Ammonia Bunkering and Simulation of Release Scenarios

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14 October 2021

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4. Safety Considerations
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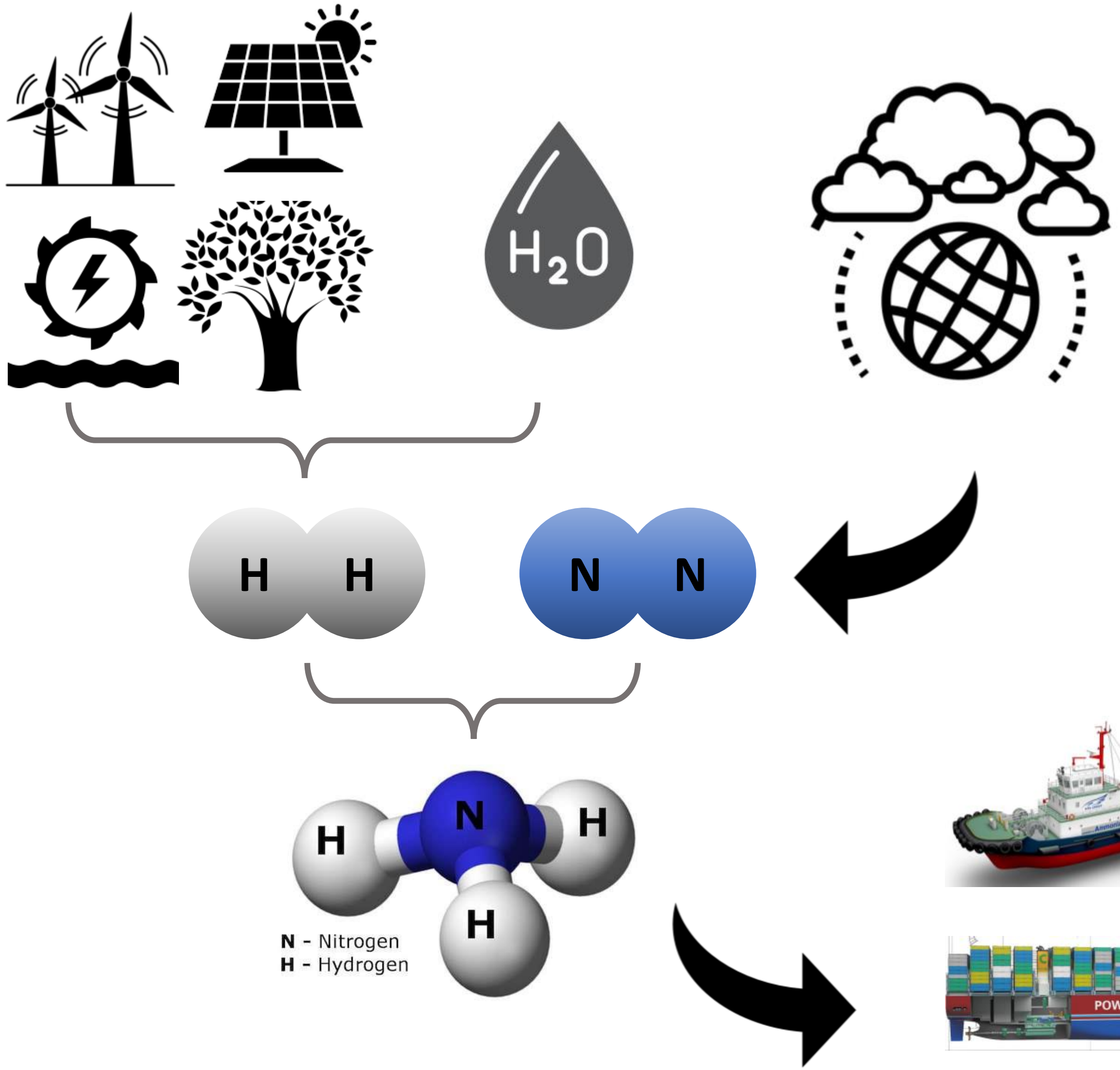
Ammonia As A Marine Fuel



Background

- Green ammonia has the potential to be a carbon-free fuel to achieve GHG reduction goal for the marine sector.
- Ammonia bunkering deserve a timely study to prepare its adoption by the marine industry.
- Applicable to many vessel types.

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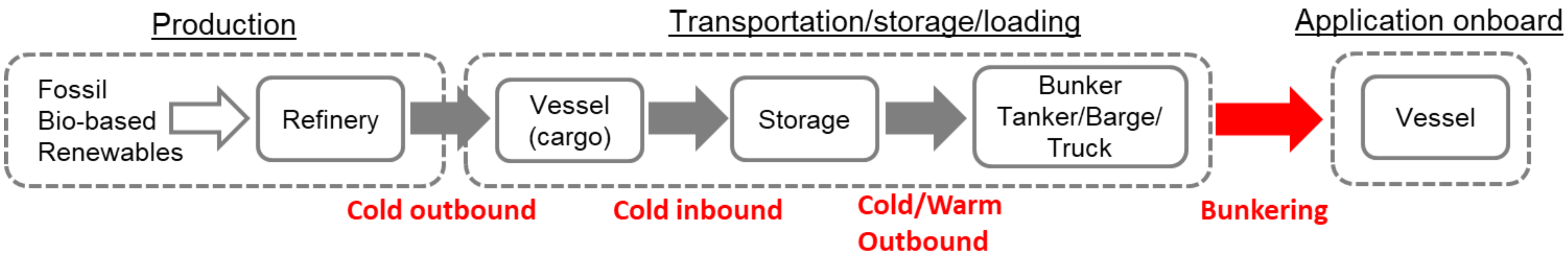
Ammonia Handled as Bunker vs Cargo

