NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE

Mitigation technology and environmental impact from ammonia bunkering release

Project Co-led by ***IHPC*** *(Institute of High Performance Computing) and* ***TMSI*** *(Tropical Marine Science Institute)*

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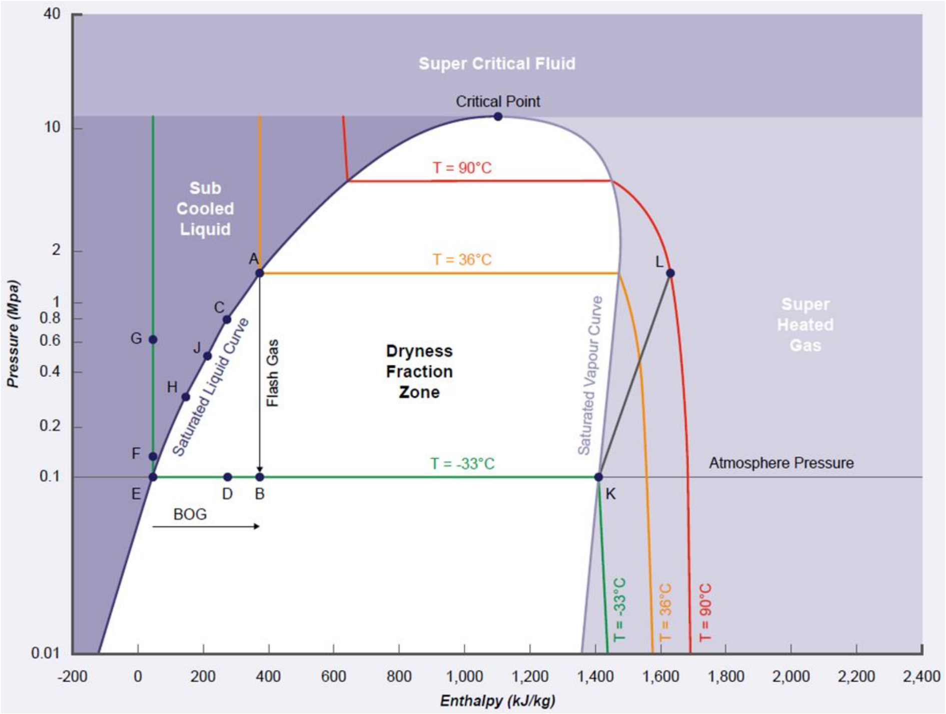
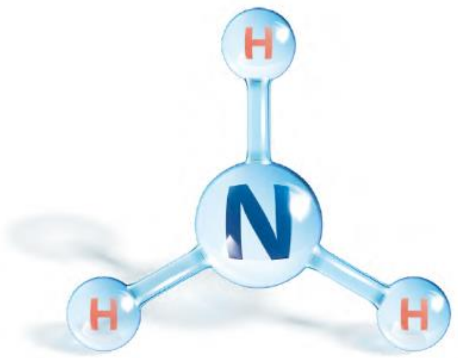
MESD 06 Nov 2023

Overview of ammonia

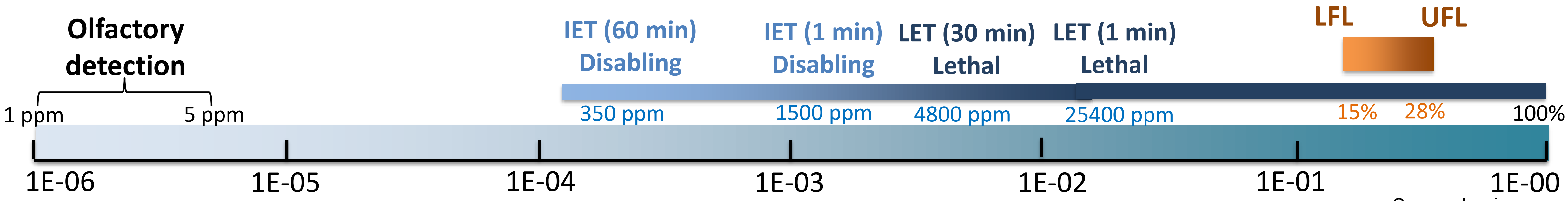


- Theoretically carbon free fuel
- Handled as a “saturated liquid” for all practical operations
- Toxic to human and environment



Exposure	10 min	30 min	1h	4h	8h
AEGL-1	30 ppm	30 ppm	30 ppm	30 ppm	30 ppm
AEGL-2	220 ppm	220 ppm	160 ppm	110 ppm	110 ppm
AEGL-3	2700 ppm	1600 ppm	1100 ppm	550 ppm	390 ppm

AEGL-1	Notable discomfort, irritation, or certain asymptomatic non-sensory effects. Effects are not disabling and are transient and reversible upon cessation of exposure.
AEGL-2	Irreversible or other serious, long-lasting adverse health effects of an impaired ability to escape
AEGL-3	Life-threatening health effects or death



