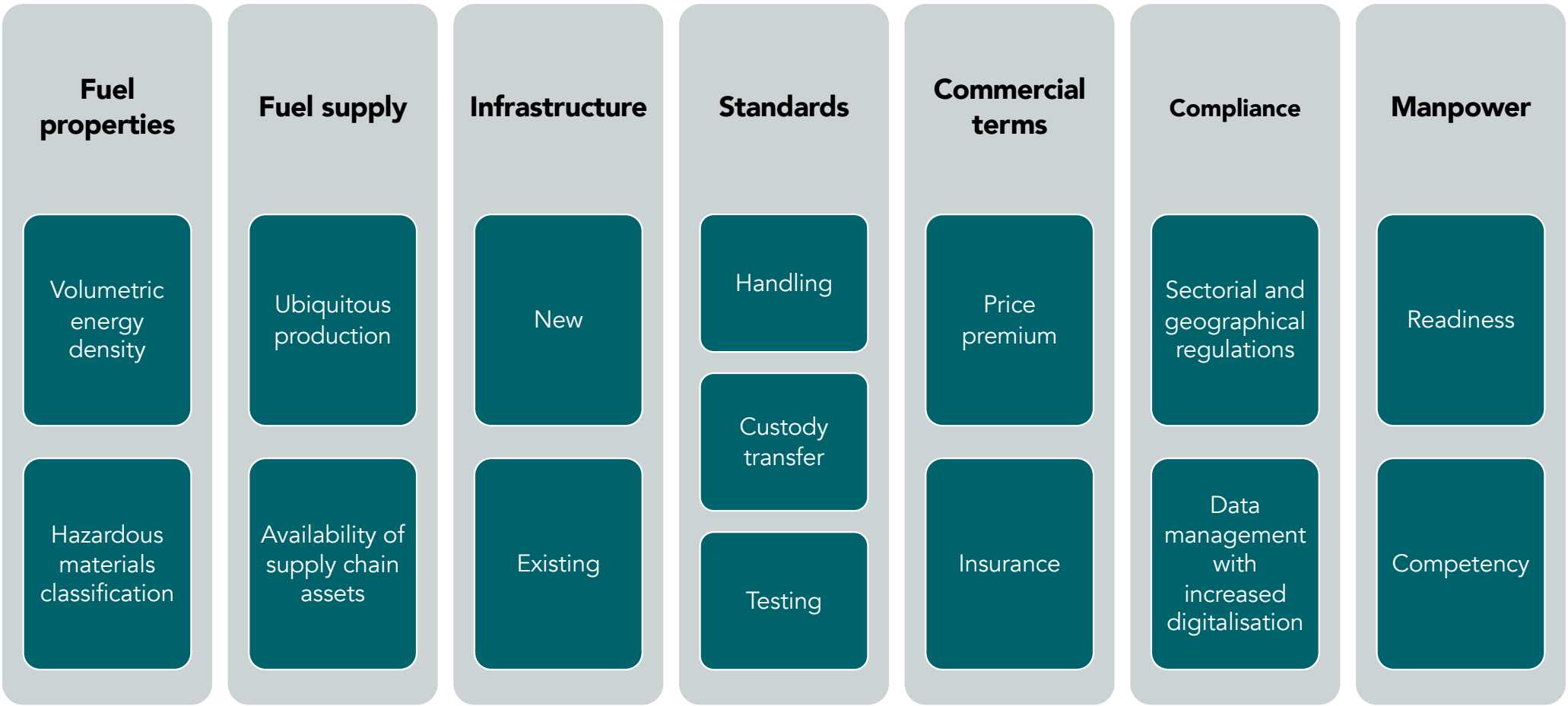


Actual volumes to be retrofitted are likely lower given constraints on shipyard capacity, willingness to spend, fuel supply availability, engine availability, port readiness, etc.

Source: Clarksons Shipping Review and Outlook as of 2022 for # of vessels (38k including bulkers, tankers and container liners)

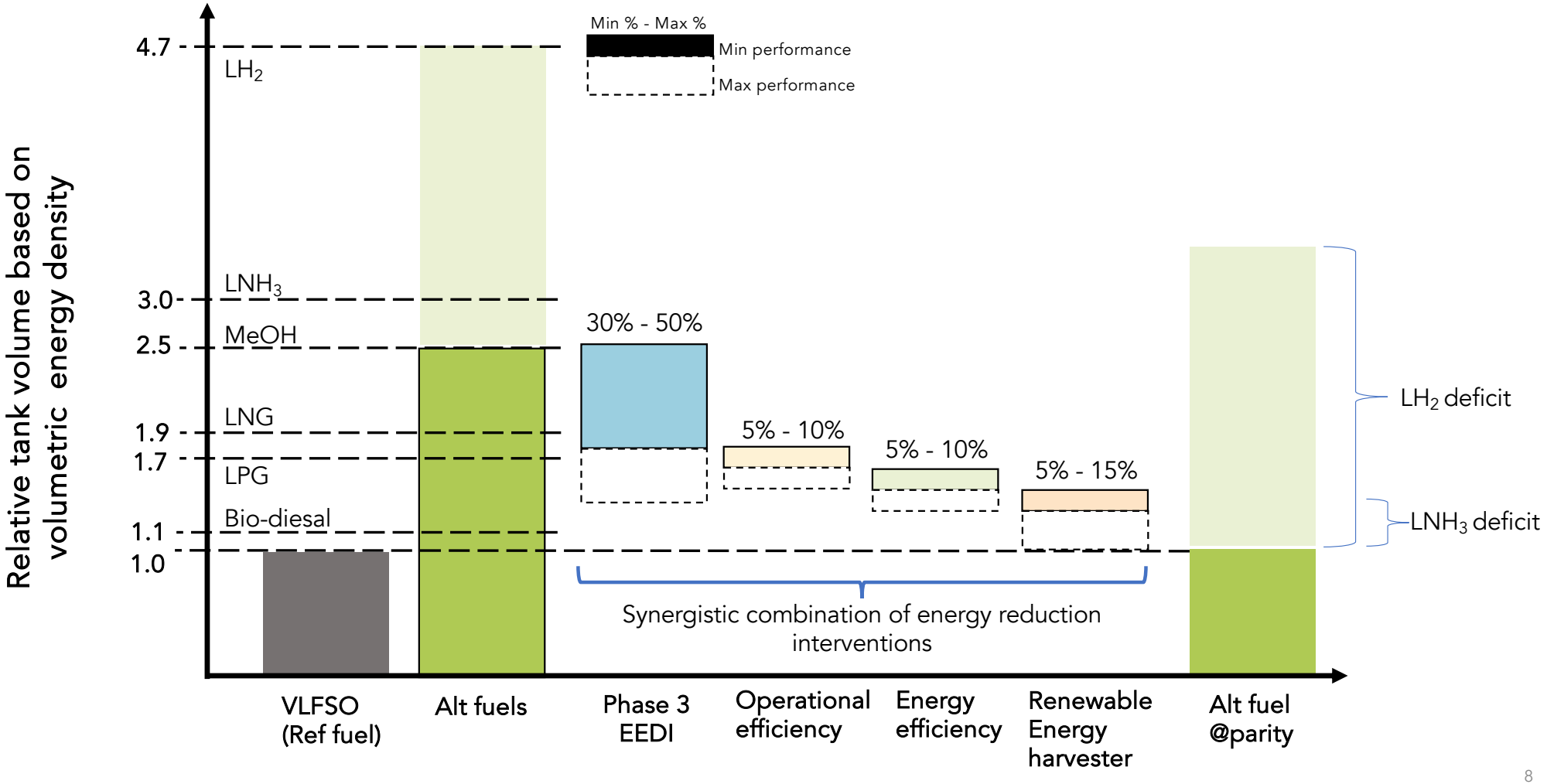
GCMD-BCG Industry Survey on Maritime Decarbonisation (N = 128), BCG analysis

Use of alternative fuels has many considerations



Source: GCMD

A holistic approach to energy management strategy required to handle higher prices, low availability and deficits in energy density