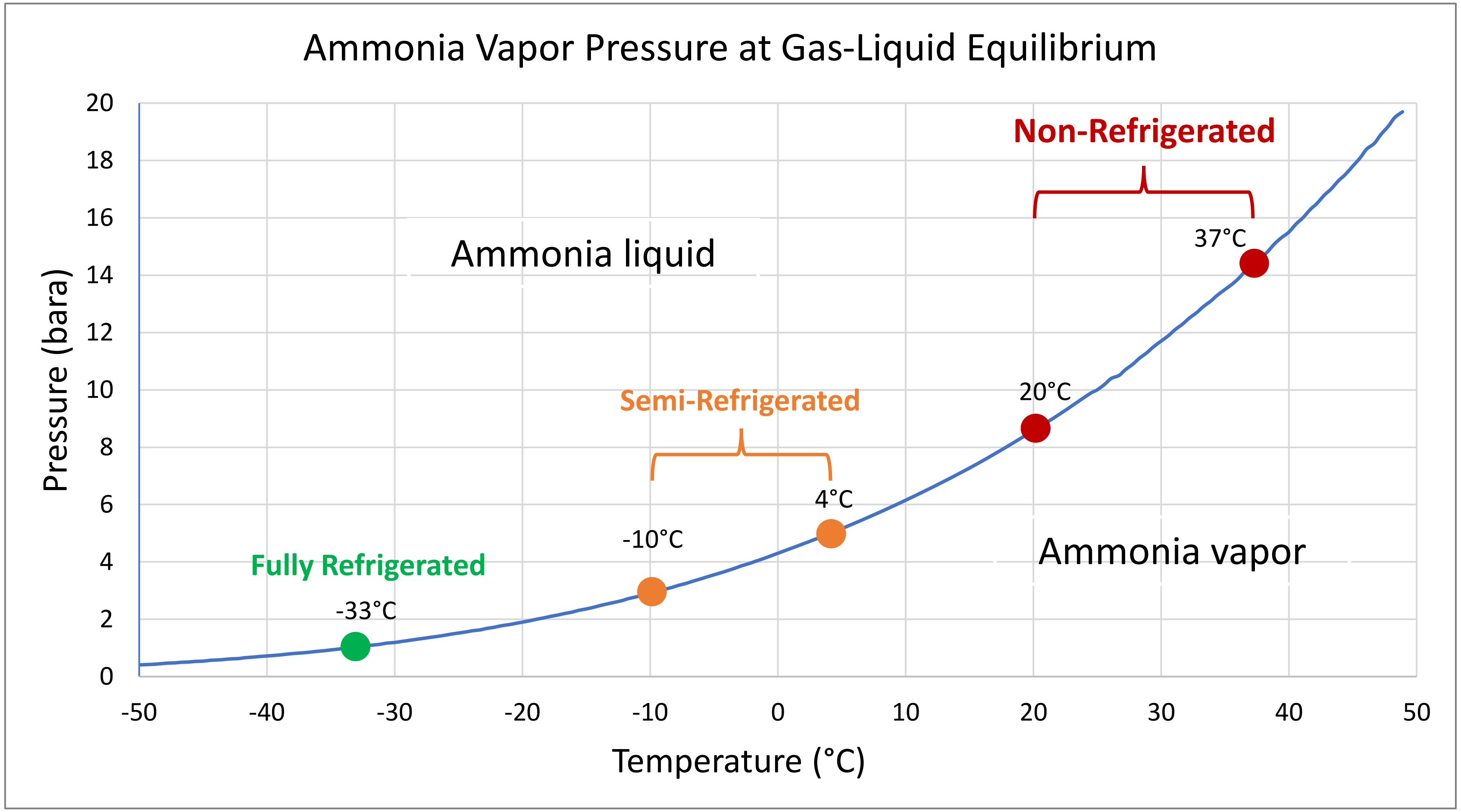


	As Cargo	As Bunker
Working principle	Boiling liquid	Boiling liquid
BOG and vapor return	Required	Optional
Tank size[1] & flow rate	Higher capacity, high flowrate	**Lower capacity, relevant to energy content[2]**
Quality	Chemical grade	**Fuel grade**
Transferring frequency	Low, limited to tankers	**Very high, applies to various type of vessels**
Dispersion study on release (land)	Limited to industrial sites	**Not established**
Dispersion study on release (water)	**Not established**	**Not established**
Operation experience	Limited to industrial use	**Not established**
Transferring process	Comprehensive (FR, SR and NR)	**Not established**
Operation mode	Less combinations	Up to 33 combinations[3]
Guidelines & Procedure	In place	**Not established**

Numerous gaps need to be filled to enable successful ammonia bunkering operation.

1. Cargo capacity around 20 ~ 60 K cbm for tankers; Fuel tank of Panamax container ship is around 5 ~ 6.7 K cbm of fuel oil.
2. Based on MPA port statistics 2020, an average of 1200 tonnes marine fuel transacted per bunker call. For the same endurance, the quantity of ammonia shall be 3 times more.
3. MESD study.

Ammonia Bunkering Concept - States of Ammonia Liquid



Source: Diagram data extracted from The Engineering ToolBox

- Three types of transferring are considered:
  - ✓ Fully refrigerated (FR)
  - ✓ Semi-refrigerated (SR)
  - ✓ Non-refrigerated (NR)
- Bunkering process shall be designed according to the physical states of ammonia
- Transferring between different physical states will create multiple bunkering configurations

Ammonia Bunkering Concept - Possible Configurations

Bunker Supply									Cassette Bunkering						Bunker Receiving
Truck			Bunker Vessel			Shore-based			Truck			Bunker Vessel			
FR	SR	NR	FR	SR	NR	FR	SR	NR	FR	SR	NR	FR	SR	NR	
1	4	7	10	13	16	19	22	25	28			31			FR
2	5	8	11	14	17	20	23	26		29			32		SR
3	6	9	12	15	18	21	24	27			30			33	NR

Source: MESD, NTU

33 possible configurations

Ship to ship bunkering

Ship to ship bunkering with simultaneous cargo handling (SIMOPS)

Truck to ship bunkering

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Ammonia Bunkering – Proposed Concept & Considerations

Pre-bunkering preparations
- All necessary administrative procedures
- Mode of transfer
- Match parameters between supply & receiving vessel

→ **Connection**
- Hose material, insulation, minimum bending…
- Leak test
- Grounding
- Electrical continuity

→ **Inerting**
- Oxygen removal, potential SCC

→ **Purging/Gassing up**
- Vent options: Direct vent; Flare; Acid absorber; Kick back to storage tank

→ **Transferring**
- Flow rate / pressure control, roll over , ESD, filling level, self-driven, pump driven…
- Sampling, latent heat management …

→ **Stripping**
- Driven by heat from surroundings
- Addition driving force (compressor…)

← **Inerting**
- Vent options: Direct vent; Flare; Acid absorber; Kick back to storage tank

← **Disconnecting**
- Leak proof connections (smart hose…)

← **Post-bunkering operations**
- All necessary administrative procedures

*Unlike conventional liquid, ammonia is bunkered as a "**boiling liquid**" at all times.*

Simplicity is the best sophistication. The overall process shall be as simple as possible.

