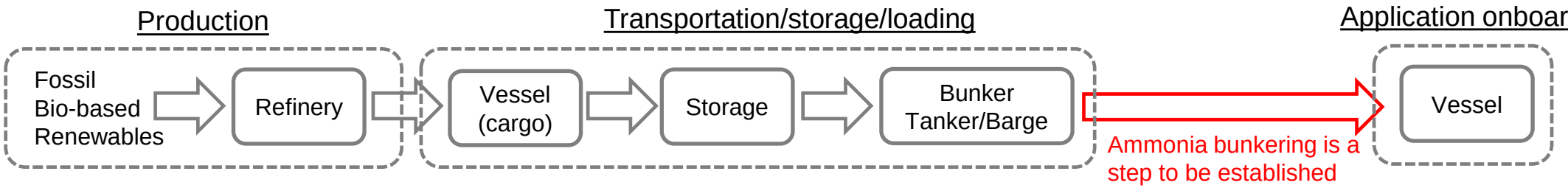
NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE

# Ammonia bunkering - simulation of hypothetical release scenarios in Singapore

Maritime Energy &Sustainable Development (MESD)
Centre of Excellence

*27 August 2021*

# Ammonia As A Bunker Fuel





! 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

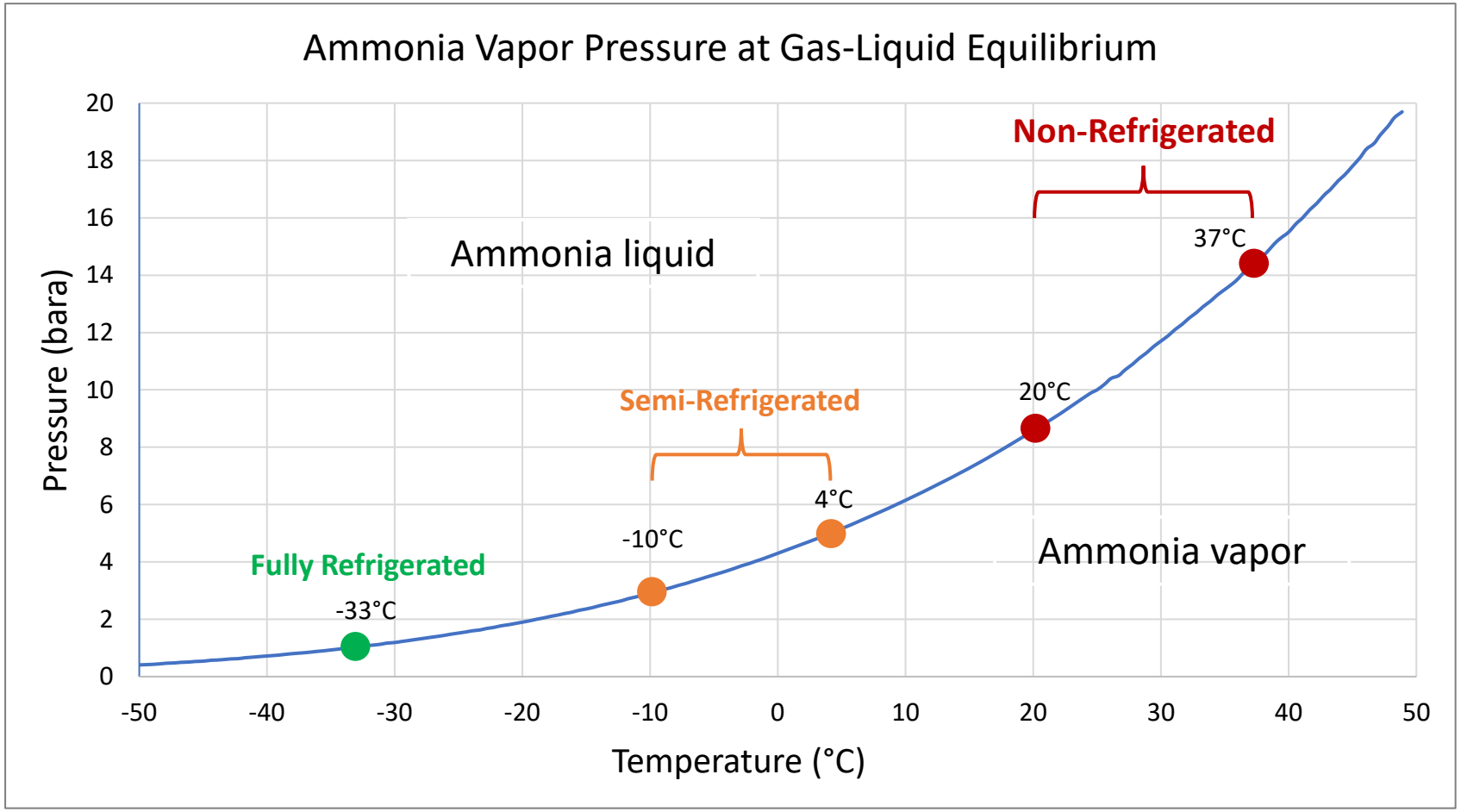
**AEGL Level 3: > 1,100 ppm for 1 hour**
Life-threatening health effects or death