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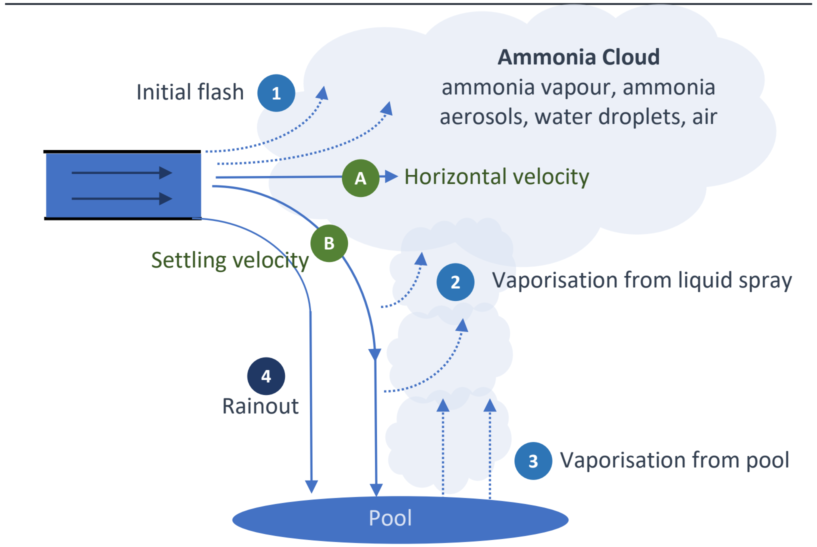
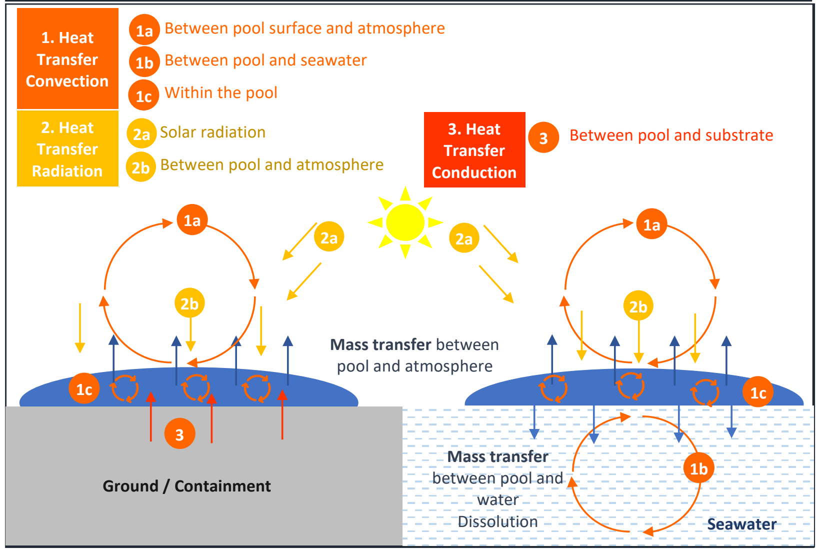
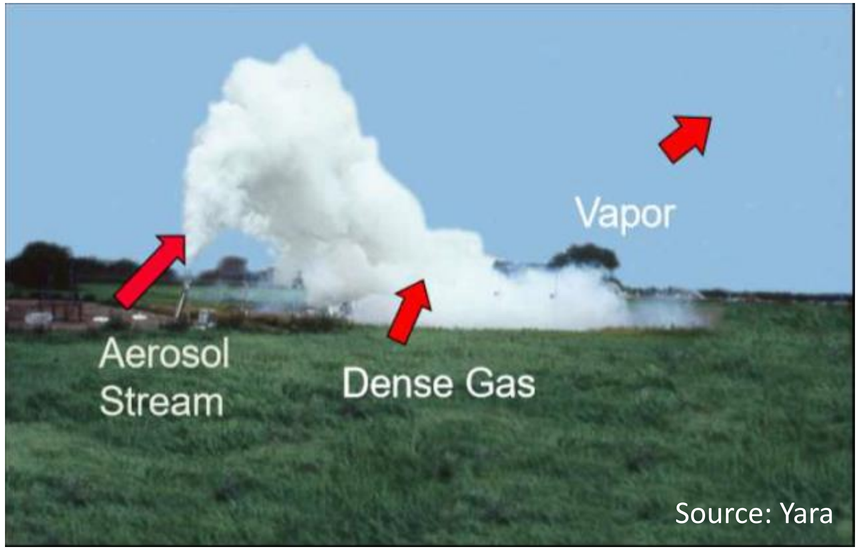
Ammonia release and dispersion







- LOC happens with sufficient driving force (pressure, momentum)
- Liquid ammonia column break bulk and flash into fine mist with huge surface area
- With rapid cooling, the fine droplets form aerosol with air and produce a “heavy” white cloud
- The cloud “clings” to the surface for some time until it gains enough dilution, heat and buoyancy to become gaseous ammonia vapor that “disappears”

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Mitigate ammonia release - overview

Release Mitigation

Reduce Likelihood
Preventive: reduce likelihood of generating hazardous vapour cloud

Release Severity
Protective: reduce magnitude of release and exposure to personnel, properties, env

Pre-release Mitigation

Inherent safer design

Inventory reduction

Process attenuation e.g., bunkering NH_3 as APSL, reduce operating pressures and flowrate.

Location Isolation
e.g., Site NH_3 bunkering at isolated anchorages, large buffer zones.

Engineering design

Physical integrity
e.g., compatible material, double-walled tanks.

Emergency control
e.g., emergency relief system

Emergency relief treatment
e.g., elevated stack to aid dispersion, flares.

Spill containment
e.g., dikes, trays

Emergency Isolation e.g., ESD, SmartHose®

Management

Operating procedures
Training
Audits and inspection
Equipment testing
Management of change
Maintenance program
Security

Eliminate cause of release
Reduce likelihood of release
Reduce impact of release

Post-release Mitigation

Early detection & warning

- Detection by sensors

Containment, Suppression, Countermeasures

- Water spray, mist, fog, curtain
- Foam
- Dilution
- Physical barrier

Emergency response

On-site communications
Emergency shutdown equipment & procedures
Site evacuation
Safe havens
PPE
Medical treatment
On-site ERP, training and drills.

Reduce severity of consequence (exposure x concentration) after occurrence of a LOC event

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Mitigate ammonia release – bunkering scenario