Source: MESD, NTU

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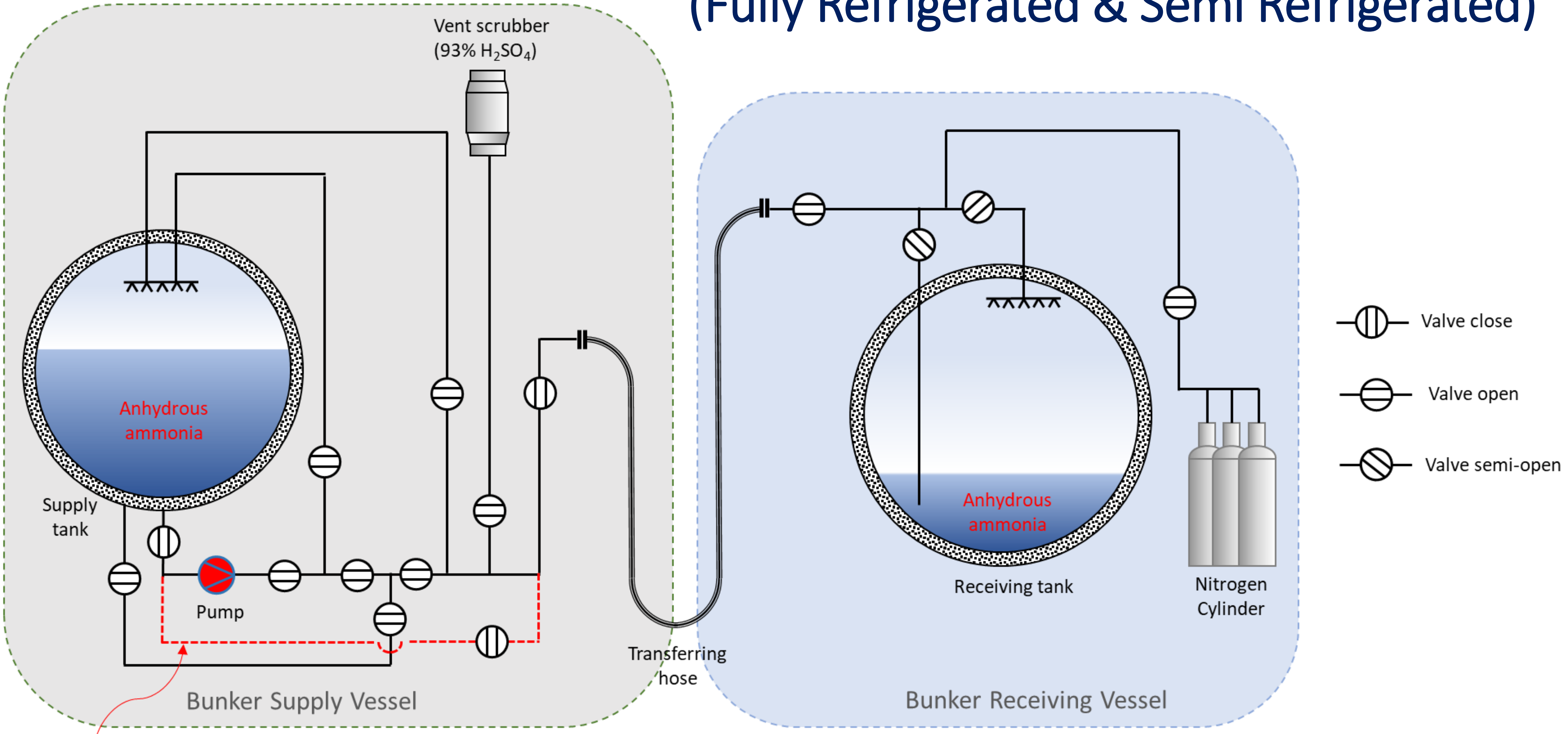
Ammonia Bunkering Concept (Fully Refrigerated & Semi Refrigerated)

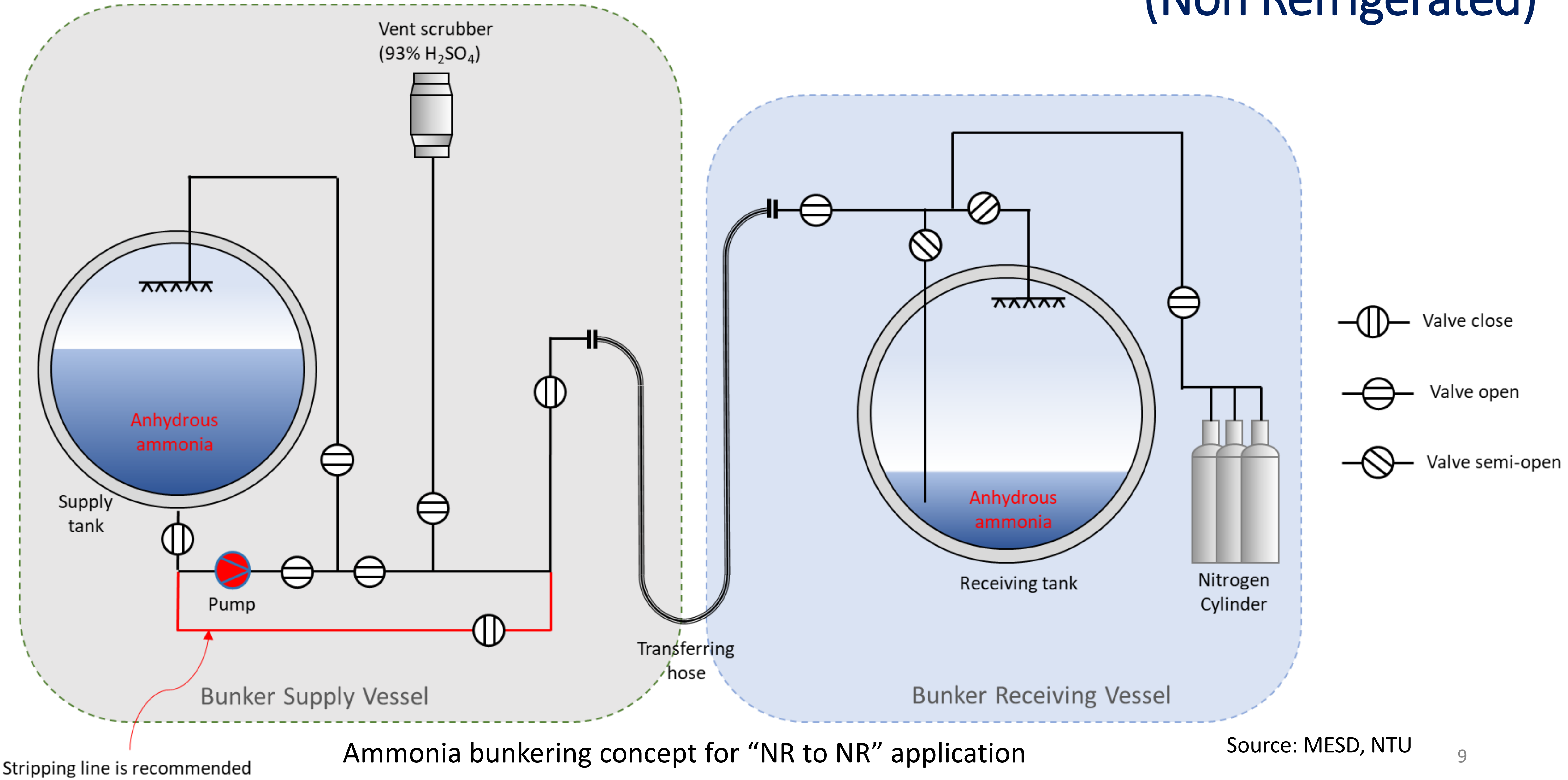


Stripping line can be optional

Ammonia bunkering concept for "FR to FR" and "SR to SR" applications

Source: MESD, NTU

Ammonia Bunkering Concept (Non Refrigerated)



Ammonia bunkering concept for "NR to NR" application

Source: MESD, NTU

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Safety Consideration of Ammonia Bunkering

! Actions should be taken long before the flammability of ammonia becomes a concern.

! Establishment of safe operating zone for ammonia bunkering shall be based on the toxicity instead of flammability.