**Flammability**

**LFL > 150,000 ppm**
Minimum concentration to cause fire in presence of ignition source

Source: US EPA

# 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 |

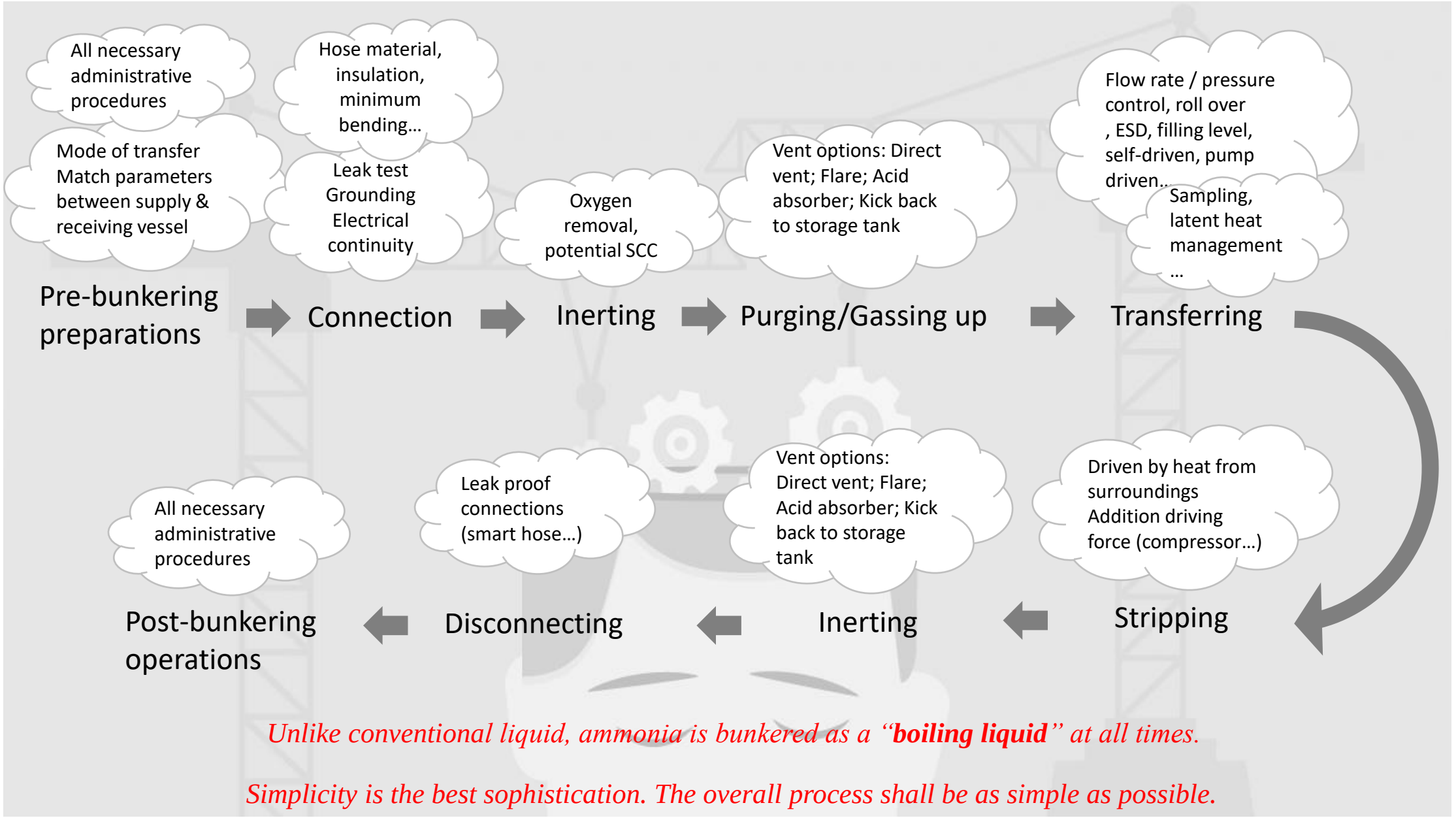