1. Detect Release

2. Stop Release

3. Reduce Impact
Reduce Lethality
(Concentration x Exposure)

3a. Containment

3b. Suppression

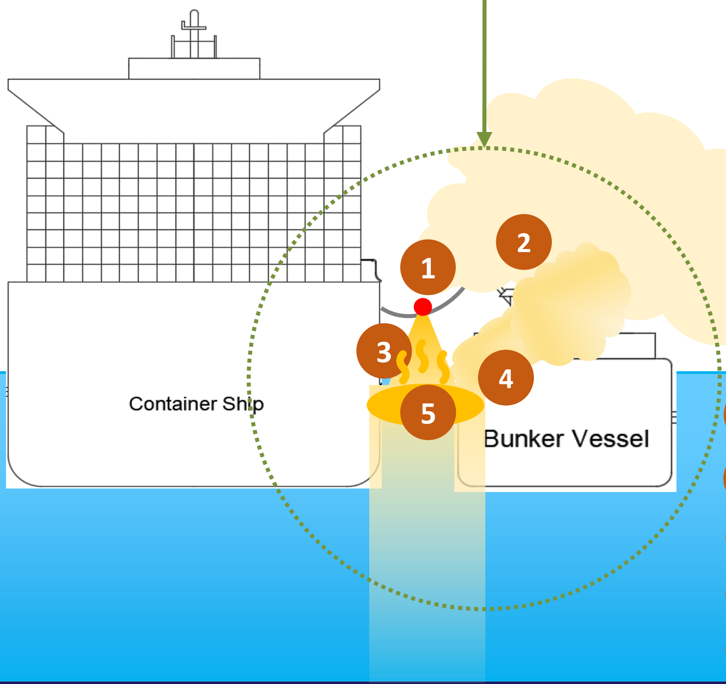
3c. Countermeasures

Prevent formation of ammonia cloud

Containment / Suppression

- Secondary containment (sumps, dikes, boom)
- Suppress vaporisation (shelter, avoid water, cool surface, foam, cover)
- Suppress momentum (increase rainout)

Post-Release Mitigations



1. Reduce initial flash momentum
2. Reduce entrainment
3. Increase rainout, reduce droplet vaporisation
4. Reduce pool vaporisation
5. Reduce pool spread or dissolution

1. Reduce cloud concentration
2. Limit cloud spreading
3. Limit cloud movement

Prevent ammonia cloud from reaching sensitive receptors

Countermeasures
Absorption
Plume Dilution
Physical Barrier

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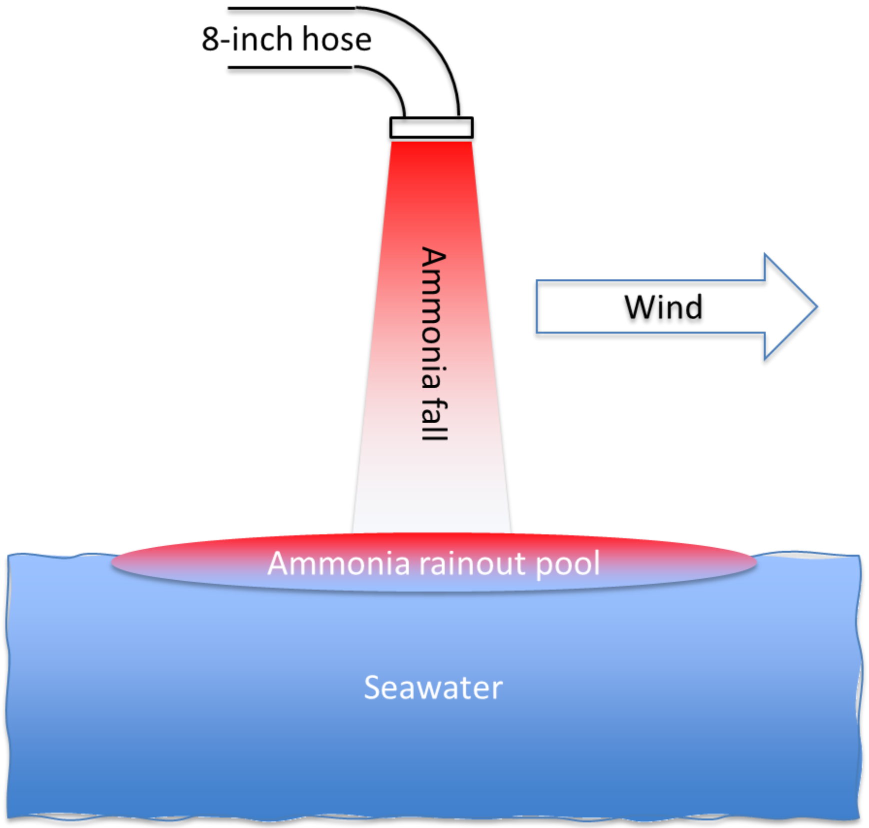
Case study 1 – change flowrate and hose diameter

Table Input parameters for case study

Parameters	Value
Location	Anchorage 28 ASSPU
Bunker Vessel Type	17,500 m^3 NH_3 carrier
Container Ship Type	14,800 TEU dual fuel container ship
Temperature	-33.4^{o}C, 1 atm
Connection	8" (203mm) hose, 40m long
Flowrate	1,000 to 1,500m^3/h
Hose diameter	8 inch
Orifice size	8 inch (full bore rupture)
Release direction	Vertical downward
Release elevation*	18.35 m
Release duration	60 s
Wind direction	Perpendicular to ammonia fall
Weather	Day 3C
Scenario in PHAST	User-defined model using parameters from short pipe (⌀8") rupture



Use the worst-case scenario with large quantity of ammonia release

Far field simulation without considering local geometry and physical obstruction

Use lethality footprint at different altitude to indicate the effectiveness of mitigation