Toxicity	**AEGL Level 1: > 30 ppm for 10min** Effects are not disabling and are transient and reversible upon cessation of exposure.
	AEGL Level 2: > 160 ppm for 1 hour Irreversible or serious, long-lasting adverse health effects
	AEGL Level 3: > 1,100 ppm for 1 hour Life-threatening health effects or death
Flammability	**LFL > 150,000 ppm** Minimum concentration to cause fire in presence of ignition source

Source: US EPA

(AEGL: acute exposure guideline level)

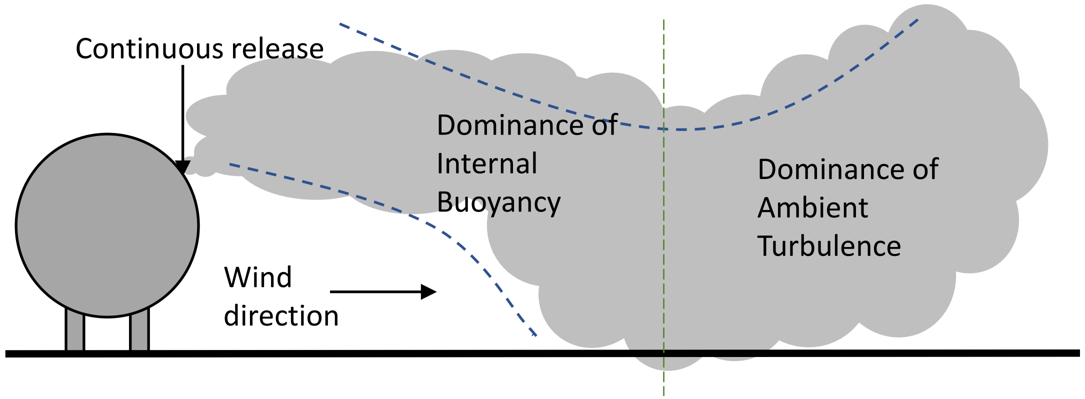
Process Hazard Analysis Software Tool (PHAST)

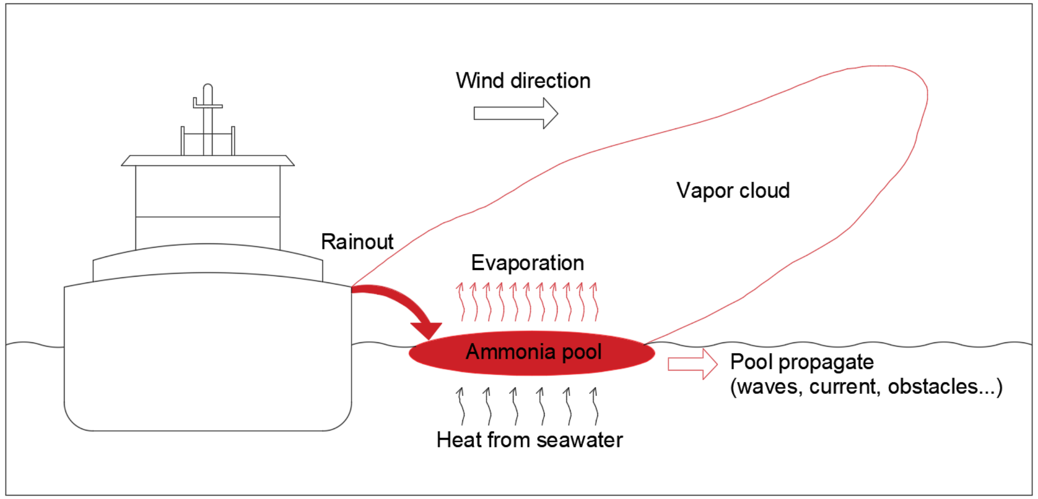
Passive Dispersion Phase
- Pasquill-Gifford model based on Gaussian diffusion model
- Dispersion coefficients are dependent on atmospheric turbulence and distance from source or duration of release

Discharge calculations
- Temperature, mass flow rate, velocity, liquid fraction @ exit of discharge
- Subsequent expansion (final droplet size) to atmospheric conditions

Modes of releases
- Continuous release (leaks from pressurized & atmospheric tanks, pipes, hose)
- Instantaneous release (catastrophic tank, pipe, hose rupture)
- Short duration and time-varying release

Application
- Provide ammonia cloud path from initial release point to far field dispersion downwind
- Predict the area affected and the concentration of ammonia cloud at any distance of interest (1 hour AEGL-2 160ppm and AEGL-3 1100ppm footprints)
- Evaluate the toxic effects of ammonia (3% lethality footprints)





Source: MESD, NTU

Ammonia Release - Sensitivity Analysis*

Scenario A: 8” hose rupture at inlet manifold of receiving vessel for 60s
Scenario B: Storage Conditions is simulated based on 5mins release from valve attached to storage tank.

Operational Parameters	Results
Storage Conditions (B) FR: -33.4^{o}C, 1 atm SR: -10^{o}C, 2.91 bar NR: 30^{o}C, 12 bar	FR has the smallest lethality footprint
Flow rate (m^3/h) (A) 500, 1000, 1500, 2,000	Doubling the flowrate from 500 m^3/h to 1000 m^3/h result in more than doubling the lethality footprint
Release Elevation (A) 5m, 10m, 15m and 20m above sea level	The higher the elevation of release, the larger the lethality footprint
Release Direction (A) Horizontal Vertical Upwards 45^{o} Downwards 90^{o} Downwards	Vertical upwards release result in the largest lethality footprint, 90^{o} downwards release result in the smallest lethality footprint
Isolation Time (A) 1 min, 2 min, 5 min	Doubling the isolation time result in doubling the lethality footprint

