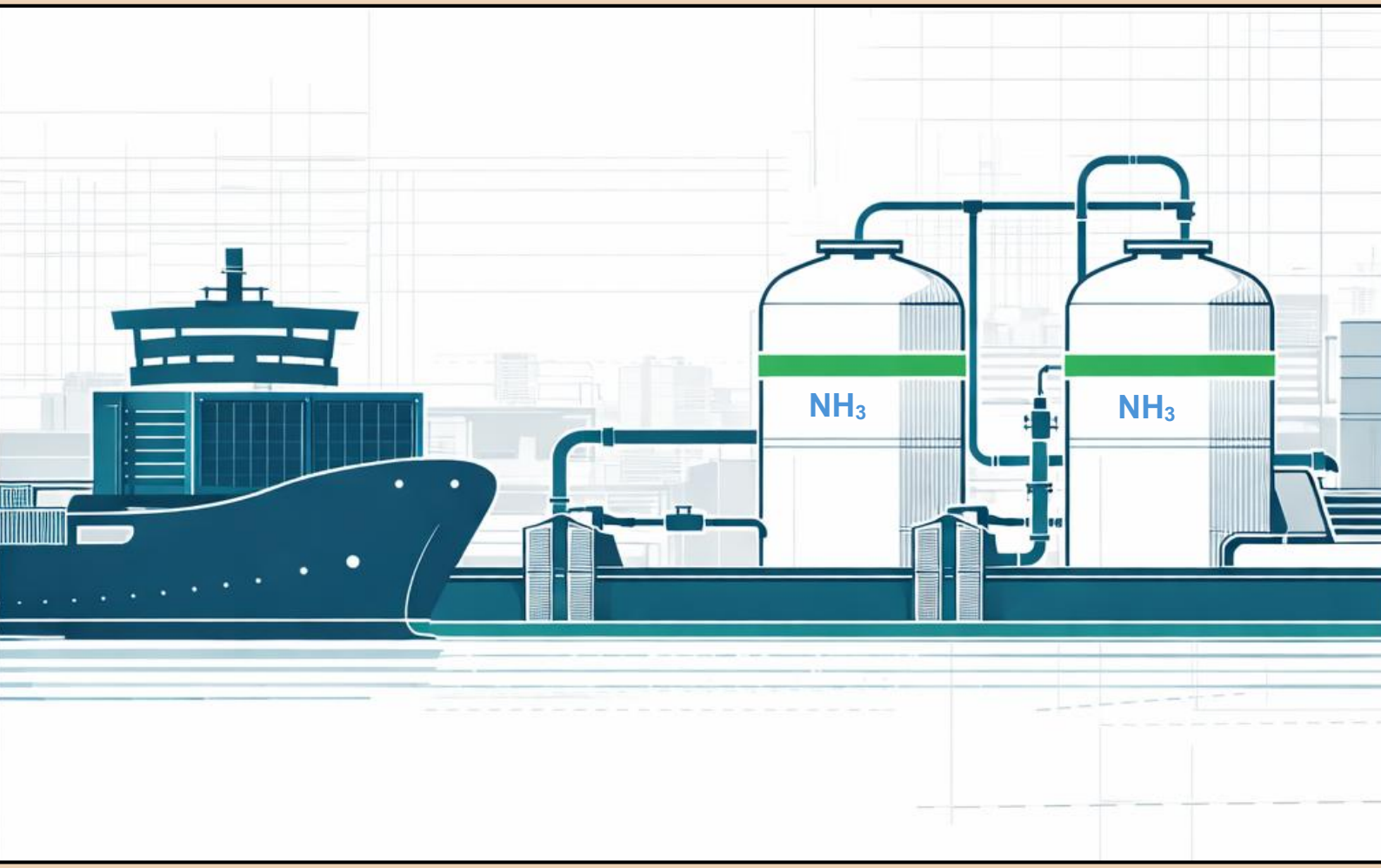
Interreg Baltic Sea Region

Co-funded by the European Union

ENERGY TRANSITION H2Deri@BSP

AMMONIA IN PORTS

HANDBOOK



Author: Dr. Reiner Brüning

ZDS

H2Deri@BSP - A cooperation project to develop proof-of concepts for the uptake of H_2-derivative fuels!	Lead Partner	Port of Hamburg MARKETING