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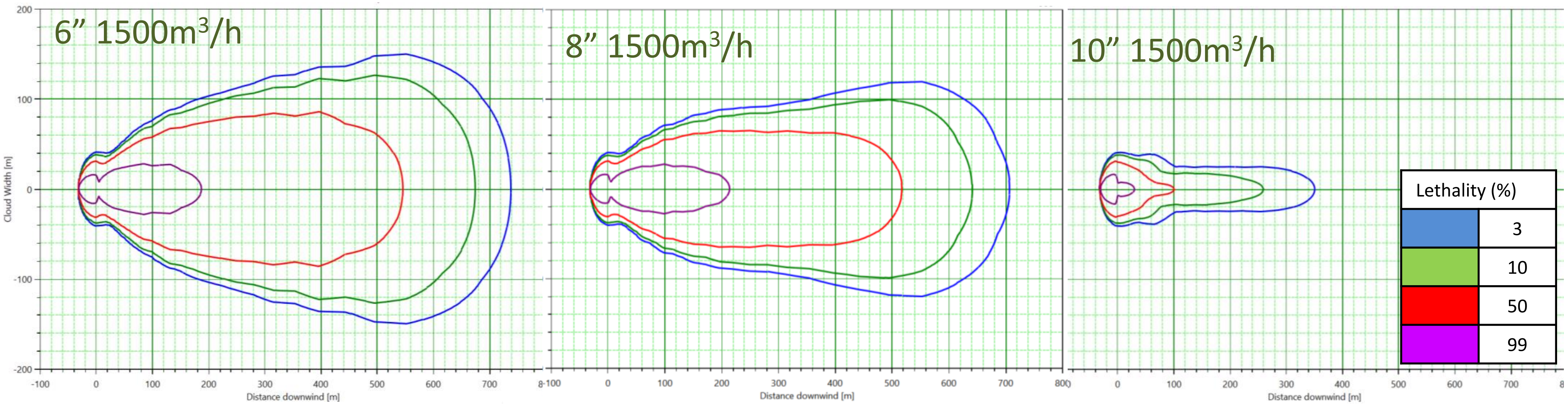
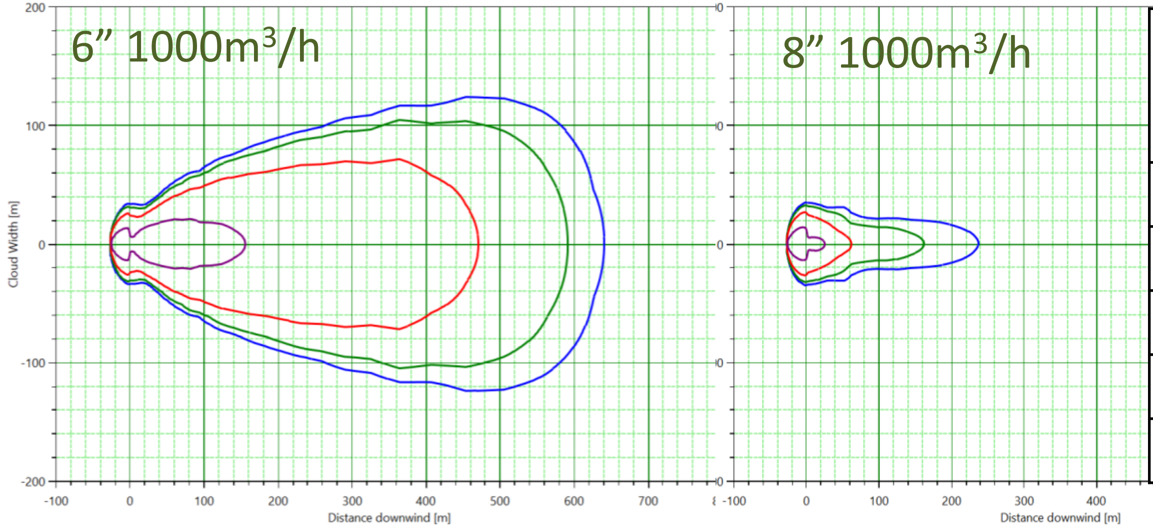
Case study 1 – change flowrate and hose diameter





Hose diameter/ flow rate	Liquid mass fraction	Droplet [um]	Velocity [m/s]
8“/1500	> 99%	424	13.49
8“/1000		4701	8.95
10“/1500		5161	8.54
6“/1500		329	23.7
6“/1000		388	15.7

Reduce velocity
Increase droplet size

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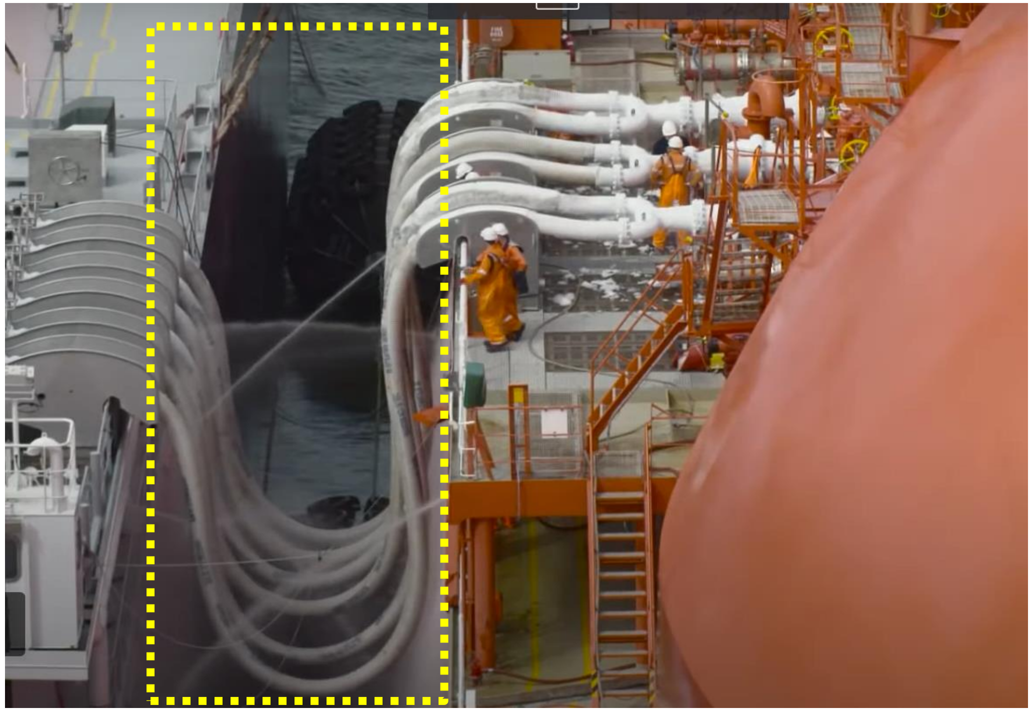
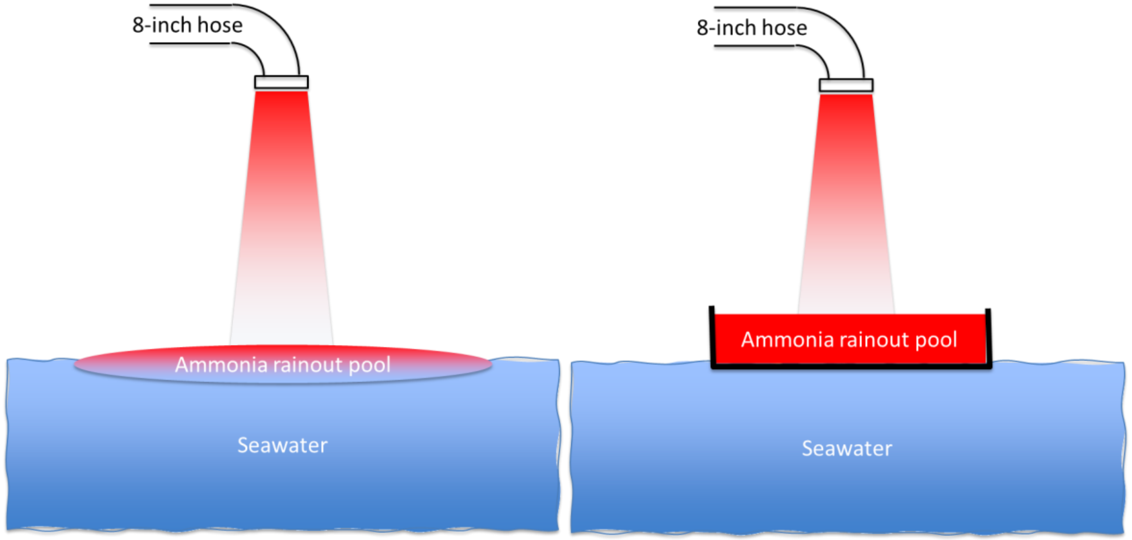
Case study 2 – use containment on sea surface