Note: downwind passive dispersion is a mixture of plume and puff model

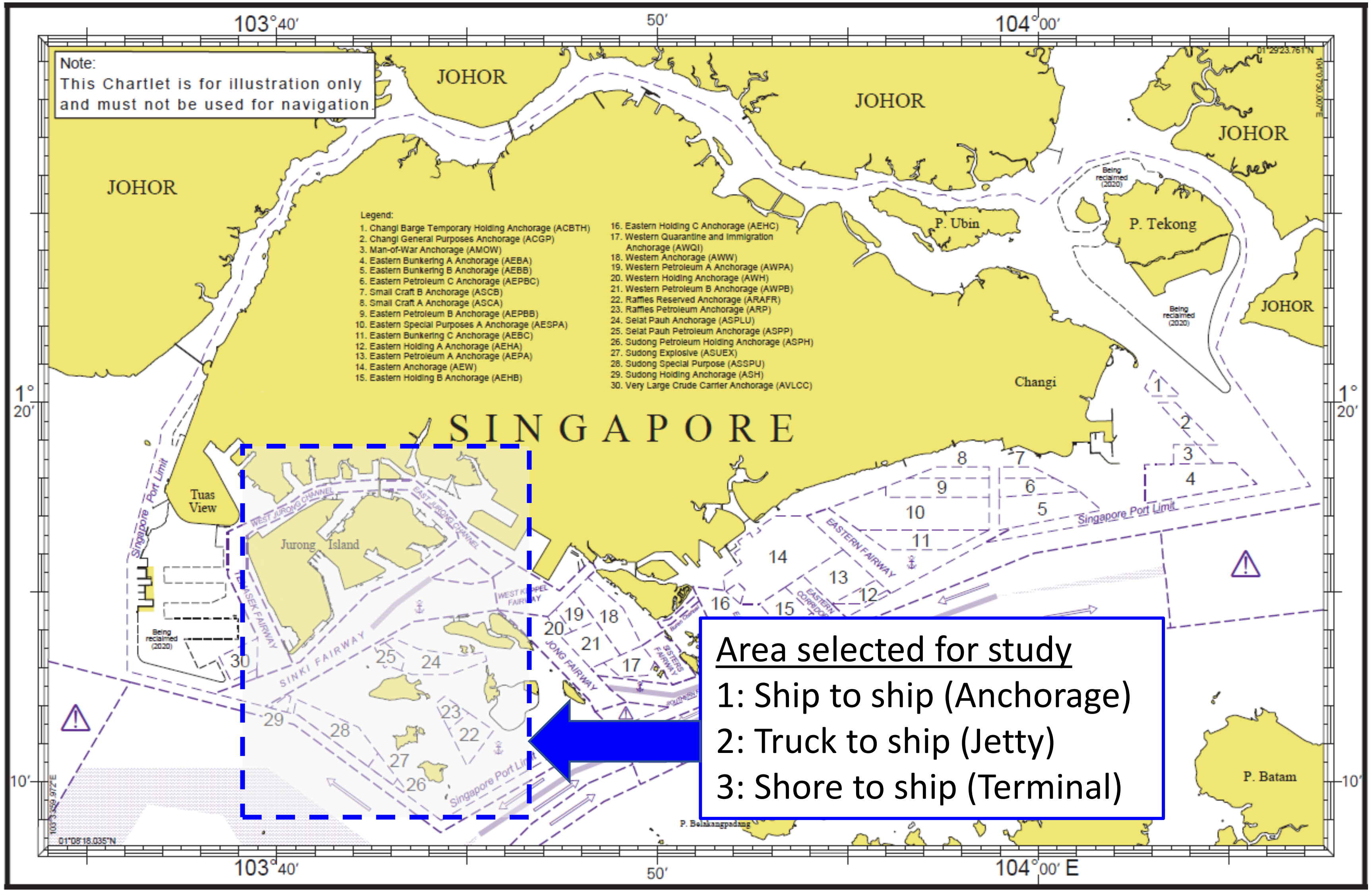
Scenario C: 225mm leak from 10,000m^3 atmospheric storage tank from a height of 3m above ground for 1 hour.

Weather Parameters	Results
Atmospheric Stability Unstable: Class A, B, C (day) Neutral: D (overcast, dawn, dusk) Stable: E (night)	The more unstable the atmosphere, the greater dispersion and/or dilution
Wind Speed Class C: 3, 5, 10, 20m/s Class D: 2, 5, 10, 20m/s Class E: 1, 2, 3m/s	Higher wind speed, greater dispersion downwind
Humidity 60, 70, 80, 90, 100%	Higher humidity, larger lethality footprint (Exception 100%: smallest footprint uplifted to a higher altitude)
Ambient Temperature Day 24-36^{o}C Night 20-32^{o}C	Higher ambient temperature, smaller lethality footprint
Surface Temperature Day 28-40^{o}C Night 20-32^{o}C	Higher surface temperature, larger lethality footprint

Note: continuous release with plume dispersion model during passive stage

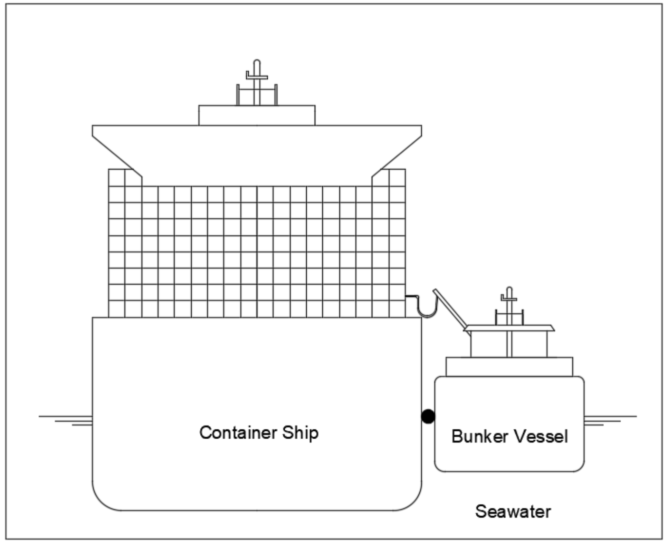
* Hypothetical results only, not meant for setting up a physical facility without verifications

Ammonia Bunkering - Hypothetical Locations



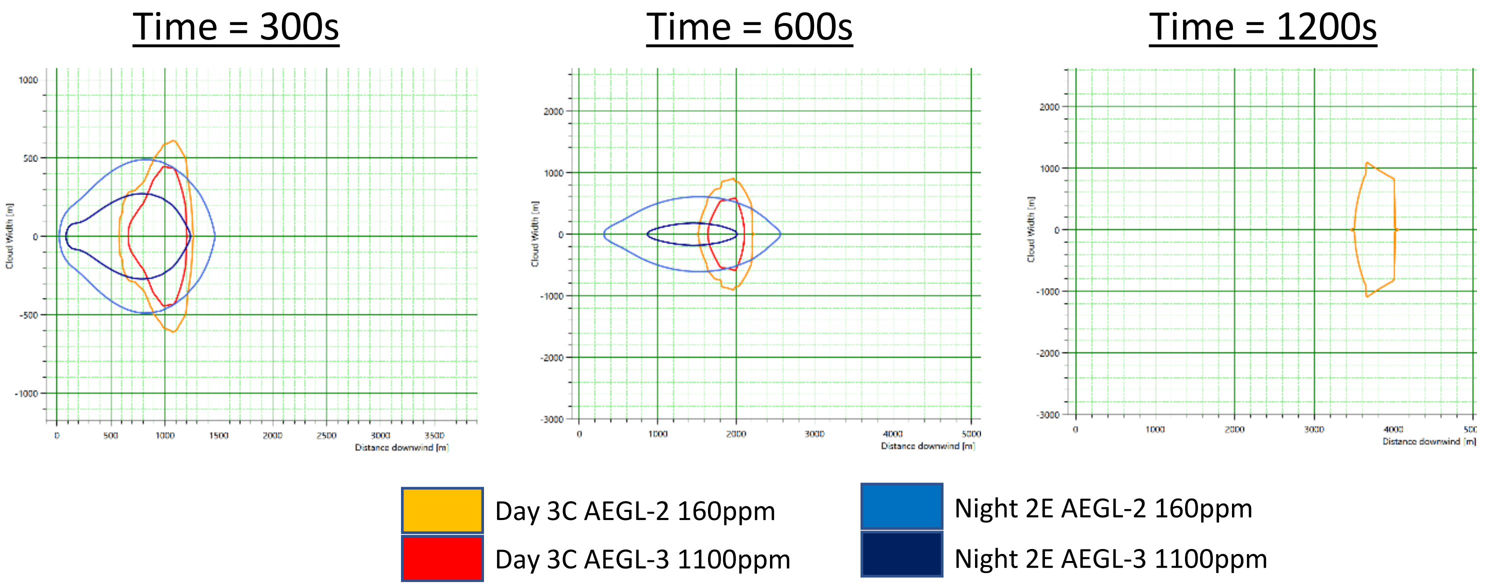
Port of Singapore – Anchorages and Fairways (source MPA, 2019)