Table of Contents

1 Introduction

1.1 Ammonia as Marine Fuel - Enabling Maritime Decarbonization:

Shipping is the sixth largest CO_2 emitter worldwide, with CO_2 emissions of over 700 million tons per year, accounting for 3% of total global CO_2 emissions. In addition, the total amount of CO_2 emissions related to shipping is still rising (see Fig. 1). To initiate a transformation, alternative fuels are needed, and one of the most promising candidates, which can reduce emissions by up to 95% compared to fossil fuels, is ammonia. Once ammonia is produced from renewable sources such as green ammonia from green hydrogen and atmospheric nitrogen, it can be a nearly completely climate-neutral fuel – provided N_2O emissions are effectively controlled.

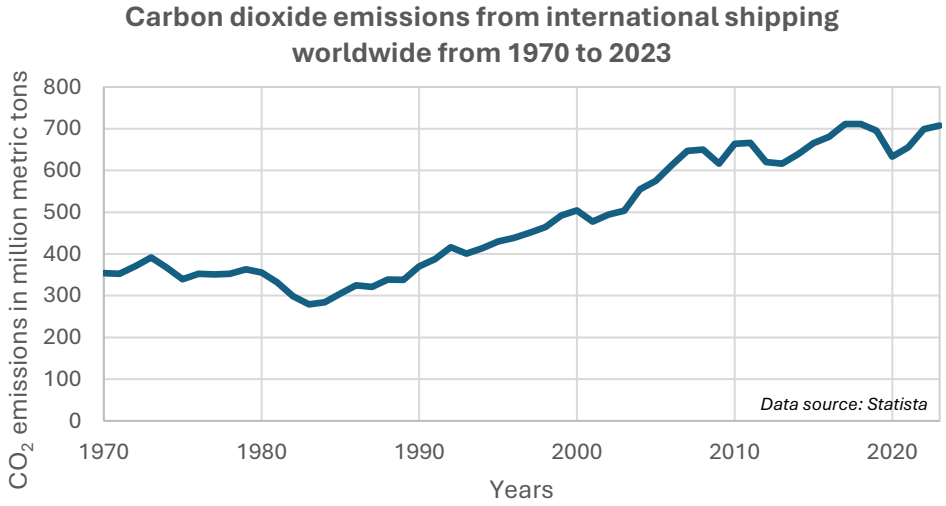


Fig. 1: Development of yearly CO_2 emissions by global shipping.

The development of ammonia-powered ships has been gaining momentum in recent years. As of February 2026, there are now almost 50 ammonia-compatible ships. Since ammonia is the basis for all nitrogen fertilizers and has global applications, there is already a lot of suitable production and transport infrastructure in place. Due to the push within the maritime industry to find suitable alternative fuels for shipping, ammonia will play a very important role in the coming decades.

1.2 Purpose and how to use the document

This manual serves as a guide for port authorities, terminal operators, and port companies planning to use or store ammonia within the port and providing an overview of relevant steps and international or European standards to be considered (e.g. Seveso-III, EN and best practices).

The handbook is divided into nine categories covering the installation of an ammonia storage facility, the handling of ammonia in the port area, and the protection of facilities against external influences. Since there are two types of storage forms for ammonia, the measures are divided into different groups. Measures for the storage in a pressure vessel are marked with a “P” and measures for the refrigerated storage of ammonia are marked with a “C”. If the measure is applicable to both storage forms, it is marked with a “C+P.” Additionally, all measure titles are color-coded: blue for „C“ measures, orange for „P“ measures, and black for „C+P“ measures. Even though converting an existing tank to an ammonia-compatible tank is not a very common practice, the document also contains instructions for converting these tanks. All relevant sections are marked in purple and are intended to provide a rough introduction to the necessary steps.