60 seconds release from 8” hose rupture (1,000m^3/h) into sea vs onto containment on sea surface





Size: 1m x 30m^2, Material: Polyurethane / PVC / combination of synthetic material (containment)

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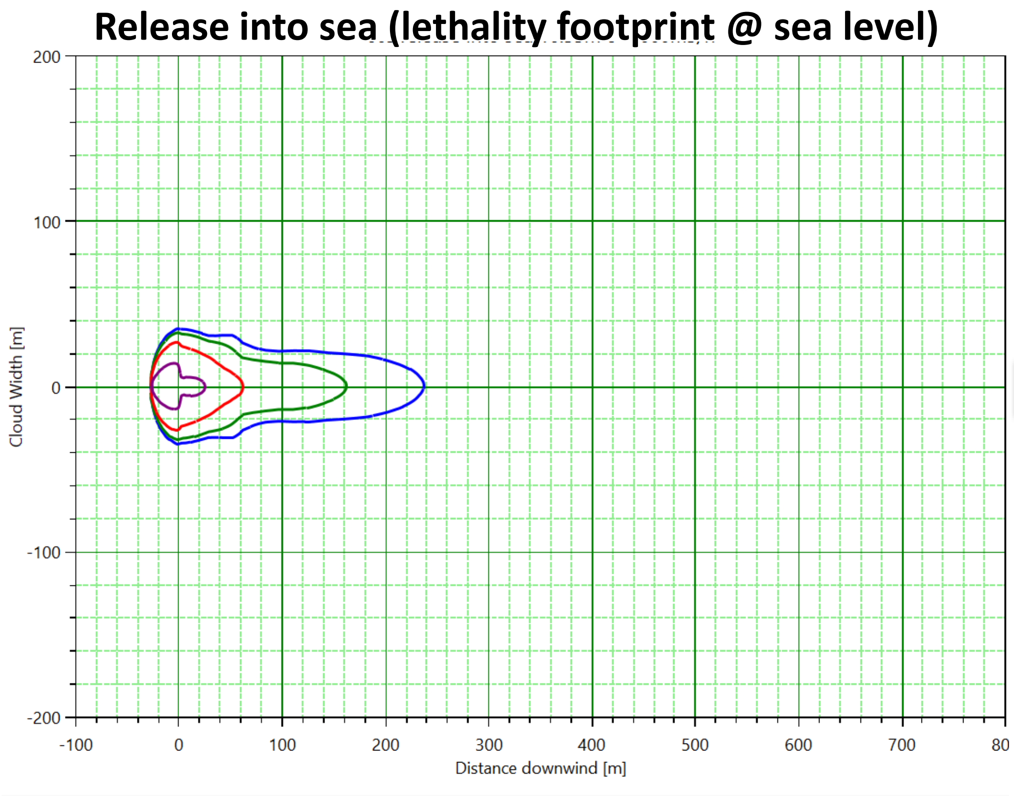
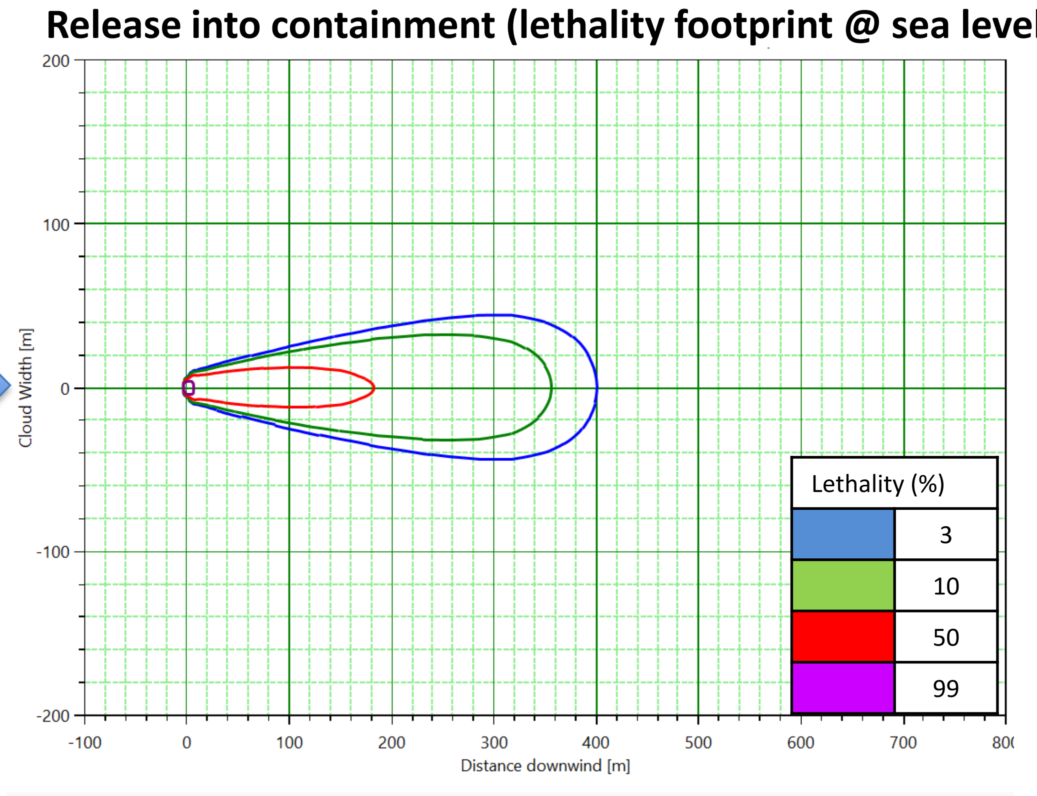
Case study 2 – use containment on sea surface