Source: GCMD analysis; Volumetric Energy Density graph from "Techno-Economic Challenges of Green Ammonia as an Energy Vector, Agustin Valera-Medina

Switch to new fuels likely to impact bunkering patterns

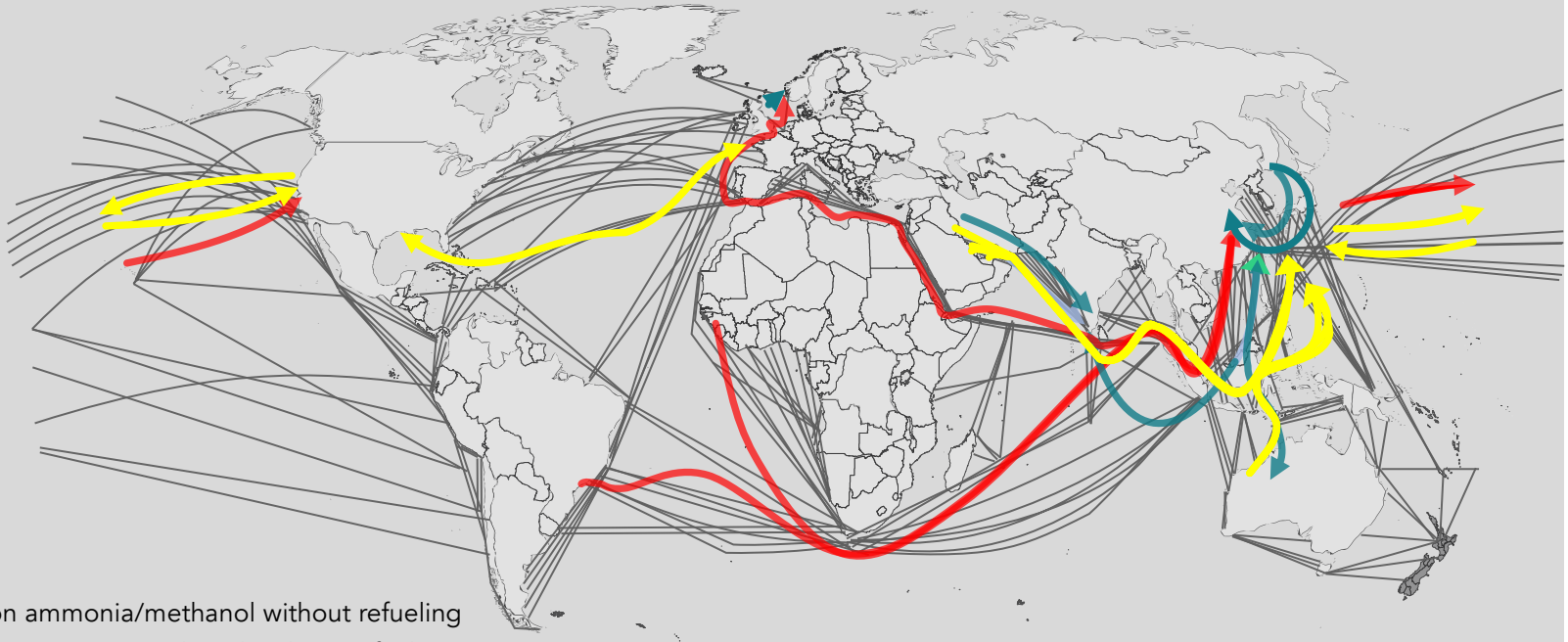
Wider network of infrastructure will be needed to support more frequent bunkering

2.4-2.8x

Lower volumetric energy density vs fuel oil

~60%

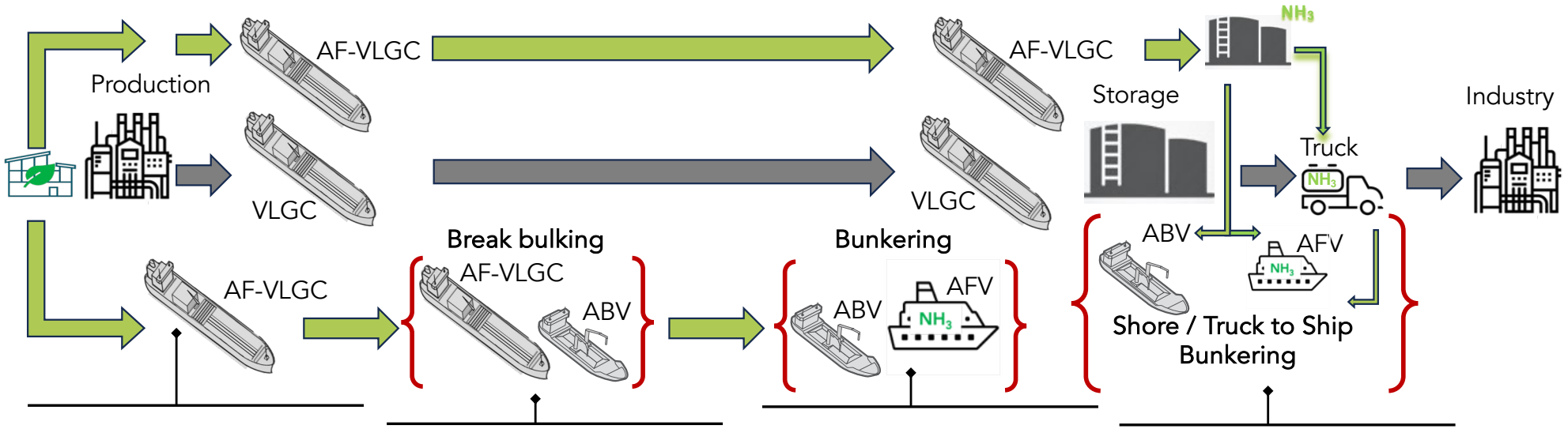
Would **bunker more often** than use larger fuel tanks



Selected major trade routes

Source: GCMD-BCG Industry Survey on Maritime Decarbonisation (N = 128), BCG analysis

Delivery of ammonia as marine fuel will be more complex



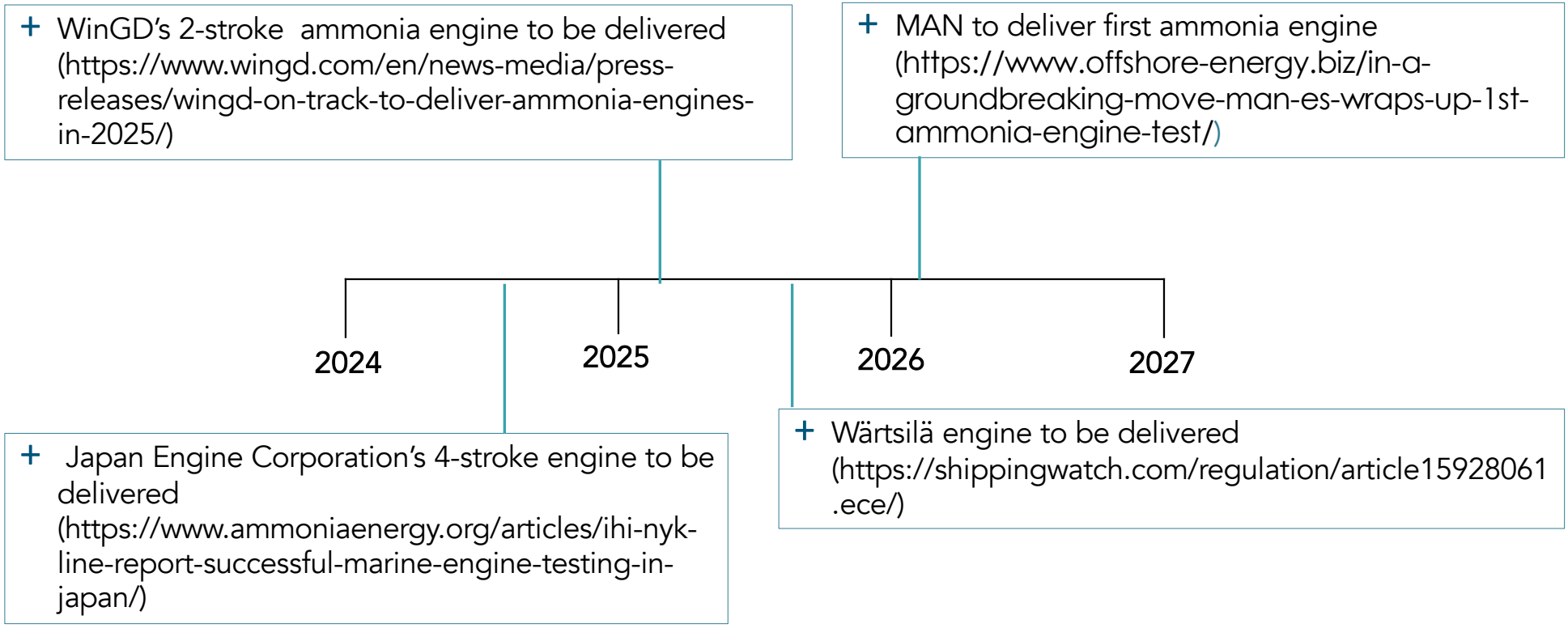
- Existing cargo loading procedures can be used
- New AF-VLGC with NH_3 engines
- Engine room
  - New designs e.g., isolation/segmentation of fuel preparation rooms
  - Additional safety designs & procedures, remote engine monitoring
  - Studies e.g., Castor initiative, Shell-DNV, LR