The regulatory framework emphasizes that the specific challenges involved in handling ammonia in ports, particularly due to its high toxicity, strong corrosive effect, and rapid vapor dispersion, require special knowledge and increased safety measures compared to conventional petroleum facilities. It is intended as a planning and compliance tool and does not replace the technical and detailed special requirements at individual port locations. In addition to this manual, users should identify applicable measures and consult the referenced standards for further details. Port facilities implementing ammonia operations should view this framework as a foundation for developing site-specific procedures and safety management systems that protect workers, the public, and the environment while enabling efficient and reliable fuel supply operations.

1.3 Ammonia in a nutshell

Under normal conditions, ammonia is a colorless gas with a pungent odor and requires special handling due to its unique properties:

- **Liquefaction:** Ammonia can be converted to the liquid state either by cooling (-33°C) or by applying low pressure (8-10 bar at 20°C). This means that cryogenic tanks or pressure tanks are required for compressed storage.
- **Toxicity:** Ammonia is highly toxic. Exposure to ammonia vapors can cause irritation and damage to the eyes, nose, throat, and lungs. At higher concentrations, ammonia can even be fatal. Also in low concentrations, the smell of ammonia is unpleasant and pungent to humans.
- **Corrosiveness:** High reactivity with copper, zinc, and carbon steel, which means that the use of stainless steel or other special coatings is essential. Reaction with water produces corrosive ammonium hydroxide solutions.
- **Flammability:** Due to its relatively narrow flammability range of 15-28% in air and high ignition energy, ammonia is less likely to ignite than hydrocarbons. If combustion does occur, however, toxic nitrogen oxides are produced.
- **Water solubility**: Ammonia is highly soluble in water, depending on temperature and partial pressure. Ammonia water poses a long-term hazard to aquatic organisms and their environment. Therefore, leakage or spillage of ammonia must be avoided under all circumstances, especially during transport by sea.
- **Vapor behavior**: Ammonia is lighter than air (vapor density of 0.6) and therefore rises very quickly, which can lead to dangerous air stratification, especially in enclosed spaces.

Due to these specific properties, the handling of ammonia requires adequate preventive safety measures and appropriate facilities to ensure safe and reliable operations within the port area.

2 Regulatory Measures

1 Site planning and infrastructure safety

Physical location, layout, access control, and basic infrastructure requirements

2 Storage Tank Design and Construction

Tank specifications, materials, structural requirements, and protection systems

3 Safety Systems and Instrumentation

Control systems, monitoring, protective devices, alarms, and safety instrumentation

4 Product Handling and Transfer Systems

Piping, loading/unloading equipment, material compatibility, and transfer operations

5 Operational Procedures and Controls

Operating procedures, training, process control, and quality management

6 Detection and Monitoring Systems

Gas detection, leak detection, environmental monitoring, and alarm systems

7 Inspection, Maintenance and Testing

Periodic inspection requirements, maintenance programs, and testing protocols

8 Emergency Preparedness and Response

Emergency plans, protective equipment, firefighting, and crisis management

9 Modern Requirements

Cybersecurity, climate resilience, physical security threats, and sustainability

2.1 Site Planning and Infrastructure Safety

Scope: Physical location, layout, access control, and basic infrastructure requirements

M1: Basic Safety (C+P)

- Regulatory Compliance: Adherence to all applicable national and international regulations governing hazardous materials storage and handling.
- Good Engineering Practice: Application of recognized codes and standards (EN, ISO) throughout facility lifecycle.
- Operational Discipline: Maintaining cleanliness, order, and systematic prevention of hazardous conditions through rigorous housekeeping protocols.
- Competent Workforce: All work performed by qualified, trained personnel with documented competencies for ammonia-specific hazards.
- Defense in Depth: Multiple independent barriers prevent minor incidents from escalating into major events.

Note: Ammonia is immediately dangerous to life or health (IDLH) at concentrations above 300 ppm. Facility planning must account for toxic cloud dispersion scenarios using tools such as ALOHA or PHAST.

M2: Site Selection and Collision Protection (C+P)

- The ammonia storage facility is positioned, considering vehicle speeds and traffic, to avoid collision risks.
- If safe placement is not possible, install a sufficiently shielding structure.
- Applicable throughout facility life, new and existing installations.