33 possible configurations


Ship to ship bunkering

Ship to ship bunkering with simultaneous cargo handling (SIMOPS)


Truck to ship bunkering

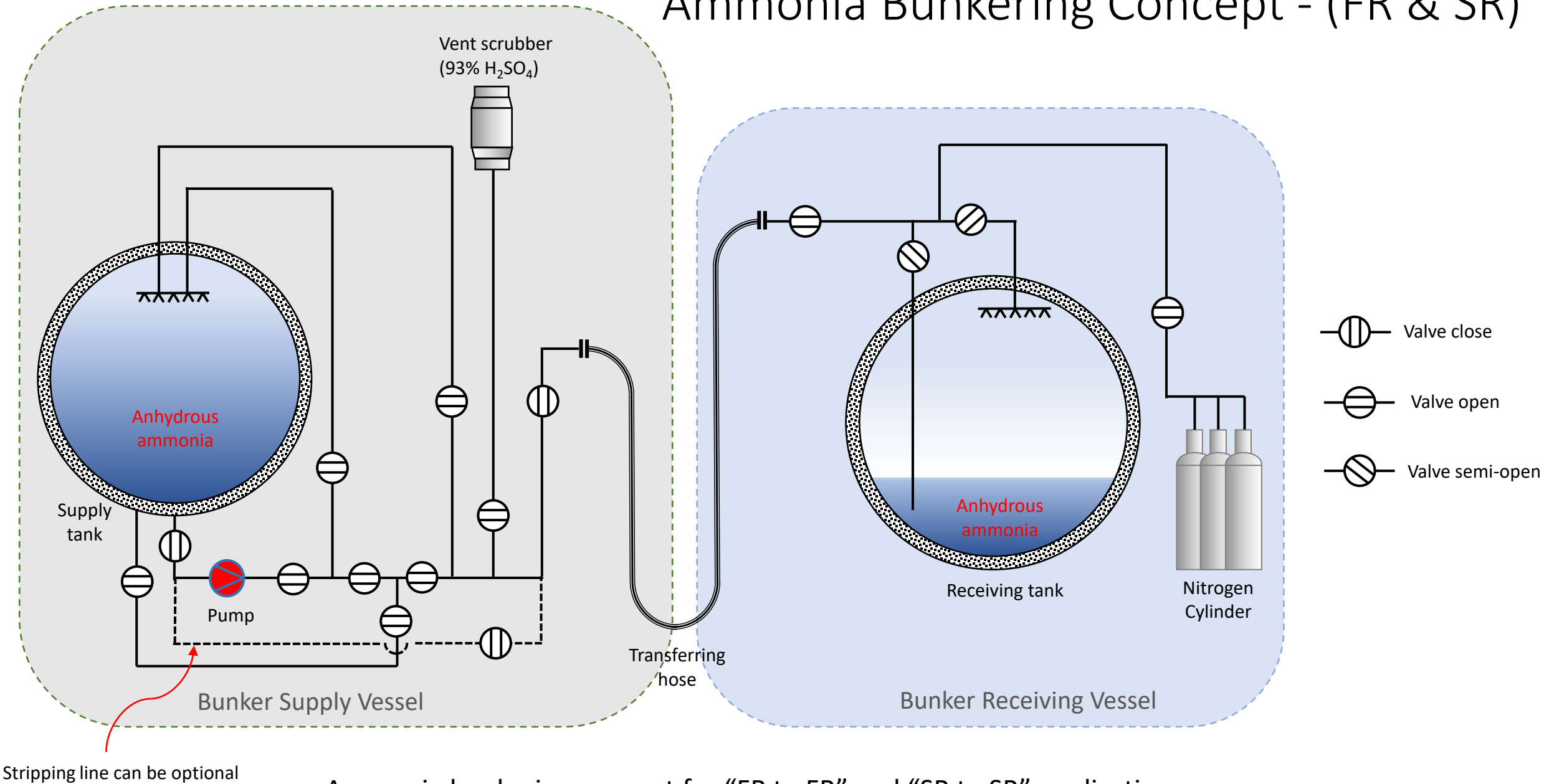
# Ammonia Bunkering Concept – Process Considerations