Ammonia Release: Ship-to-Ship Bunkering*



Bunker Vessel	:	17,500 m^3 NH_3 carrier
Receiving Vessel	:	14,800 TEU container ship
Temperature	:	-33.4°C, 1 atm (FR to FR)
Connection	:	8" (203mm) hose, 40m long
Flowrate	:	1,500m^3/h

Scenario	Release Elevation	Release Duration
8" Hose Rupture at inlet manifold of container ship	18.35m	60 s

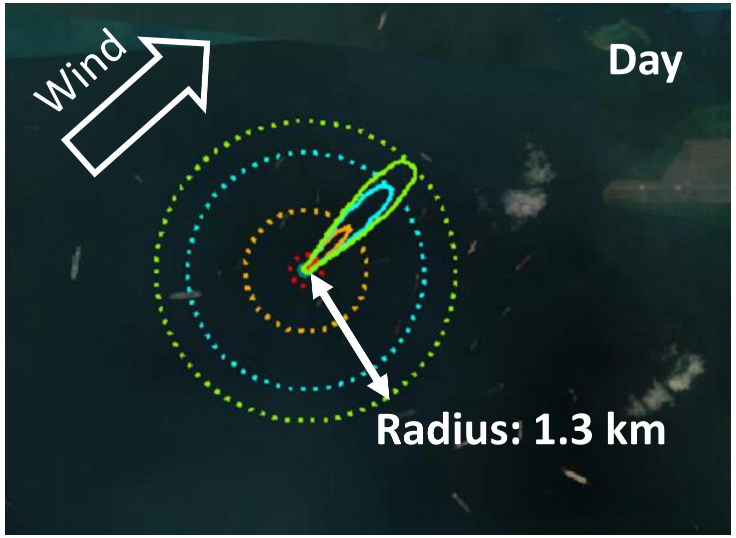


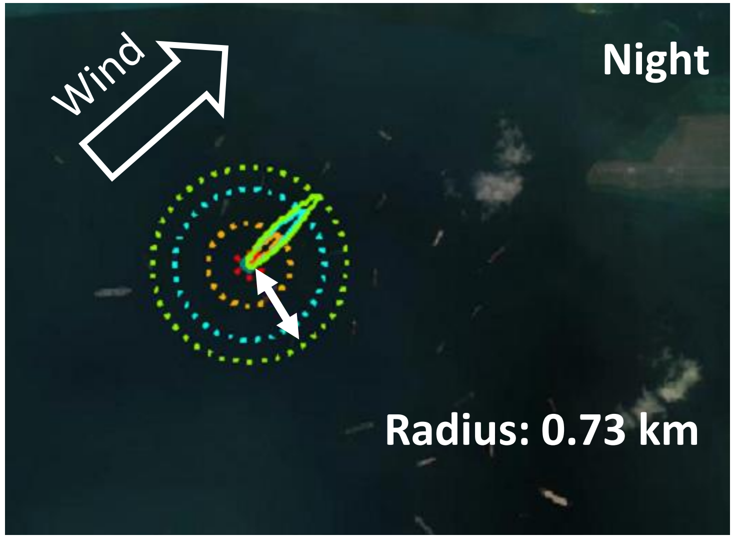
Released mass distribution table

Released Mass (kg)	Day 3C	% of total mass	Night 2E	% of total mass
Total Mass released	17,040	-	17,040	-
Mass flashed as vapor cloud	3,384	19.9%	2,964	17.4%
Mass Rainout as pool	13,656	80.1%	14,076	82.6%
Mass vaporised from pool	5,260	30.8%	5,680	33.4%
Mass dissolved in sea	8,396	49.2%	8,396	49.2%

* Hypothetical results only, not meant for setting up a physical facility without verifications

Ship to Ship Bunkering - Hazardous Zone (Without Mitigation)



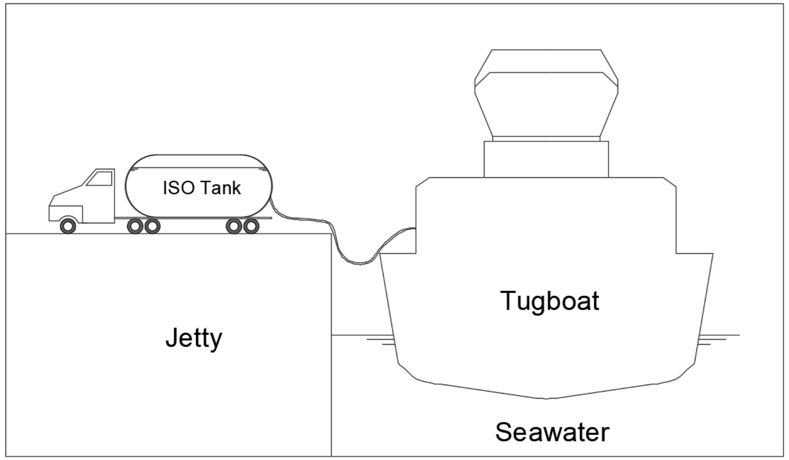


- **Lethality footprint instead of cloud coverage provides further understanding of the hazardous impact upon release**.
- Night time release has a significantly lesser lethality footprint than that of day time.
- **With mitigation, the lethality footprint can be reduced.**

Simulated lethality footprint

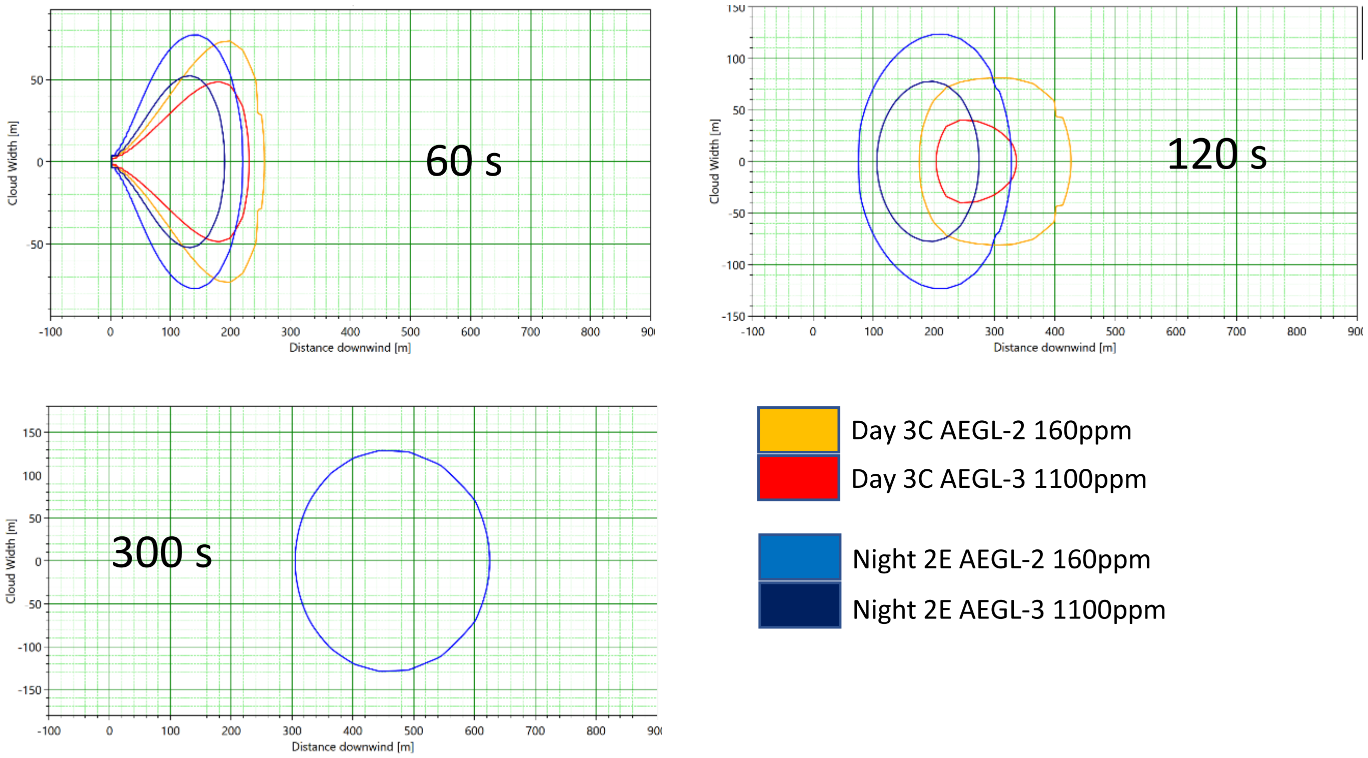
Lethality (%)	Coverage	
	Day	Night
3	280 x 1,275 m	140 x 725 m
10	210 x 1,000 m	120 x 550 m
50	80 x 520 m	80 x 300 m
99	20 x 125 m	30 x 100 m