M3: Terrain Delineation and Accessibility (C+P)

- The facility area is secured against unauthorized entry (using fences, ditches, or building walls, e.g. height 1.8 m).
- Access gates/doors are locked after hours

BUT

- Ammonia storage facility must be accessible via at least two entrances for emergency services.
- Entrances are monitored when open; alternatives like camera surveillance may apply.
- Roads and paved areas are maintained for uninterrupted emergency access.
- Storage tanks, loading areas, and buildings must be reachable by at least two independent roads with clear access on at least two sides.
- Perimeter marked with hazard signage including GHS pictograms (H314 Corrosive, H331 Toxic, H400 Environmental) and “TOXIC GAS - CORROSIVE” warnings in local language(s) and English. (per ISO 7010)
- Wind direction indicators (wind socks) visible from all facility entrances and loading areas.

M4: Prevent Heat Radiation Load (C+P)

- Sufficient distance from buildings/structures with fire risks to keep ammonia facilities below 10 kW/m^2 heat radiation load.
- Additional measures (e.g. fireproofing, plant cooling) required if sufficient distance is not possible.

Note: While ammonia itself has limited flammability (flammable range 15-28% in air), facilities must be protected from external fire sources that could cause pressure vessel failure (Boiling Liquid Expanding Vapor Explosion, BLEVE) or compromise tank integrity.

M5: Distance to Above-Ground Stationary Pressure Storage (C+P)

- Maintain at least 150 m between ammonia storage tanks and any above-ground stationary pressure storage (>150 m^3) where BLEVE is a possible scenario.
- Assesses risks of projectiles from vessel explosions.

M6: Internal Safety Distances (C+P)

- Distances between the ammonia facility and buildings must comply with e.g. EIGA Doc 75/21; for toxic release.
- Maintain minimum 10 m between storm drains and loading/unloading areas to prevent ammonia ingress.

- Toxic dispersion modeling per ALOHA, PHAST, or equivalent methodology required for determining safety distances to occupied buildings.
- Control room and permanently occupied buildings equipped with positive pressure ventilation and ammonia detection at air intakes with automatic damper closure.
- Emergency assembly points located upwind (based on prevailing wind direction) and minimum 300 m from storage tanks.
- Hazardous Area Classification:
    - Facility areas where flammable ammonia-air mixtures may occur shall be classified according to EN 60079-10-1 or equivalent (e.g., NPR 7910).
    - Zone classification determines equipment requirements per ATEX 2014/34/EU.

Location	Typical Zone	Radius / Extent
Inside storage tank (vapor space)	Zone 0	Entire vapor space
Pressure relief valve discharge	Zone 1	3 m radius around outlet
Loading arm connections	Zone 1	1.5 m radius during operations
Pump seals and compressor seals	Zone 1	1 m radius
Flanged connections (outdoor)	Zone 2	1 m radius
General tank farm area	Zone 2 or non-hazardous	Based on ventilation assessment

Table 1: Typical zone classification for ammonia facilities

Note: These are typical classifications. Actual zone extents must be determined by qualified personnel based on site-specific assessment according to EN 60079-10-1.

M7: Loading and unloading area – distance from property boundary and public road (C+P)

- Minimum 15 m from property boundary/public road
- if boundary is water, reduction by water width (max 10 m).

M8: Tank truck loading and unloading area (C+P)

- Loading/unloading on designated site section, connected to process sewer (see also M70)
- Section of road is closed to other traffic by barriers or other suitable closure.
- Loading/unloading connections equipped with dry-break (dry-disconnect) couplings to minimize ammonia release during connection/disconnection operations.
- Excess flow valves installed on all liquid ammonia transfer lines to limit release in case of hose or connection failure.
- Breakaway couplings installed on loading arms to prevent catastrophic failure if vehicle moves during transfer.

M9: Tanker loading and unloading area – shielding from through traffic (C+P)

- Loading/unloading area on private road; if adjacent road <10 m, shield with guardrail/rampart (withstands traffic impact); min 2.5 m from adjacent road.
- Preferable to separate the loading by modality type.

M10: Loading and unloading bay railroad tank car (C+P)

- Loading/unloading on designated track section, connected to process sewer (M70), signaling/locking system to prevent entry during operation, derailment mechanisms.