At sea level

- The containment does not reduce 3%, 10% and 50% lethality footprint
- Only the 99% lethality footprint is reduced

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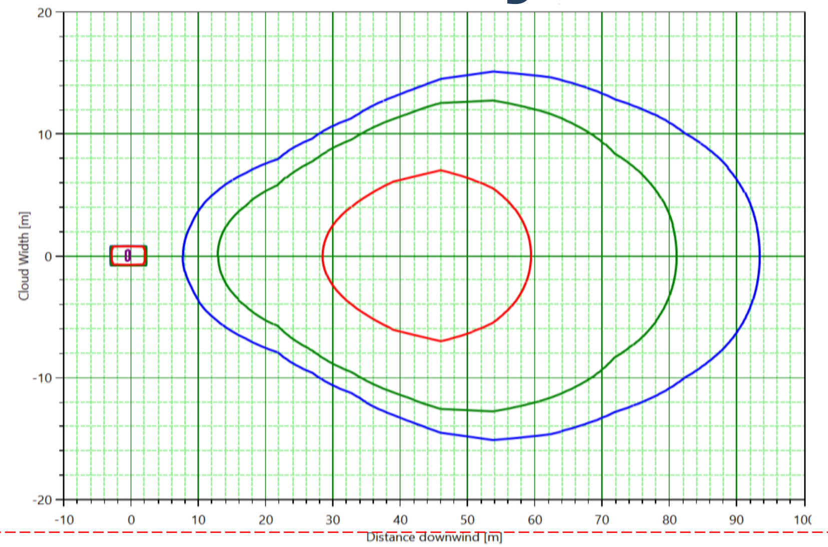
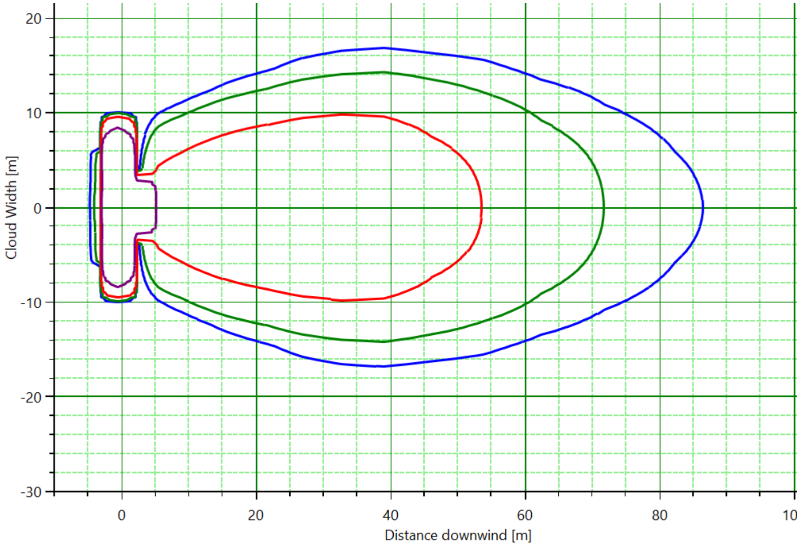
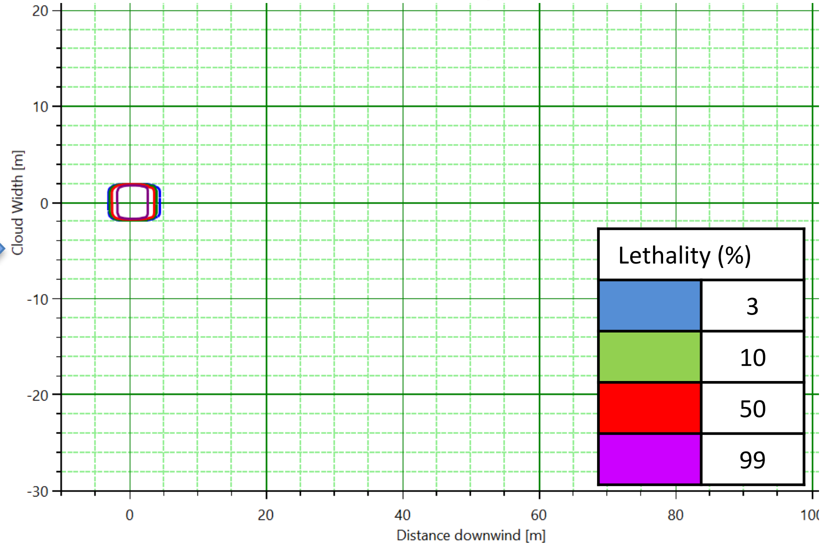
Case study 2 – use containment on sea surface



Lethality footprint on container vessel deck @ 15.35m freeboard





Lethality footprint on bunker vessel deck @ 8.5m freeboard

Release into sea **Release into containment**

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Case study 3 - use containment on vessel decks

60 seconds release from 8” hose rupture (1,000m^3/h) into sea vs onto containment on sea surface