- No existing NH_3 transfer procedures
- 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

- No existing NH_3 related bunkering procedures
- 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

- No existing NH_3 related bunkering procedures
- Existing storage to truck can be used
- Bunkering procedures and emergency response plans to be refined when vessels are available

Mapping of ammonia engine readiness



Paving the way for an eventual bunkering pilot in SG

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

- **No** projections for ammonia bunker demand or storage capacity requirements
- **No** technical reference for ammonia bunkering
- **No** competency framework to support training
- **No** site(s) identified for a pilot
- **No** appreciation of CAPEX needed to ready bunkering sites
- **No** risk identification or assessment for different bunkering concepts
- **No** guidelines for custody transfer to assure quality and quantity
- **No** regulatory guidelines or sandbox for conducting a pilot

Ammonia bunkering safety study

To define the safety + operations envelopes to enable ammonia bunkering

Study consultants: DNV Singapore Pte Ltd, Surbana Jurong, Singapore Maritime Academy

Expected outcomes will 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

Operational readiness of future ammonia bunkering ecosystem

- Study conducted by DNV, Surbana Jurong and Singapore Maritime Academy
- GCMD assembled **22** study partners with expertise and experience in handling ammonia as participants
- **8** regulatory agencies were consulted
- **>130** industry consultation and alignment panel members provided feedback