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

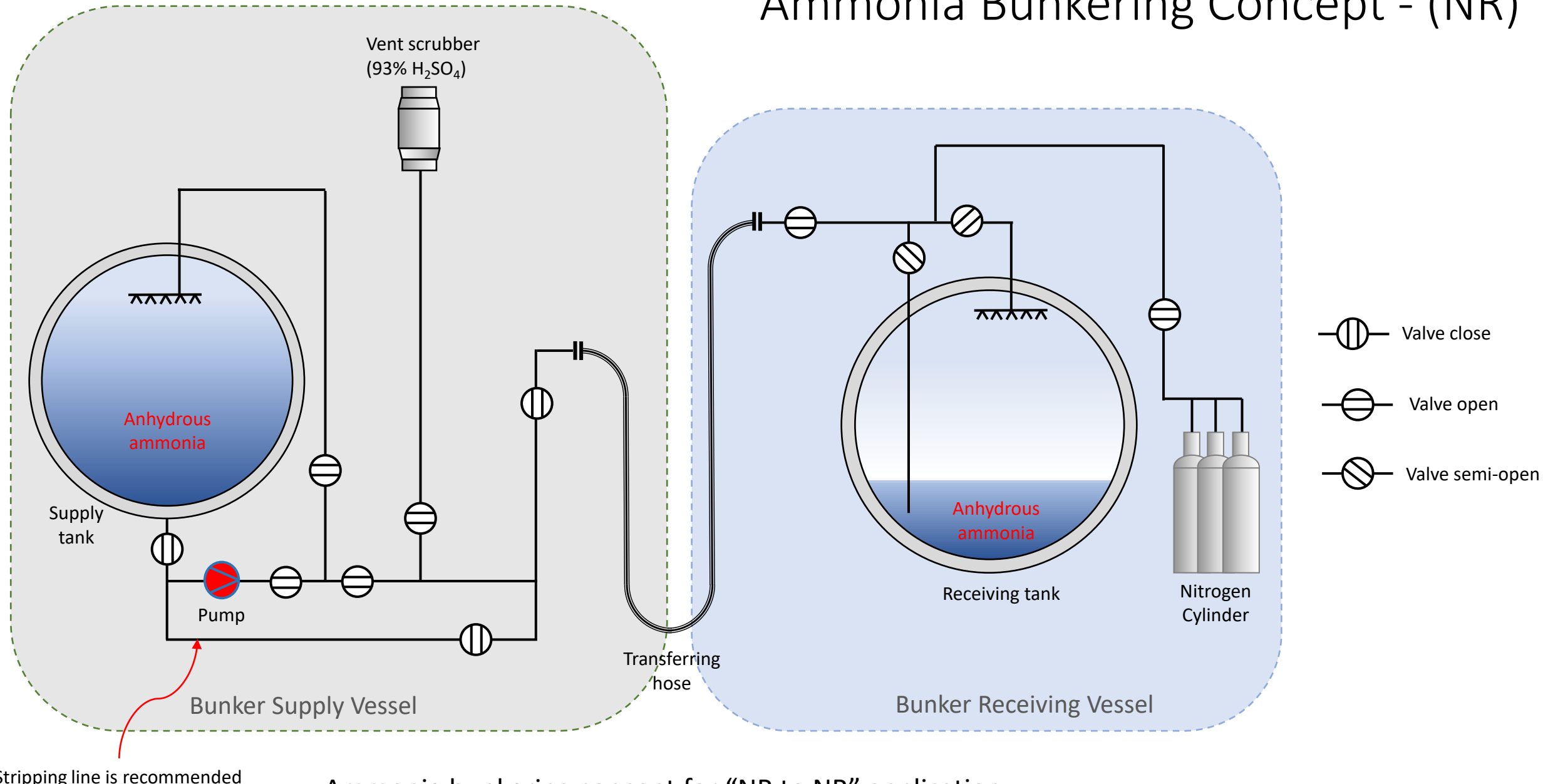
*Simplicity is the best sophistication. The overall process shall be as simple as possible.*