M11: Loading and unloading area – marine and inland vessels (C+P)

- Loading/unloading only at place designated/permitted by port authority.
- More details to the bunkering process (see Baltic Ports Bunkering Guidebook in the Annex)

2.2 Storage Tank Design and Construction

Scope: Tank specifications, materials, structural requirements, and protection systems

M12: Design Standard (C)

- Tanks for refrigerated ammonia storage use the EN-14620 series, with certain stricter requirements (see following measures).
- Minimum design pressure is 100 mbar.
- Air-testing for leak-tightness of the external tank (see M122).

Note: Refrigerated ammonia is stored at -33°C at atmospheric pressure. Thermal stress during cooldown and warmup cycles is critical for tank integrity; maximum temperature change rate 1°C/hour for tanks >1,000 m^3.

M13: Form of Construction (C)

- Full containment tank required: inner and outer tank walls both designed to retain liquid; no penetrations except via the top (with few exceptions).
- Application of perlite as insulation is not permitted.
- Roof is welded and self-supporting.
- Full containment design must account for instantaneous release of entire inner tank contents (cold spill scenario with rapid vaporization).
- Secondary containment sized for 110% of largest tank volume plus freeboard for rainwater accumulation.

M14: Construction Material (C)

- **Material Requirements:**
  - Minimum yield strength: 215–355 MPa (EN 10028-3, table 4).
  - Permitted steel grades: P275NL2 and P355NL2.
  - Softer weld filler material is used, just above the sheet strength.
  - Weld hardness max.: 225 HV.

  - Use P275NL2 cold-resistant carbon steel as much as possible; P355NL2 may be used for specific parts needing higher yield strength.
- **Welding Requirements:**
  - In accordance with the relevant tank construction standard or EN-ISO 15614-1.
  - Welding method approval is part of the inspection/testing program (refers to M122, M123).
- All instrumentation in refrigerated ammonia service rated for cryogenic operation (minimum -40°C ambient rating).
- Safety-critical instruments installed in 2oo3 (two-out-of-three) voting configuration for high reliability and reduced spurious trip rate.
- Instrument impulse lines heat-traced where ammonia freezing or hydrate formation is possible.
  - Welders must be qualified to EN-ISO 9606 series.
- Prohibited materials in ammonia service: copper, brass, bronze, zinc, galvanized steel, and silver-containing alloys (ammonia forms corrosive metal-ammonia complexes).
- All pressure-containing welds subject to 100% volumetric examination (radiographic or ultrasonic testing per EN ISO 17636/EN ISO 17640).

Note: Ammonia causes stress corrosion cracking (SCC) in carbon steel under specific conditions. Water content in ammonia must be maintained at 0.2-0.5 wt% to inhibit SCC.

M15: Concrete Protective Wall (C)

- The tank must be equipped with a concrete protective wall nearly as high as the tank, connecting to the roof slope.
- The wall must resist:
  - Static pressure: 0.3 bar for 300 ms.
  - Projectile/fragment impact: e.g., 150 kg valve at 50 m/s; 200 kg object at 100 m/s.
  - Heat radiation load: 10 kW/m^2 from external fire scenarios.
- Manholes for inspection are allowed in this wall if they are also resistant to these loads.

M16: Foundation Design (C)

- Tank and concrete wall must be on an elevated pile foundation transferring all loads to suitable base soil.

- Design complies with EN-14620-1:2024 section 7.1.10.
- Free space under the tank: ≥1.60 m for new, ≥1.00 m for existing tanks (for ventilation and inspection).

M17: Lock Pump Housing (C)

- Pump housing design: Equipped with a lock (sluice) to prevent ammonia release during maintenance.
- The lock can be flushed with nitrogen and equipped with a presence sensor to detect the pump.

M18: Lifting Installation (C)

- Tank is fitted with a fixed lifting device on the roof for pulling internal pumps vertically out.
- The hoist allows horizontal movement over the tank edge for safe lowering.
- Built so that tank integrity remains even if load is accidentally released.