Fuel producers

YARA

Fuel storage terminal operators

ADNOC

Vopak

Bunker suppliers + barge operators

Fratelli Cosulich

PAVILION Energy

KENOIL

HONG LAM MARINE

Port + terminal operators

Jurong Port

PSA

Vessel owners + operators

Asiatic Lloyd

EASTERN PACIFIC SHIPPING

MOL

PIL

ONE OCEAN NETWORK EXPRESS

NYK LINE NIPPON YUSEN KAISHA

Shipyards + vessel design + consultancy

Keppel*

SEATECH Trusted Solutions

sembcorp* marine

Fuel (quality + quantity) testing service providers

National Metrology Centre NMC

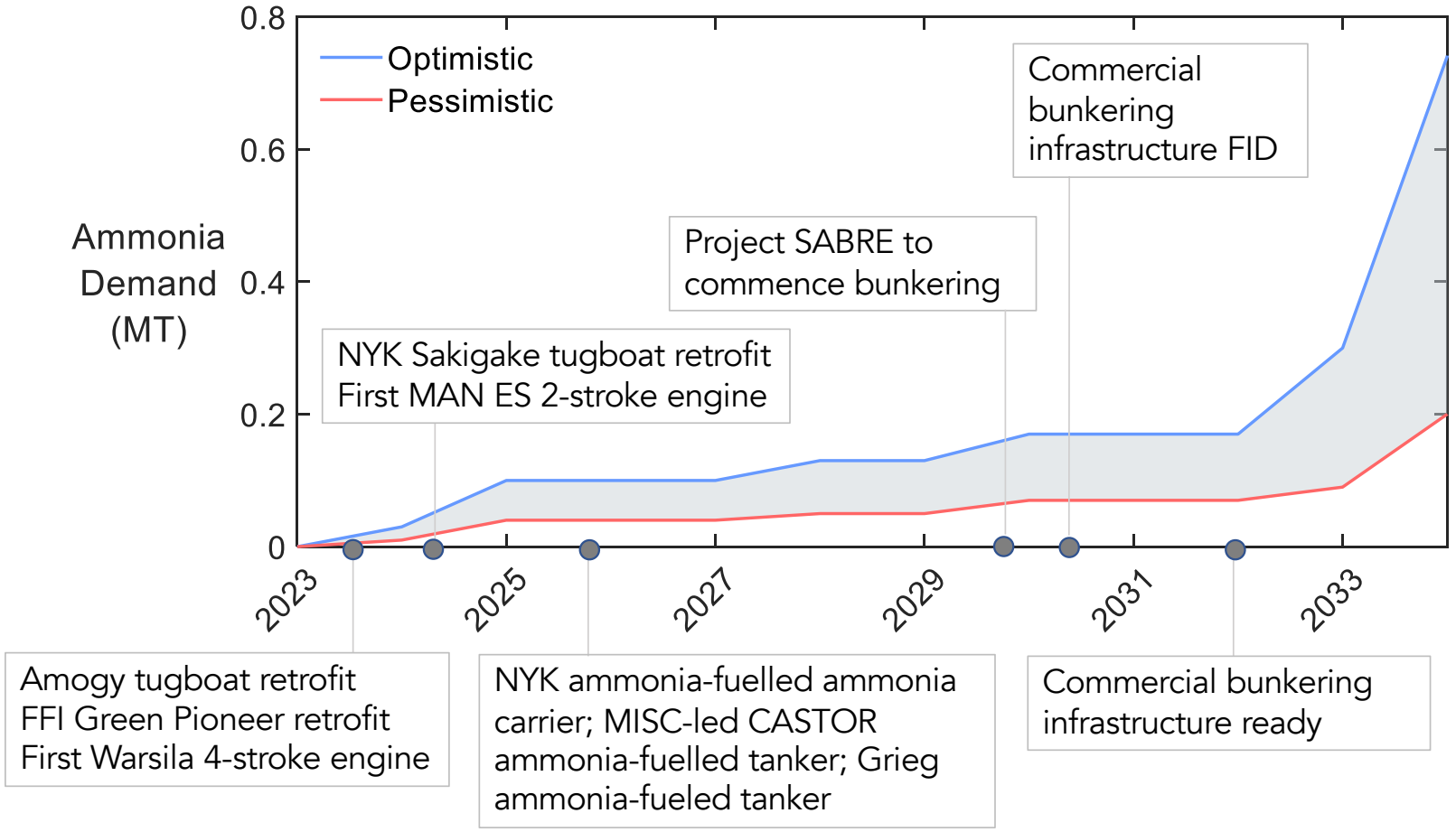
VISWA GROUP

VPS

** Keppel Offshore & Marine and Sembcorp Marine merged in April 2023; the new entity is known as Seatrium*

Need to build up capability and infrastructure now

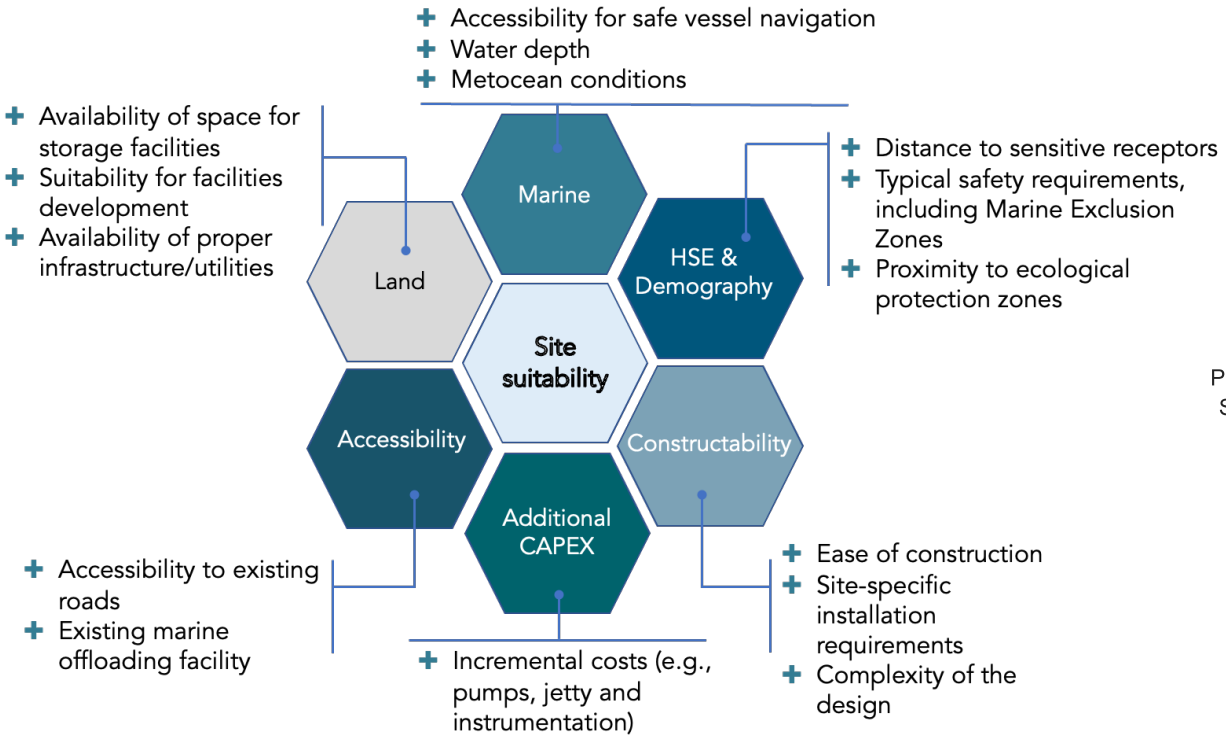
Bunkering ecosystem needs to be operationally ready by 2026

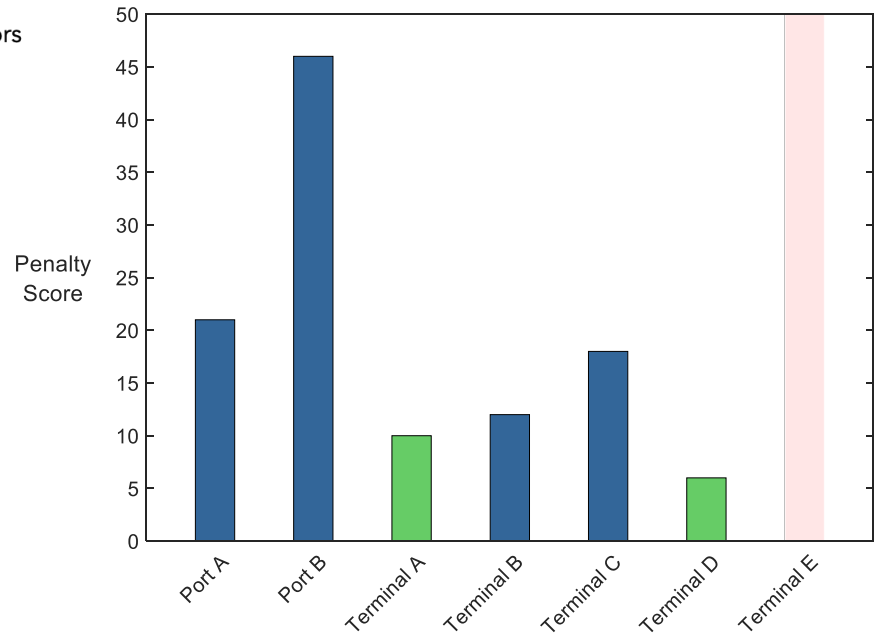


Singapore's ammonia bunker demand expected to take off in **mid-2030's**; projected to be **2 MTPA** in **2035,** supportable by **one** 15,000 cbm bunker vessel

Compilation not exhaustive

43 criteria across 5 categories for site selection





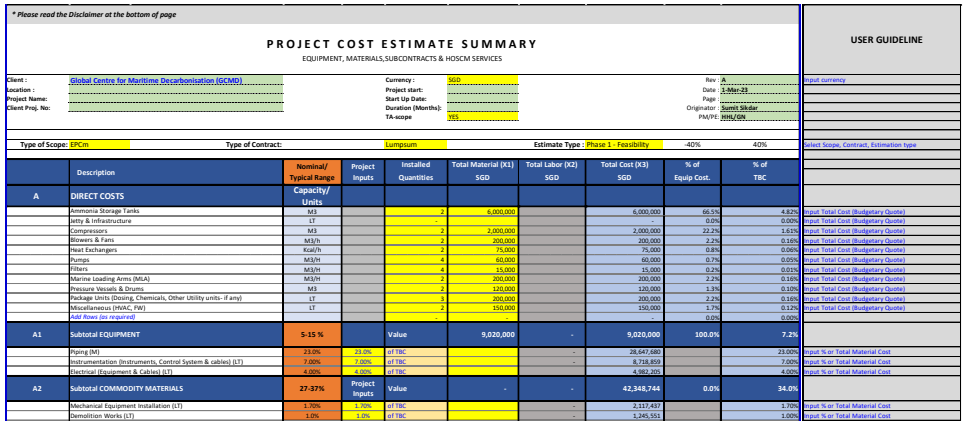
+ **2 land-based sites** with minimal upfront investment and **Raffles Reserve Anchorage** selected for further study
+ Other sites may be suitable with additional investments; these were not part of study

Variance in CAPEX to ready for ammonia bunkering

Basis of Estimates (BoE) based on:

- ✚ Concept and site-specific information
- ✚ HSE considerations
- ✚ Project risks
- ✚ Direct cost (materials and installation
- ✚ Indirect costs (services)