# Ammonia Bunkering Concept - (FR & SR)




Ammonia bunkering concept for “FR to FR” and “SR to SR” applications

# Ammonia Bunkering Concept - (NR)




Ammonia bunkering concept for “NR to NR” application

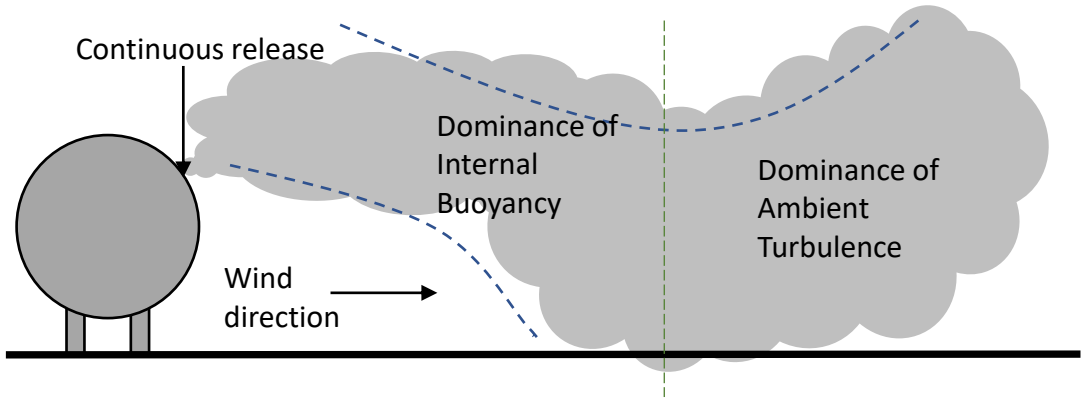
# Process Hazard Analysis Software Tool (PHAST)

**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

**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

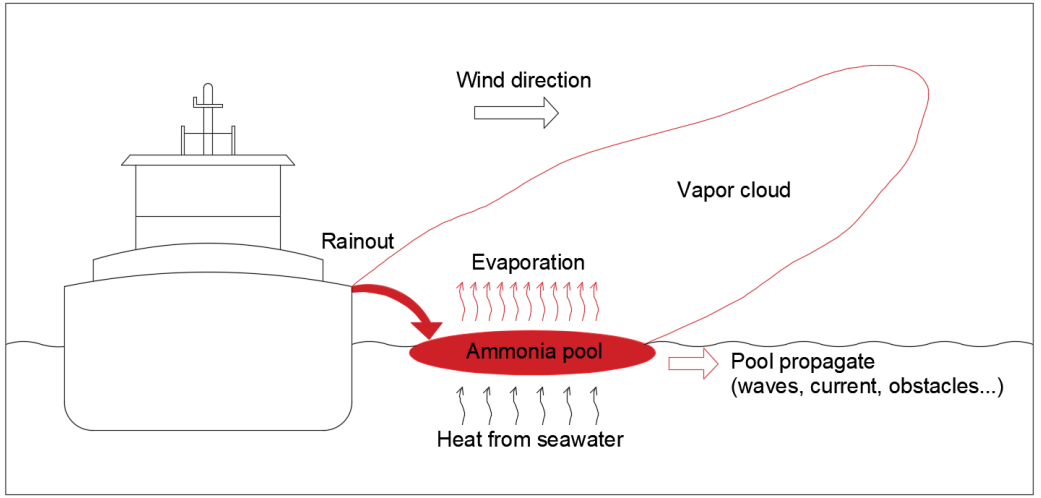



**Discharge calculations**

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

**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)



# 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)<br>FR: -33.4°C, 1 atm<br>SR: -10°C, 2.91 bar<br>NR: 30°C, 12 bar | FR has the smallest lethality footprint |
| Flow rate ($m^3/h$) (A)<br>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)<br>5m, 10m, 15m and 20m above sea level | The higher the elevation of release, the larger the lethality footprint |
| Release Direction (A)<br>Horizontal<br>Vertical Upwards<br>45° Downwards<br>90° Downwards | Vertical upwards release result in the largest lethality footprint, 90° downwards release result in the smallest lethality footprint |
| Isolation Time (A)<br>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