Leak from outlet manifold to be contained on the vessels’ decks

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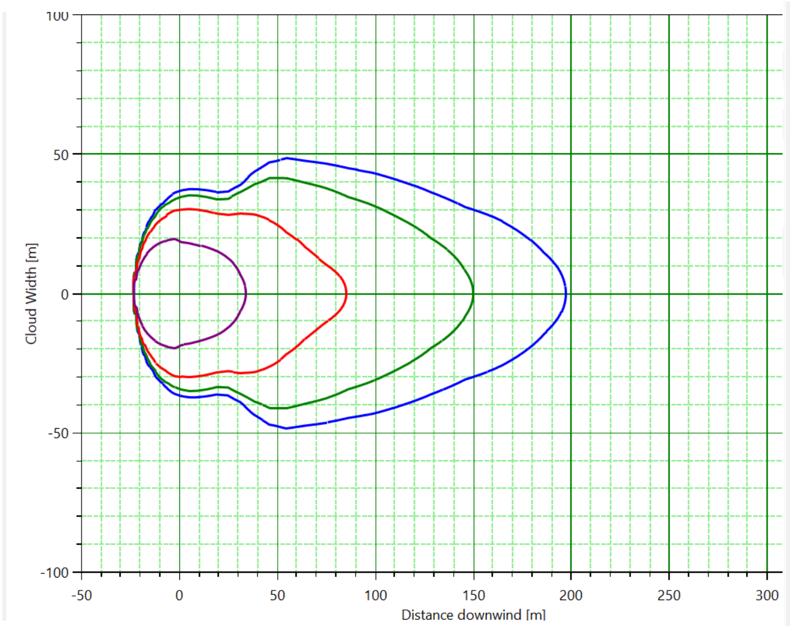
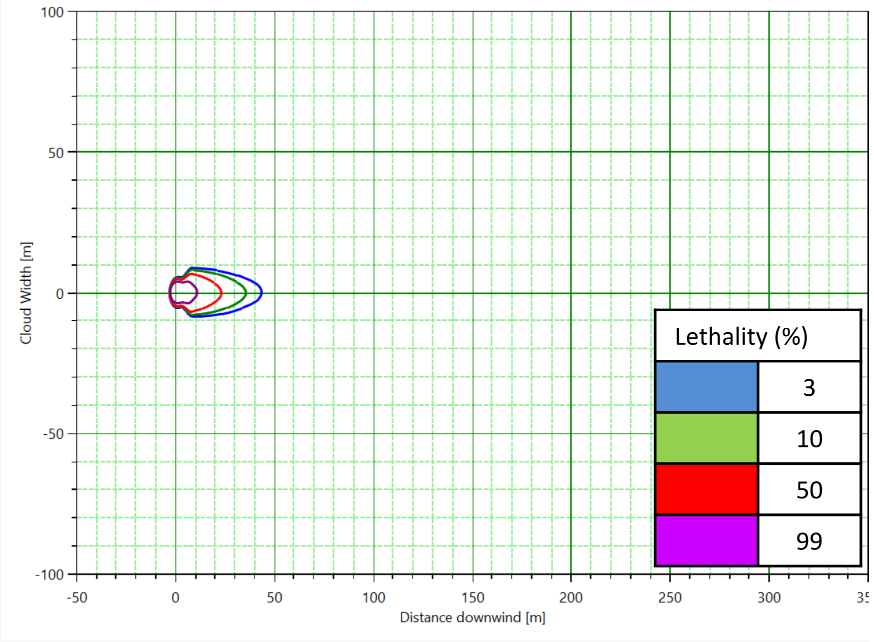
Case study 3 - use containment on vessel decks

Release directly onto deck



Release onto deck with containment (2 x 20m²)



Lethality	Release onto deck (m^2)	Release onto containment (m^2)	Reduction with containment
3%	15,513	588	-96%
10%	10,607	441	-96%
50%	4,927	244	-95%
99%	1,688	88	-95%

*Footprints taken on deck level

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Moving forward – barrier concept

✓ Use the taller & longer receiving vessel as a physical barrier

Point of release

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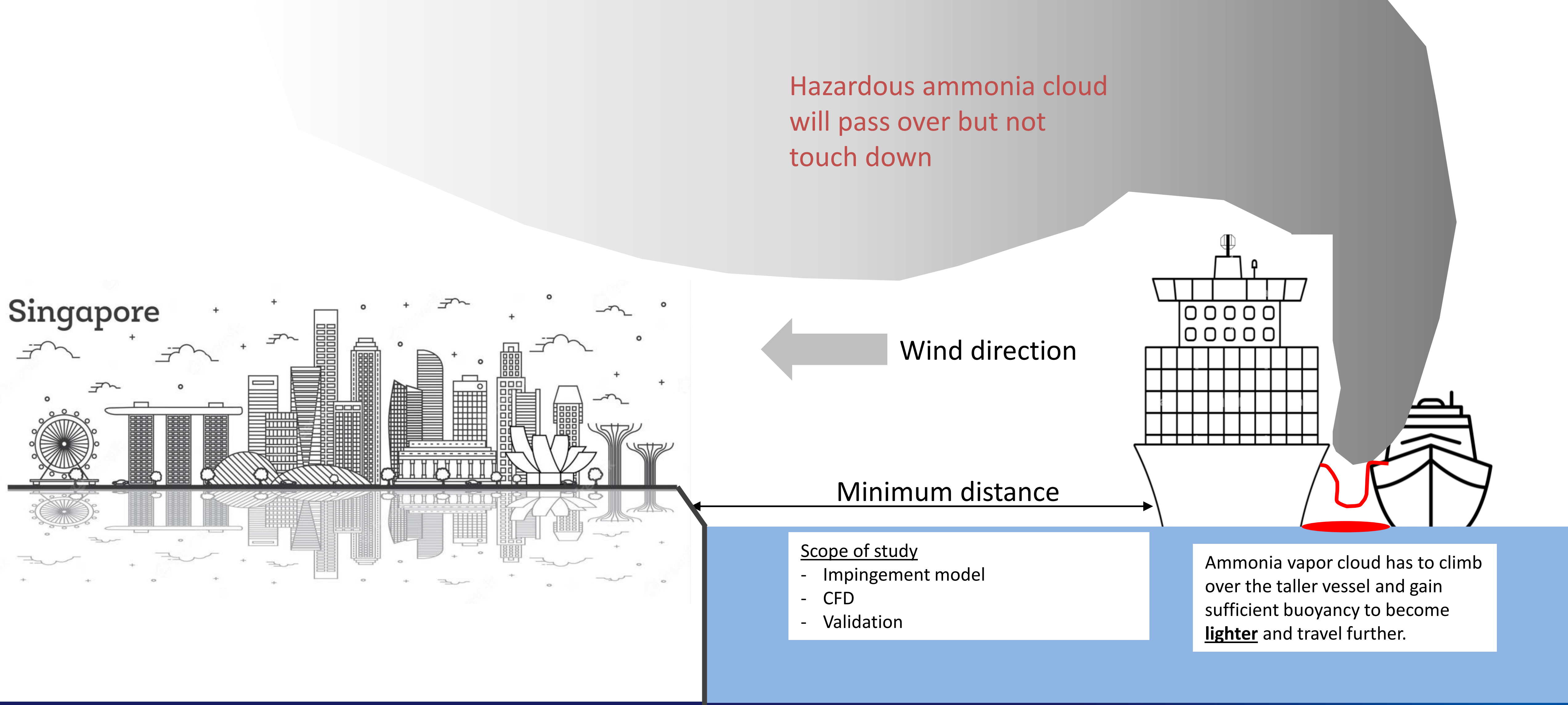
Moving forward – barrier concept