Cost data from quotes and in-house database



* Please read the Disclaimer at the bottom of page

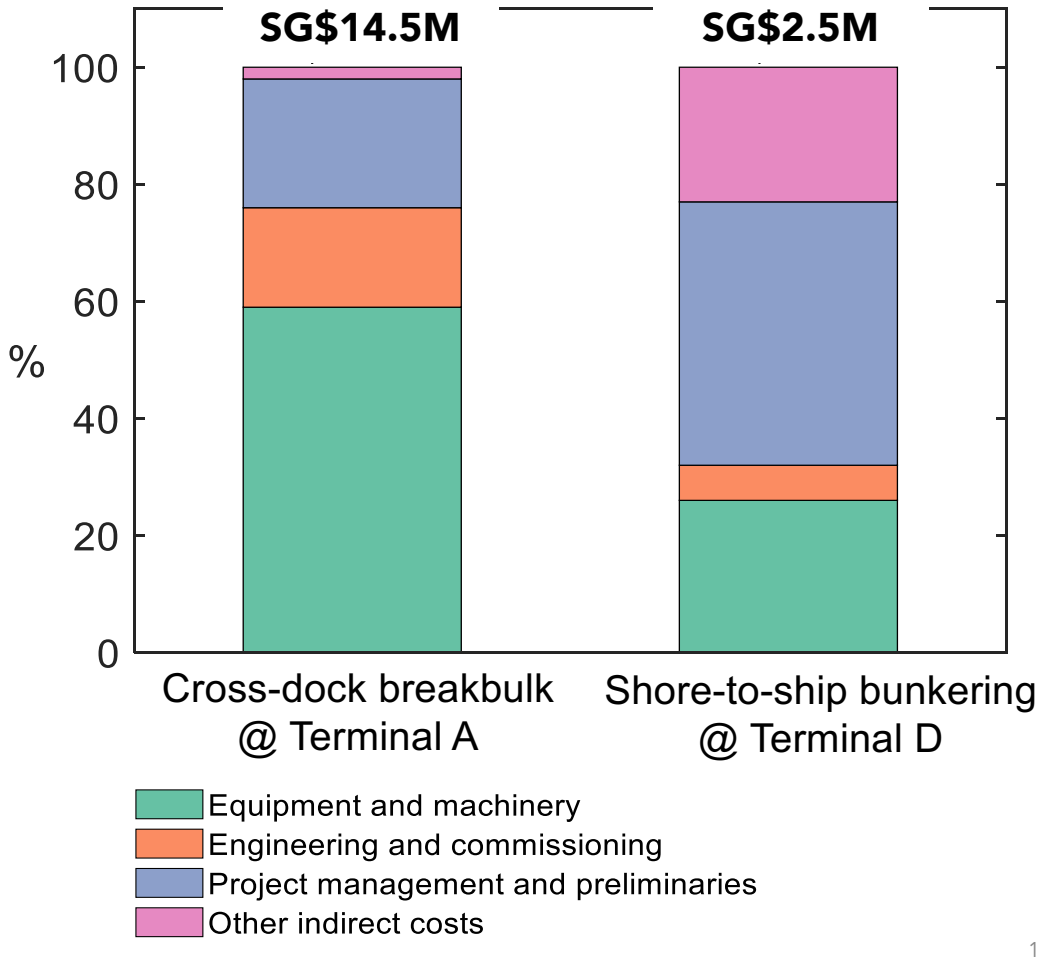
PROJECT COST ESTIMATE SUMMARY

EQUIPMENT, MATERIALS,SUBCONTRACTS & HOSCM SERVICES

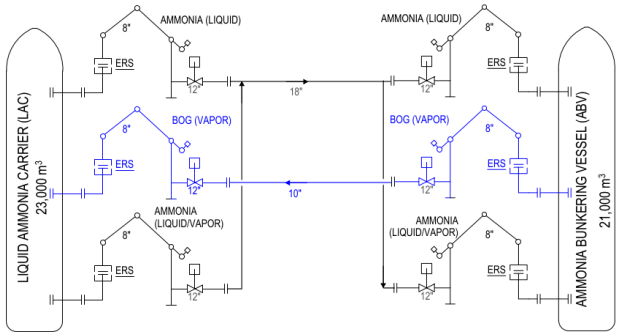
Client :	Global Centre for Maritime Decarbonisation (GCMD)			Currency :	SGD			Rev :	A	
Location :				Project start:				Date :	1-Mar-23	
Project Name:				Start Up Date:				Page :		
Client Proj. No:				Duration (Months):				Originator:	Sumit Sikdar	
				TA-scope	YES			PM/PE:	NHL/GN	
Type of Scope:	EPCm	Type of Contract:		Lumpsum	Estimate Type :	Phase 1 - Feasibility		-40%	40%	

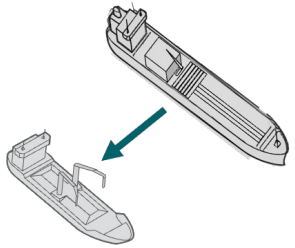
	Description	Nominal/ Typical Range	Project Inputs	Installed Quantities	Total Material (X1) SGD	Total Labor (X2) SGD	Total Cost (X3) SGD	% of Equip Cost.	% of TBC	USER GUIDELINE
A	DIRECT COSTS	Capacity/ Units								
	Ammonia Storage Tanks	M3		2	6,000,000		6,000,000	66.5%	4.82%	Input Total Cost (Budgetary Quote)
	Jetty & Infrastructure	LT		-			-	0.0%	0.00%	Input Total Cost (Budgetary Quote)
	Compressors	M3		2	2,000,000		2,000,000	22.2%	1.61%	Input Total Cost (Budgetary Quote)
	Blowers & Fans	M3/h		2	200,000		200,000	2.2%	0.16%	Input Total Cost (Budgetary Quote)
	Heat Exchangers	Kcal/h		2	75,000		75,000	0.8%	0.06%	Input Total Cost (Budgetary Quote)
	Pumps	M3/H		4	60,000		60,000	0.7%	0.05%	Input Total Cost (Budgetary Quote)
	Filters	M3/H		4	15,000		15,000	0.2%	0.01%	Input Total Cost (Budgetary Quote)
	Marine Loading Arms (MLA)	M3/H		2	200,000		200,000	2.2%	0.16%	Input Total Cost (Budgetary Quote)
	Pressure Vessels & Drums	M3		2	120,000		120,000	1.3%	0.10%	Input Total Cost (Budgetary Quote)
	Package Units (Dosing, Chemicals, Other Utility units- if any)	LT		3	200,000		200,000	2.2%	0.16%	Input Total Cost (Budgetary Quote)
	Miscellaneous (HVAC, FW)	LT		2	150,000		150,000	1.7%	0.12%	Input Total Cost (Budgetary Quote)
	Add Rows (as required)			-			-	0.0%	0.00%	
A1	Subtotal EQUIPMENT	5-15 %		Value	9,020,000	-	9,020,000	100.0%	7.2%	
	Piping (M)	23.0%	23.0%	of TBC		-	28,647,680		23.00%	Input % or Total Material Cost
	Instrumentation (Instruments, Control System & cables) (LT)	7.00%	7.00%	of TBC		-	8,718,859		7.00%	Input % or Total Material Cost
	Electrical (Equipment & Cables) (LT)	4.00%	4.00%	of TBC			4,982,205		4.00%	Input % or Total Material Cost
A2	Subtotal COMMODITY MATERIALS	27-37%	Project Inputs	Value	-	-	42,348,744	0.0%	34.0%	
	Mechanical Equipment Installation (LT)	1.70%	1.70%	of TBC		-	2,117,437		1.70%	Input % or Total Material Cost
	Demolition Works (LT)	1.0%	1.0%	of TBC		-	1,245,551		1.00%	Input % or Total Material Cost

Model available for download on report site

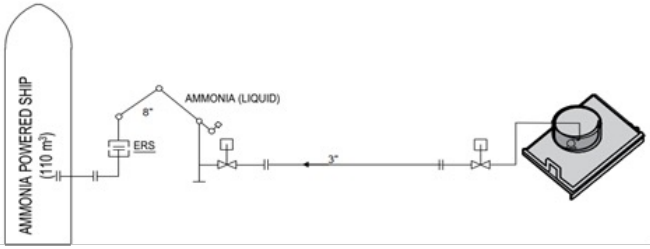


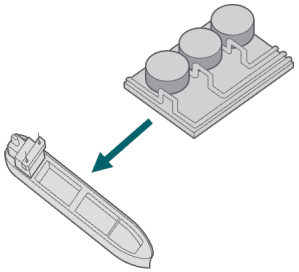
Four concepts at three sites for HAZID and c-QRA