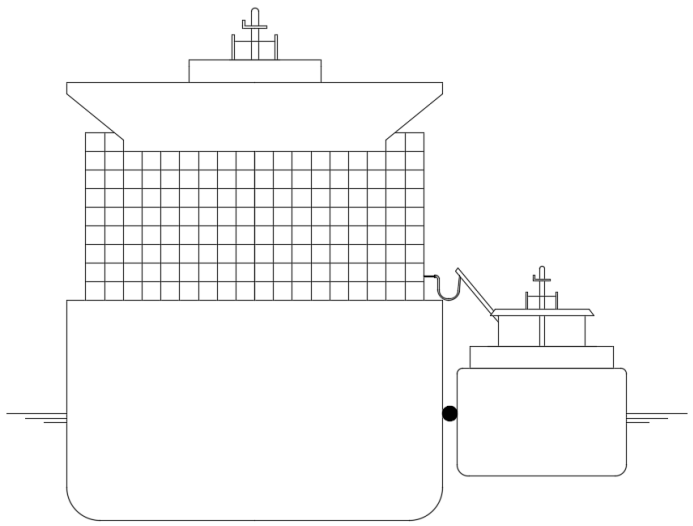
**Scenario C:** 225mm leak from 10,000$m^3$ atmospheric storage tank from a height of 3m above ground for 1 hour.

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

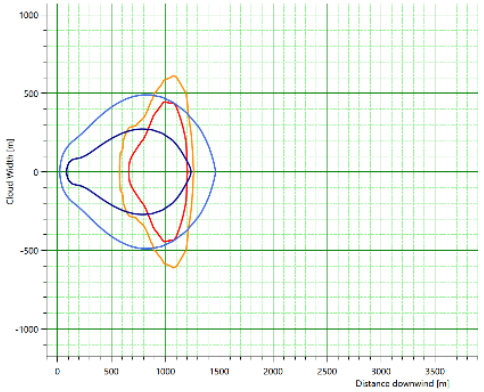
# Ammonia Release: Ship-to-Ship Bunkering*



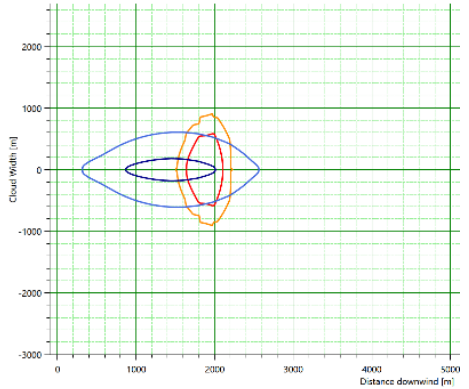
| | | |
|---|---|---|
| **Bunker Vessel** | : | 17,500 $m^3$ $NH_3$ carrier |
| **Receiving Vessel** | : | 14,800 TEU container ship |
| **Temperature** | : | -33.4°C, 1 atm |
| **Connection** | : | 8” (203mm) hose, 40m long |
| **Flowrate** | : | 1,500$m^3$/h |

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

Time = 300s




Time = 600s




Time = 1200s


Legend:

- Day 3C AEGL-2 160ppm
- Day 3C AEGL-3 1100ppm
- Night 2E AEGL-2 160ppm
- Night 2E AEGL-3 1100ppm