Scope of study
- Impingement model
- CFD
- Validation

Ammonia vapor cloud has to climb over the taller vessel and gain sufficient buoyancy to become **lighter** and travel further.

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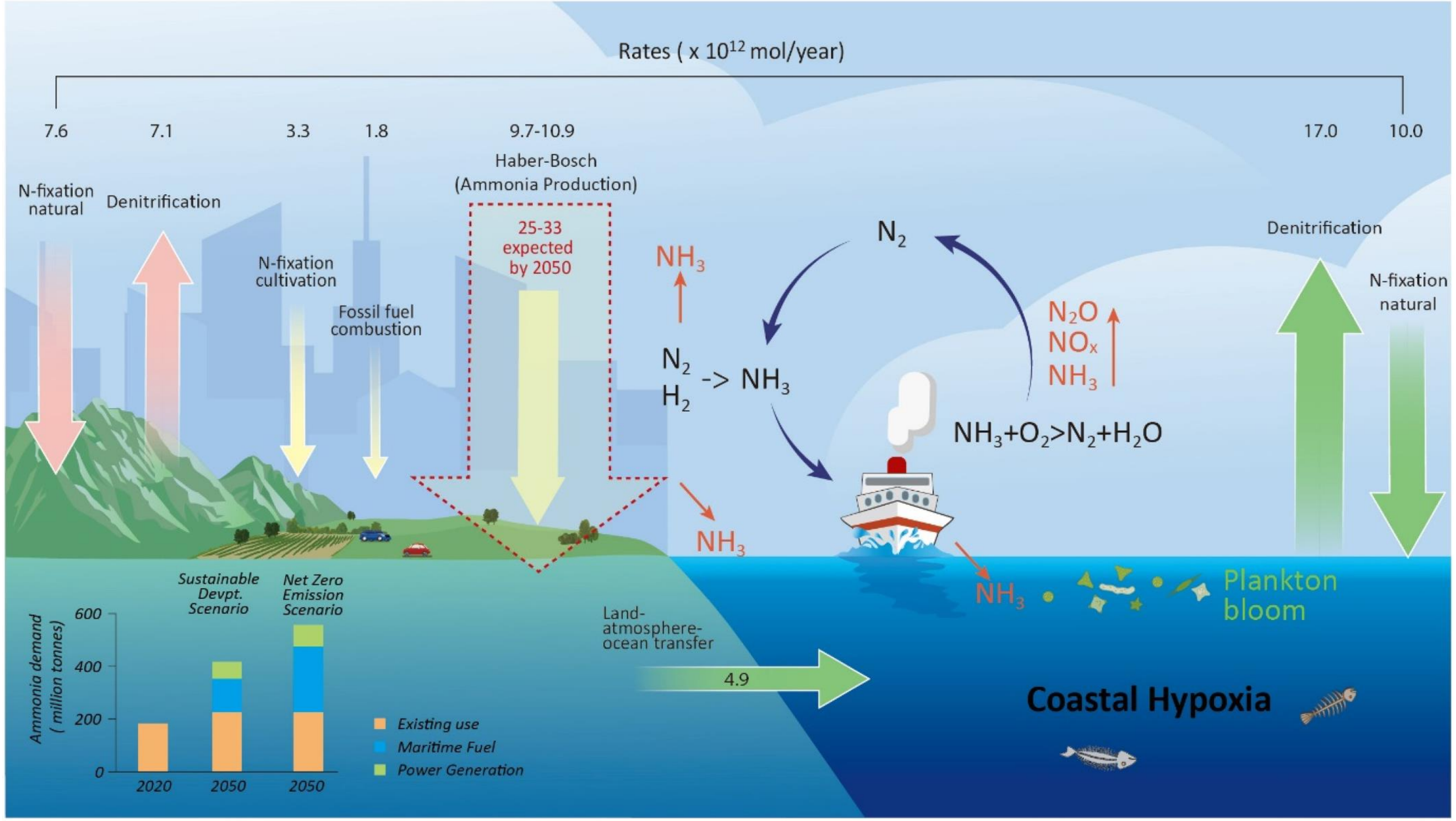
Environmental impact study on ammonia release



"Bunkering for change: Knowledge preparedness on the environmental aspect of ammonia as a marine fuel", Mengli Chen, et al, Science of the Total Environment 907 (2024) 167677

- **Global nitrogen cycling**
  Essential to ecosystem and the overall health of our planet.
- **Alteration by bunkering**
  Release due to bunkering may greatly alter the global nitrogen cycle.
- **Key Knowledge gaps**
  Quantify the environmental impact.
  More gaps suggested in the paper.

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Conclusion and future work

- Containment on sea surface
  - Unable to reduce lethality footprints at sea level
  - Significantly reduce lethality footprints at deck level
- Containment on deck
  - Reducing pool radius on deck by 10 times, and reduce lethality footprint by > 90%
- Further advanced simulation
  - Modelling and simulation of ammonia interaction with sea water for both near-field and far-field
- Further validation work
  - To seek experimental support or use surrogate molecules
- Further environmental impact study
  - Experiment to quantify rates of marine nitrogen cycle and water quality model

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