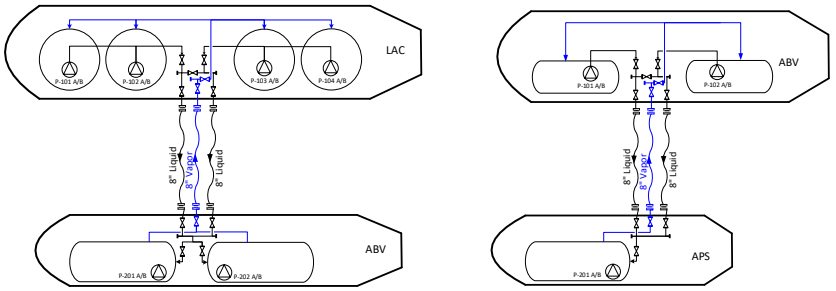


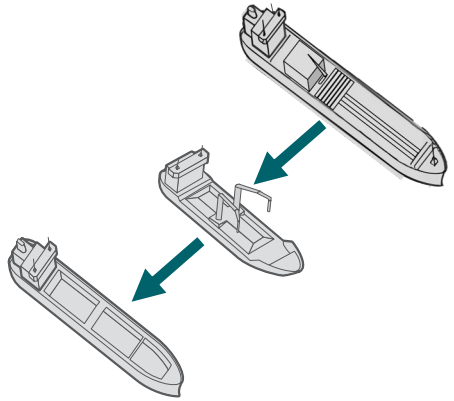
Cross-dock breakbulk
@ **Terminal A***
750 m^3/hr x 2





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





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

* Site identification and site-specific information not disclosed until further notice

400 risks identified; all low or medium, i.e., mitigable

Risk type	Configuration and location	High risk (frequency)	Medium risk (frequency)	Low risk (frequency)	Not relevant for site
Locational	Breakbulk at anchorage	0	37	3	13
	Bunkering at anchorage	0	36	3	13
	Breakbulk @ Terminal A	0	25	7	16
	Bunkering @ Terminal D	0	23	9	15

Risk type	Configuration and location	High risk (frequency)	Medium risk (frequency)	Low risk (frequency)	Not relevant for site
Operational	Breakbulk at anchorage	0	33	3	4
	Bunkering at anchorage	0	38	1	3
	Breakbulk @ Terminal A	0	34	4	4
	Bunkering @ Terminal D	0	41	5	4

Low risk: risk considered broadly acceptable; no addition preventative measures required

Medium risk: mitigation measures must be implemented so risks are As Low as Reasonably Practicable (ALARP)

High risk: risk intolerable; measures must be implemented to reduce risk to a tolerable level

Safety zone determination

- Safety zones for Terminals A and D determined **probabilistically,** and added to risk from existing operations; cumulative risk for pilots lower than criteria in MHD guidelines

Risk associated with ammonia transfer pilot	+	Risk associated with existing operations	=	Cumulative risk

- No guidelines for risk assessment of piloting ammonia transfer at anchorage; assumed TR 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**

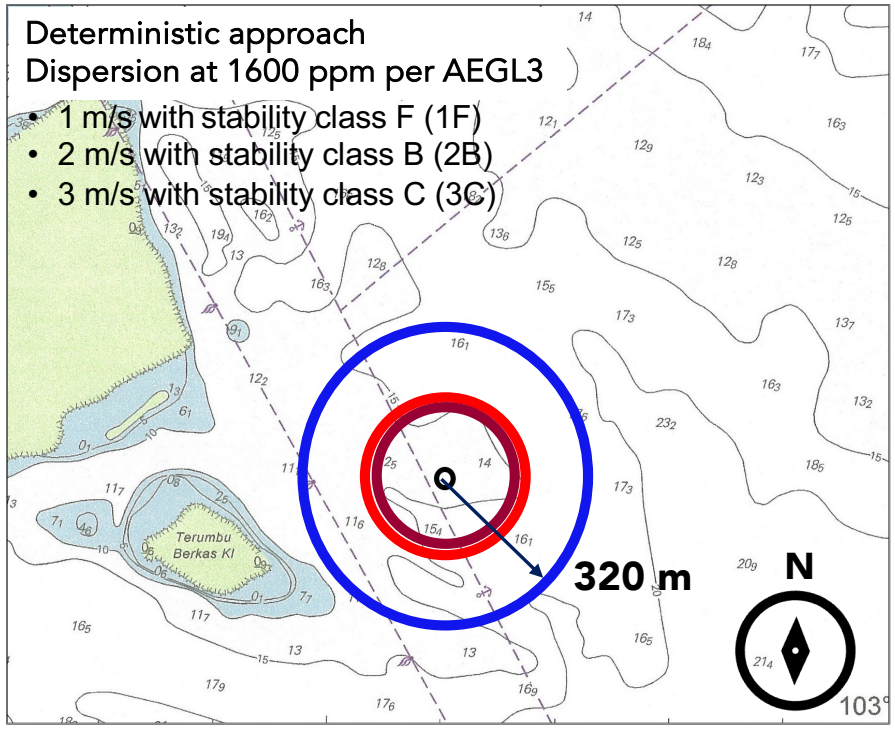
* Based on a "most credible" loss scenario of a small leak (10 mm diameter) in pipe/hose

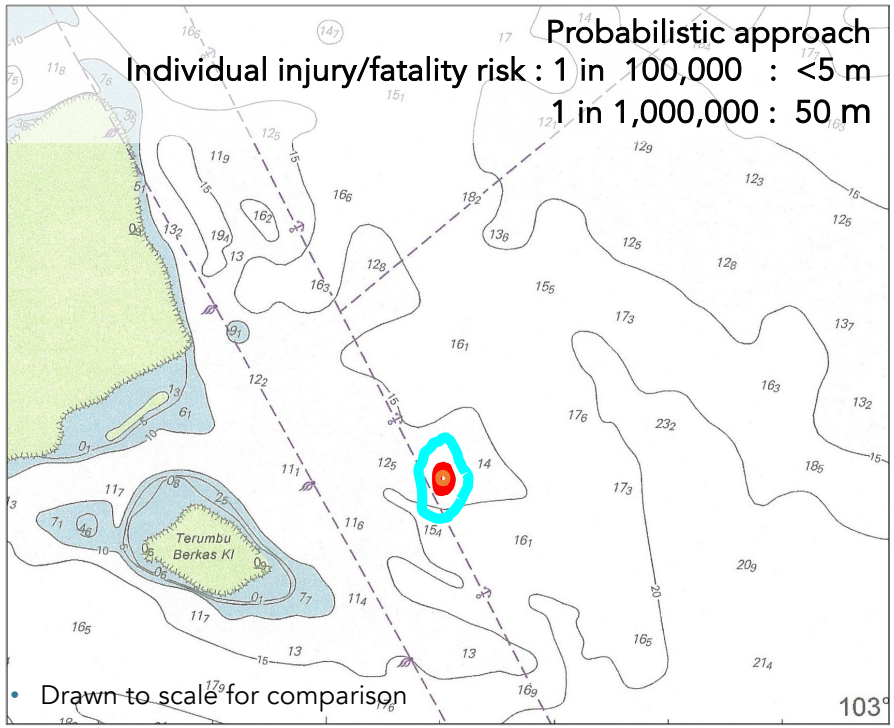
MHD guidelines: National Environment Agency (NEA) Singapore (2016). "QRA Criteria Guidance," Revision No. 3, 9th November 2016

Safety Assessments are Defined by Operating and Risks Assumptions to Comply with Local Regulations

- Examples of operating assumptions
  - Transfer frequency and duration
  - Flowrates, pressure and temperature
- Examples of environmental assumptions
  - Meteorological conditions
  - Location of transfer
- Example of risks assumptions
  - Potential failure cases
  - Leak frequencies for equipment
  - Leak size
  - Credible events

Representative safety zones at Raffles Reserve Anchorage





- ✚ Risk assessment and safety zone estimation consider lay persons not involved pilot
- ✚ Injury and fatality risks low given **limited number** of pilots and **small inventory volume**
- ✚ Safety zones are **≈300 m**, subject to ALARP; this distance is comparable with that initially estimated for LNG bunkering (500 m)

Safety Radius is Not Directly Proportional to Inventory Release

Case No. and Description	Hole Size (mm)	Pressure (barg)	Temp. (Deg.C)	Flow rate (m3/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, 1600 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**

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 generalised as guidebook

Guidebook on handling ammonia as a **fuel**

Part 1: Introduction

Part 2: Requirements for **custody transfer**

Part 3: Bunkering and **safety** procedures

Part 4: **Competency** requirements for shipboard and shore personnel

Enable **training** *of seafarers and operators:*

+ Incorporated into SMA's *Advanced Training for Ships Subject to the IGF code* curriculum
+ First course offered in March 2023; 14 industry participants
+ June 2023 course open for registration