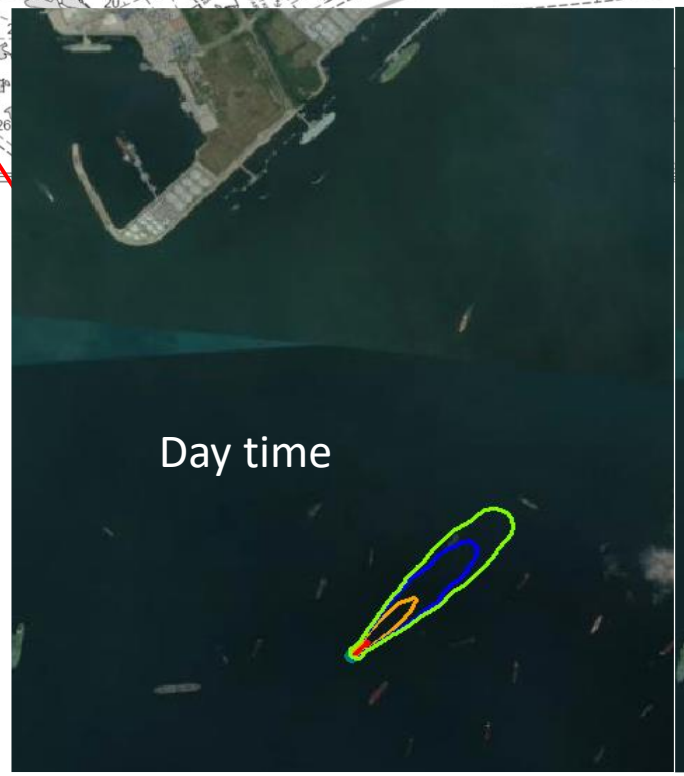
## Released mass distribution table

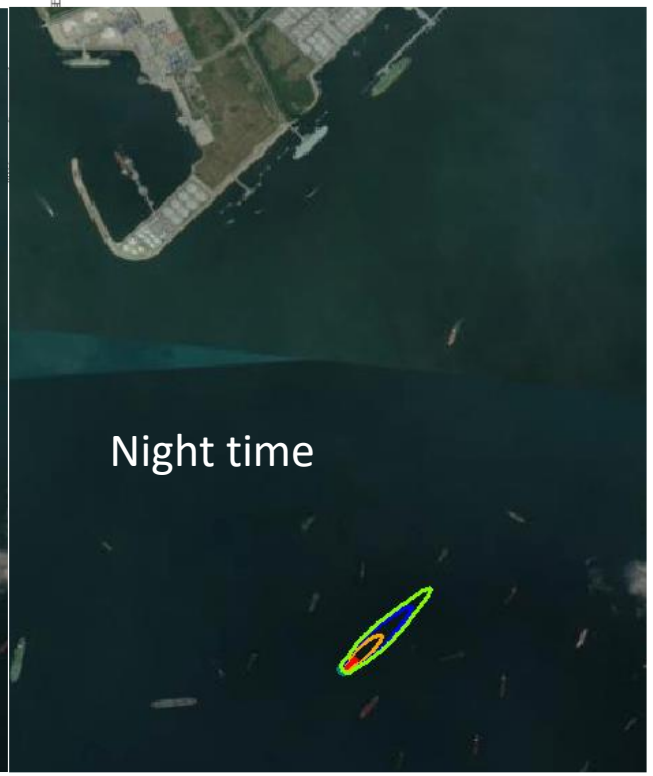
| Released Mass (kg) | Day 3C | % of total mass | Night 2E | % of total mass |
|---|---|---|---|---|
| Total Mass released | 17,040 | - | 17,040 | - |
| Mass flashed as vapor cloud | 3,384 | 19.9% | 2,964 | 17.4% |
| Mass Rainout as pool | 13,656 | 80.1% | 14,076 | 82.6% |
| Mass vaporised from pool | 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

# Ammonia Release – Lethality Footprint


- Based on the 3% lethality footprint, impact of ammonia release is confined within 1 to 1.5 km downwind from the source.
- Night time release has a significantly lesser lethality footprint than that of day time.




Simulated lethality footprint

| Lethality (%) | Footprint ($m^2$) | |
|---|---|---|
| | Day | Night |
| 3 | 264,879 | 74,659 |
| 10 | 148,632 | 49,464 |
| 50 | 36,827 | 18,895 |
| 99 | 2,542 | 1,768 |

# Moving forward

- Completion of all selected bunkering simulations
- Mitigation methods and PPE recommendation
- Near-field dispersion simulation in both water and air