Ammonia Release: Truck-to-Ship Bunkering*



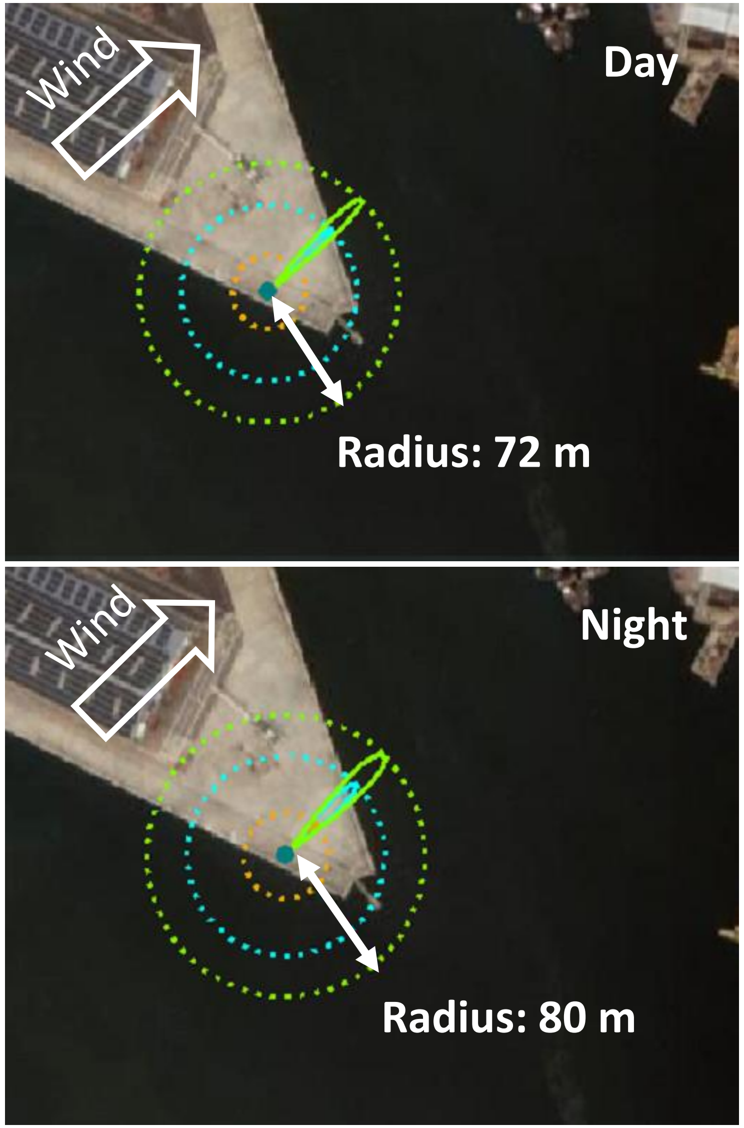
Bunker Truck	:	20 m^3 ISO truck tank
Receiving Vessel	:	Tugboat
Temperature	:	30°C, 12 bar (NR to NR)
Connection	:	2” hose, 15m long
Flowrate	:	20 m^3/h

Scenario	Release Elevation	Release Duration
Full bore hose rupture	0.4 m	60 s



- Small release quantity (198 kg).
- No rainout.
- Vapor cloud forms a puff right after the end of the release.

Truck to Ship Bunkering - Hazardous Zone (Without Mitigation)

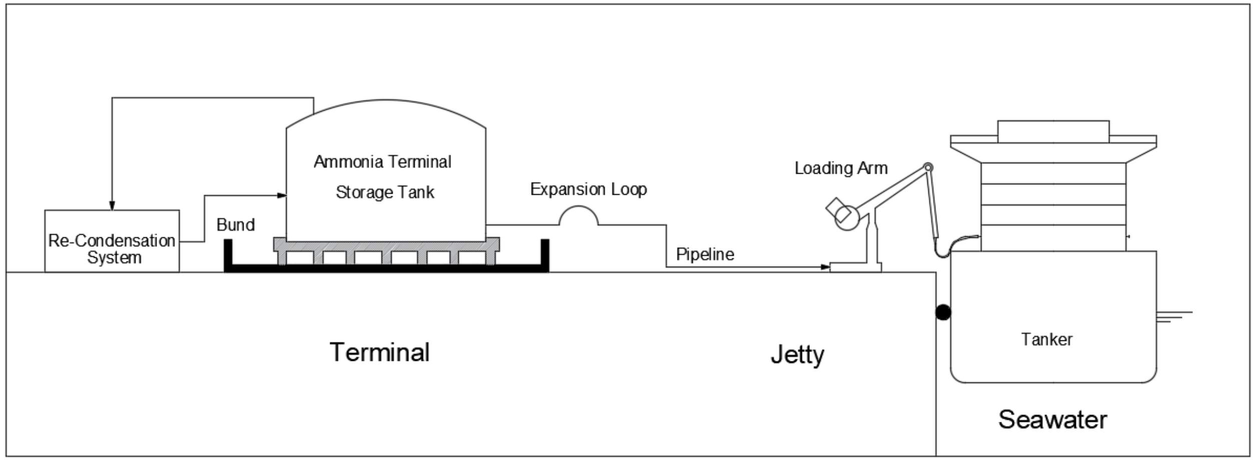


- As the released quantity is very small and the ammonia cloud gets diluted and dispersed rapidly, the 3% lethality footprint only extends approximately 80 m downwind.
- **With mitigation, the lethality footprint can be reduced.**