Help shape **bunkering standards** *domestically and internationally:*

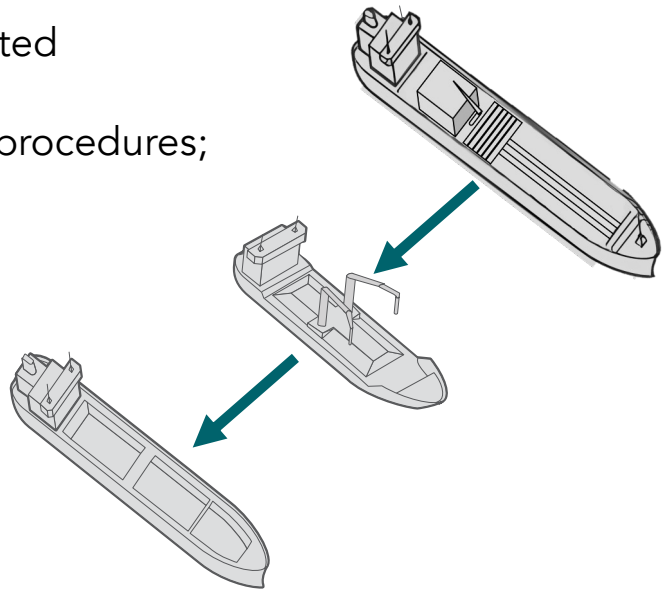
+ Submit guidebook to Standards Development Organisation of Singapore Standards Council's Chemical Standards Committee, May 2023
+ Participate in ammonia bunkering working group to refine and finalise technical reference
+ Engage international standards organisations, like OCIMF, SGMF, SIGTTO

Learnings from study in preparation for STS pilot

- Use **deterministic** safety zones to scope pilots
- Mitigate risks further by **reducing inventory** transferred and/or transfer **duration**
- Operate at **flow rates** close to design specification; operating at flow rates substantially lower than specification can result in two-phase flow that has 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 **at strategic locations** to minimise 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**

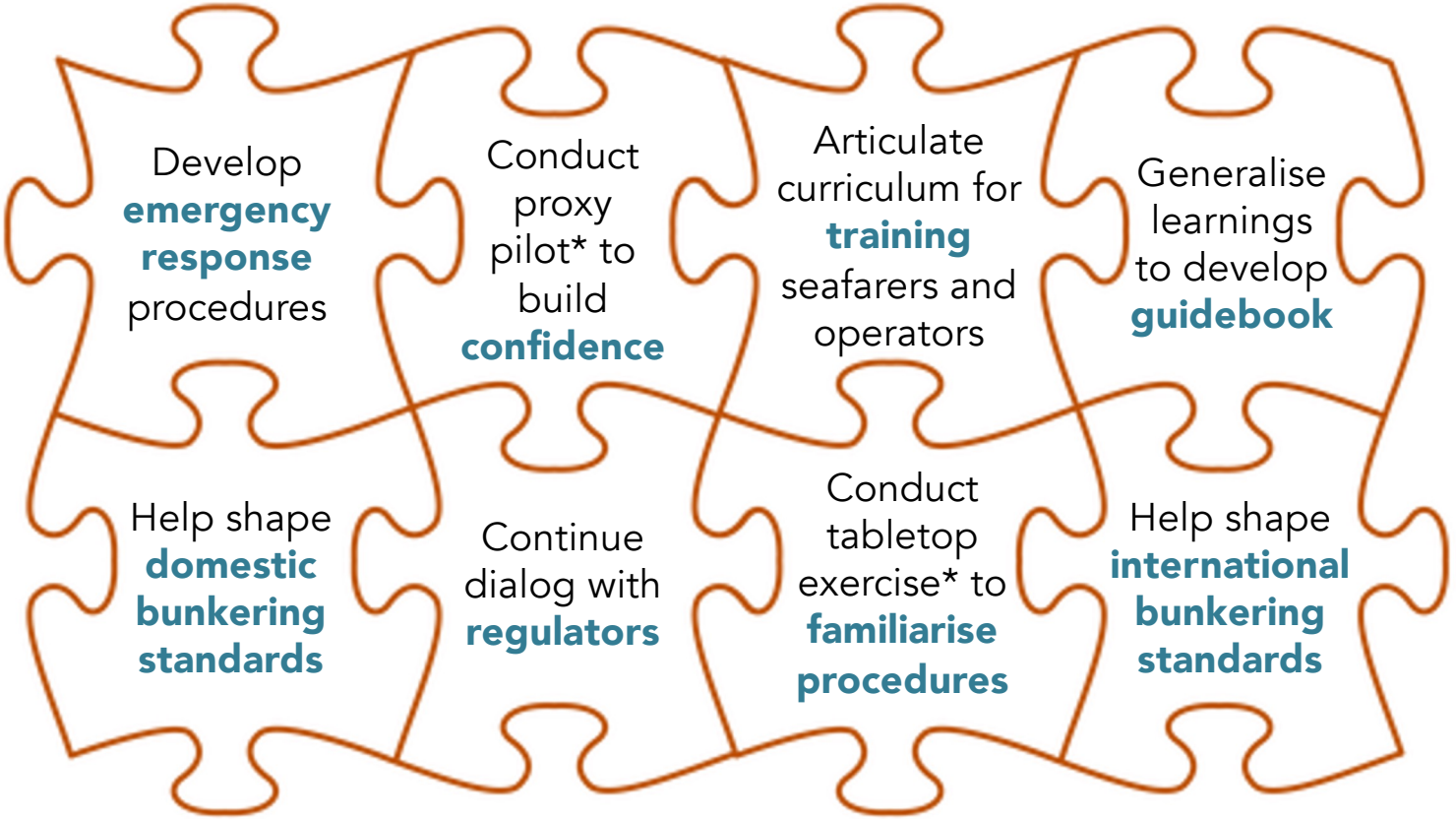
STS ammonia transfer to build confidence + competence

- Scoping ammonia transfer pilot to take place in port waters of Singapore
- Identified two ammonia carriers of different sizes; transfers will mimic breakbulk and bunkering
- Detailed safety assessment, including HAZID, HAZOP, QRA to be conducted
- Currently speaking with OSRL/BlueTack to develop emergency response procedures; identifying STS service provider to help execute pilot
- Ongoing conversations with regulatory agencies
- Discussions ongoing to develop process for cargo integrity assurance
- "Learning by doing" to build confidence, competence and capability



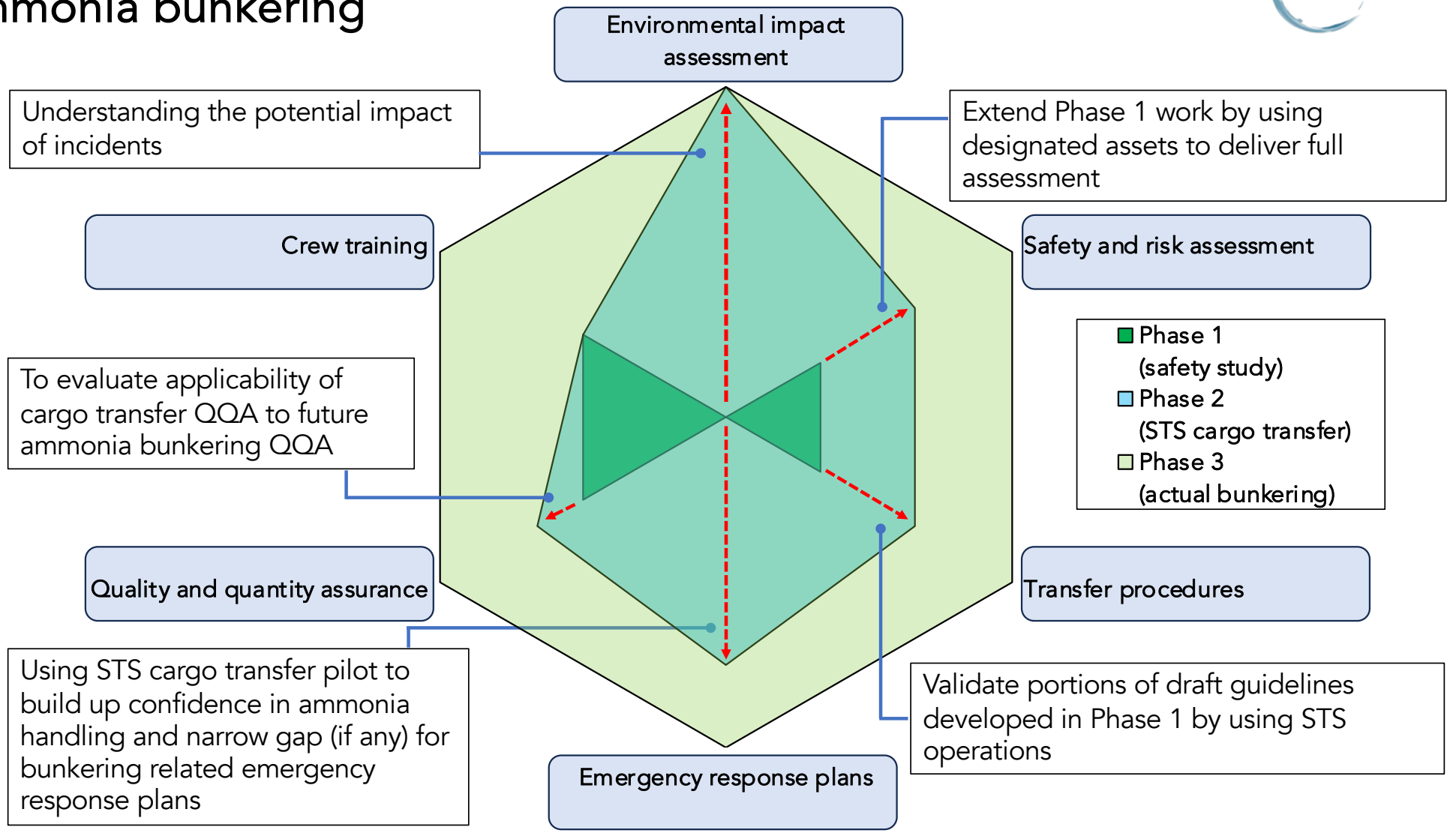
Exercise will pave the way for an eventual bunkering pilot when ammonia-fueled vessels become available

Leveraging study to mobilise the pieces

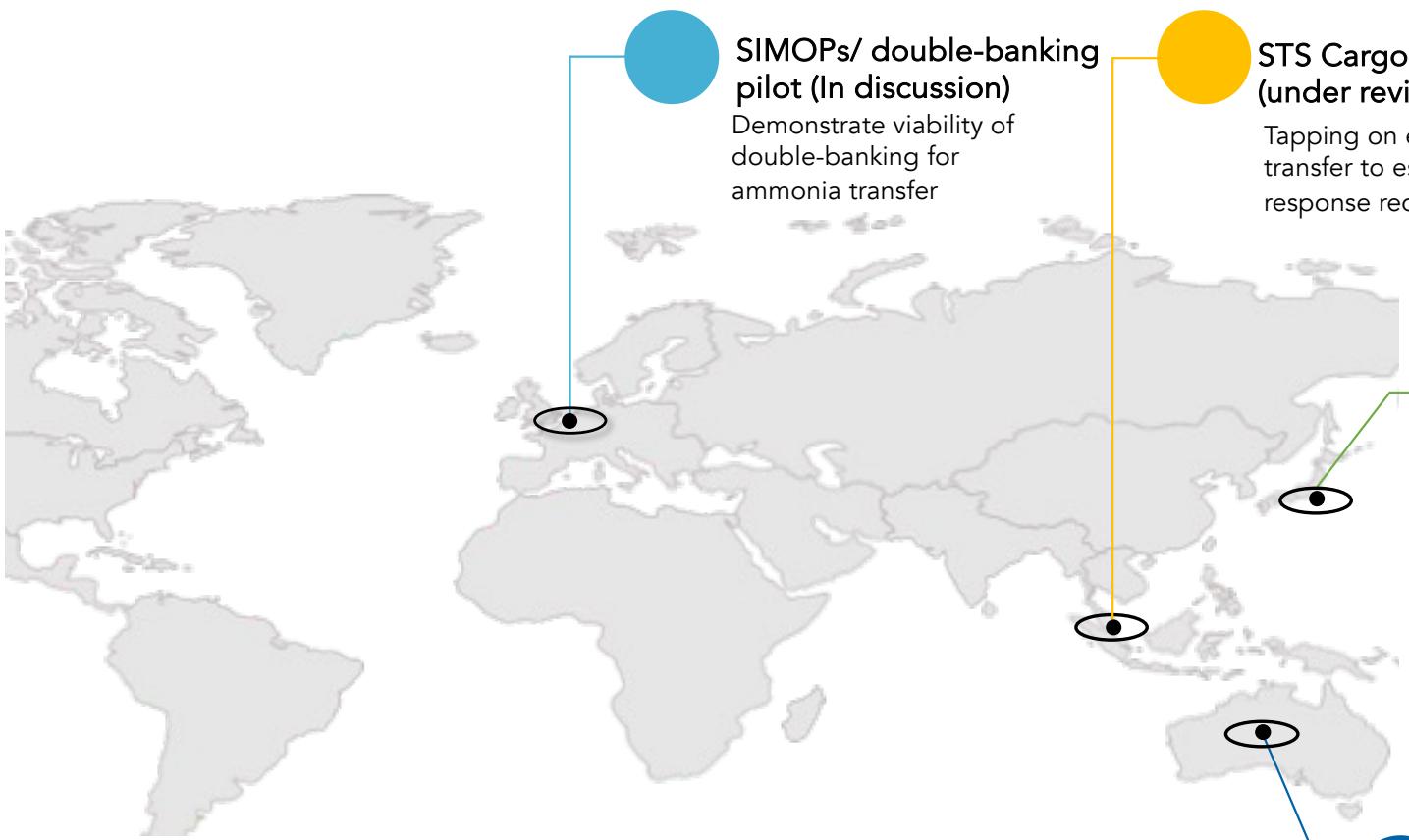


* Alongside regulators and with regulatory approvals

Phased approach to close gaps of key drivers to ensure safe ammonia bunkering



Building up capabilites through complementary trials



SIMOPs/ double-banking pilot (In discussion)
Demonstrate viability of double-banking for ammonia transfer

STS Cargo transfer within Port Limits (under review)
Tapping on existing knowledge on STS cargo transfer to establish safety and emergency response requirements for bunkering

Shore-to-ship bunkering (In-discussion)
Demonstrate actual bunkering to end-user

STS Cargo transfer within Port Limits (in discussion)
Work with ammonia export terminal, using STS as a proxy for bunkering

Complete greening of the maritime supply chain requires all stakeholders across the value chain to play their role

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Stakeholders

Production	Distribution + Storage	Bunkering	Application	Buyer of logistics services
+ ISCC, REDII or Green certification of products + ESG Compliance	+ Investment into infrastructure to handle green fuels + Use of renewable energy or zero carbon fuels + Green certification of services	+ Investment into green fuel bunkering vessels + Use of zero carbon/GHG emission fuels	+ Adoption of energy efficiency technical and operational measures + Adoption of zero carbon/GHG emission fuels	+ Green procurement policy for green goods and services + Green consumer demand for green goods

Classification societies, certification bodies, safety consultants, ESG consultants, digital and enterprise systems

Regulatory + safety authorities, policy makers

Financial institutions, carbon market mechanisms

Source: GCMD analysis;

Collaborating with the right partners to ensure success

To establish the use of ammonia as a marine fuel, we overcome the paralysis of the risk adverse by collaborating with partners that are highly risk aware.

Scan the QR code to download a "living" version of the report now

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