Simulated lethality footprint

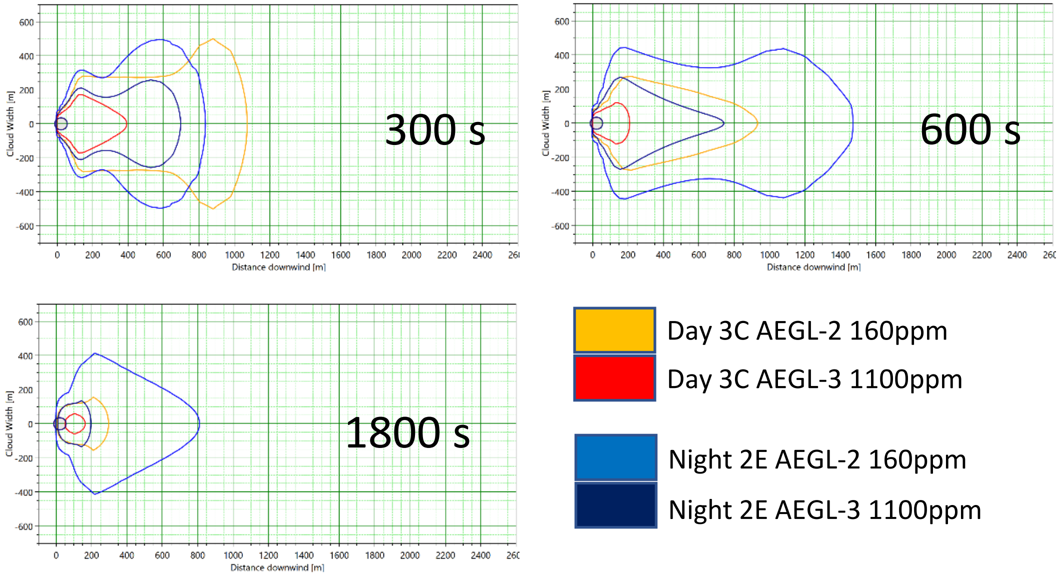
Lethality (%)	Footprint (m^2)	
	Day	Night
3	8 x 72 m	12 x 80 m
10	4 x 46 m	7 x 53 m
50	1 x 12 m	2 x 15 m
99	0	0

Ammonia Release: Shore-to-Ship Bunkering*



Bunker supply	10,000 m^3 shore tank (max 85% filled)
Receiving Vessel	17,500 m^3 (max 85% filled) Chemical Carrier
Temperature	-33.4ºC, 1 atm (FR to FR)
Connection	8” pipeline, 1000 m long and 8” (203 mm) hose, 40 m long
Flowrate	1,500 m^3/h
Bund	42.1 m x 38.4 m x 2.3 m

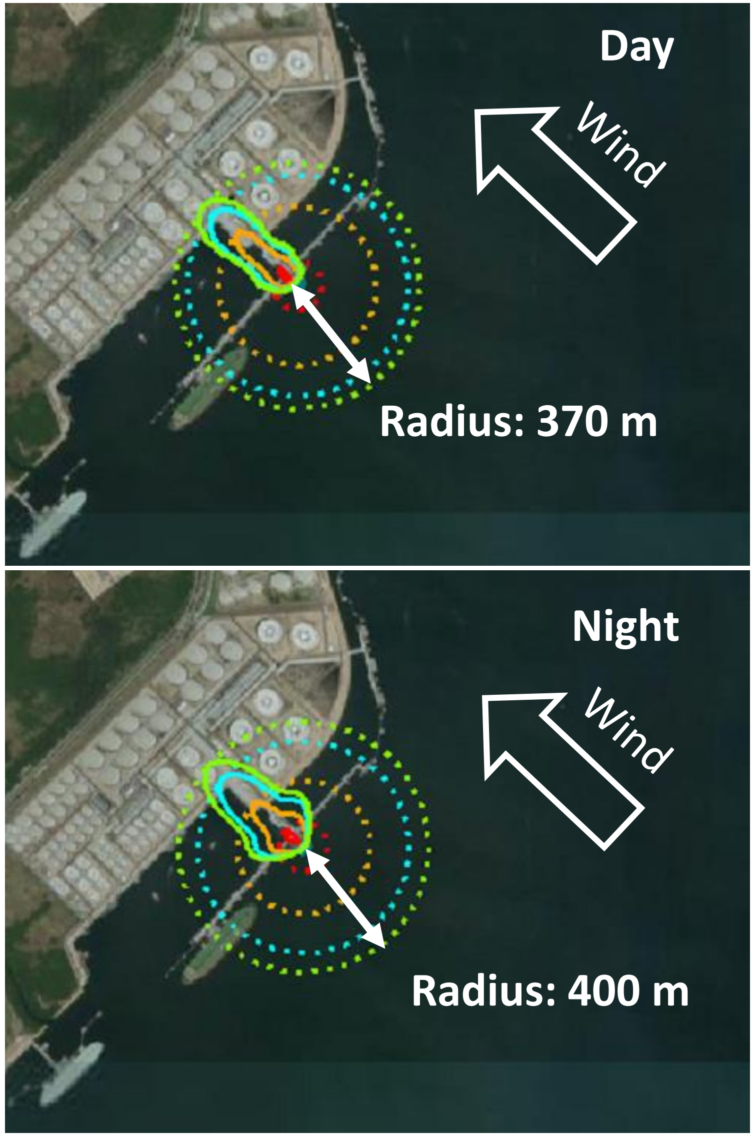
Scenario	Release Elevation	Release Duration
Hose rupture @ highest point of loading arm	10 m	60 s



Released mass distribution table

Released Mass (kg)	Day 3C	% of mass released	Night 2E	% of mass released
Total Mass released	17,040	-	17,040	-
Mass released as vapor cloud	2,801	16%	2,279	13%
Mass Rainout as pool	14,239	84%	14,761	87%
Mass vaporised from the pool	13,706	80%	13,066	77%
Mass remaining in pool @1h	533	4%	1,695	10%

Shore to Ship Bunkering – Hazardous Zone (Without Mitigation)



- The 3% lethality footprints reached a maximum downwind distance of approximately 400 m.
- The 3% lethality footprint in the night is larger than that for the day, as the more stable atmosphere in the night is able to sustain the vapour cloud concentration.
- **With mitigation, the lethality footprint can be reduced.**

Simulated lethality footprint

Lethality (%)	Footprint (m^2)	
	Day	Night
3	140 x 370 m	250 x 400 m
10	120 x 370 m	200 x 400 m
50	80 x 230 m	140 x 210 m
99	20 x 60 m	20 x 70 m

Summary

Conclusion

- There are gaps to fill and studies required to enable ammonia bunkering operation despite the fact that ammonia has long been handled as cargo.
- Transferred as a boiling liquid, ammonia can be bunkered at three states: FR, SR and NR, by two similar processes developed by the study.
- Far-field simulations were conducted to provide the cloud coverage and the lethality footprint of several ammonia release scenarios.
- It is expected that mitigation measures be developed to reduce the impact of ammonia release.

Project Partners

ASTI, ABS, EPS, Jurong Port, Vopak, PSA, ExxonMobil, Itochu Group, MOL, Hoegh LNG, MAN ES, TOTAL Marine Fuels…

Project Report Release

- Early 2022

Further Enquiry

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