M19: Cool down upon commissioning (C)

- A piping system with nozzles is provided for cooling the storage tank to achieve complete evaporation and/or distribution of the liquid ammonia.
- This cooling system is designed to meet specified cooling rates (linked to M79).
- The cooling line is typically an atomizer-equipped ring installed at the top of the vapor space inside the tank.

M20: Capacity and redundancy BOG processing system under atmospheric storage (C)

- The Boil-Off Gas (BOG) processing system must be redundant: during compressor maintenance or failure, at least one additional compressor is available (requirement is a minimum of three compressors in practice).
- Each compressor's minimum required capacity matches the needs for boil-off gas in a static storage situation and during possible inflow (e.g., stopped loading).
- If BOG processing is insufficient, filling (loading) of the storage tank must be stopped automatically.
- The BOG system includes both compressor(s) and a refrigeration unit, returning condensed ammonia to storage.

M21: Emergency power supply BOG processing system during atmospheric storage (C)

- The BOG processing system must have a secondary power supply (e.g., internal generator or emergency power unit).
- Emergency/secondary power must allow operation of at least one compressor at required minimum capacity.
- An uninterruptible power supply (UPS) is provided for control systems, with sufficient battery capacity (to last until emergency power activates or at least 1 hour for internal generation).
- Monthly tests must prove operability of the UPS and emergency systems; full system functionality is tested annually.

M22: Drainage of inerts from BOG processing system (C)

- All expected emissions (inerts and ammonia) from the BOG processing system are handled by a vapor processing plant.
- A vent flare is not considered a mitigation system: inerts are purged and processed, not simply vented.

M23: Location of connections (C)

- All tanks' connections (inlets, outlets, vapor discharge, safety/instruments) are installed at the top of the atmospheric storage tank.
- Only penetrations for inspection robots into the annular space are allowed through the secondary steel wall, and only above maximum liquid level.
- Two manholes in the secondary wall are permitted for access during construction/maintenance, which must be welded closed and heat-treated after use.
- For existing double-containment tanks, outlets and maintenance manholes through wall/bottom are allowed.

M24: Drain connections (C)

- Up to four drains are allowed through the floor or wall in the annular space between primary and secondary containment to drain condensate.
- Drain connections must be robust: not larger than DN 100 (4 inches), not smaller than DN 50 (2 inches).

- Valves with lockable closed position are installed for maintenance and testing on instrumentation lines in the drains.
- For existing double-containment tanks, DN 200 (8 inches) drains through the secondary containment wall/bottom are permitted.

M25: Maximum number and capacity (P)

- Limit to two ammonia pressure storage tanks per site, each max. 1,000 tons.
- For existing situations, and when replacing existing pressurized storage tanks, more than two pressurized storage tanks may be present with a total maximum of 2,000 tons.
- Exceptions possible for large Seveso sites with hydrogen backbone, after authority consultation.

M26: Design criteria (P)

- Design tanks for full vacuum, pressure resistance of up to 20 bar, and temperatures from –33°C to +50°C.
- Horizontal tanks: Max. two support points to reduce stress.
- Existing tanks with lower design values require additional safeguards (e.g., cooling, instrumentation).

M27: Dedicated installation (P)

- Entire pressurized ammonia storage, including piping and accessories, must be dedicated to ammonia (no mixing with other substances except water content adjustment).

M28: Construction material (P)

- Steel with minimum yield strength 215–355 MPa (P275NL2 or P355NL2).
- Weld filler marginally stronger than base material; hardness ≤ 225 HV.
- Welding performed according to EN 14620-2 standards by certified welders (EN-ISO 9606).
- Post-weld heat treatment (PWHT) mandatory for all welds.
- Stainless steel only if proven resistant to SCC.
- Existing tanks: Material properties must be verifiable by certificates. If unavailable, risk-based inspection required.

M29: Low-stress annealing / Post Weld Heat Treatment (P)

- New tanks must undergo full PWHT.
- No welded mounting fittings inside tank; allowed externally.
- All penetrations post-weld treated.
- Existing tanks exempt.

M30: Safety wall (P)

- Install safety wall at least 1 m above tank's highest point to protect against jet spray and horizontal discharge.
- Wall and floor form liquid-tight containment for ammonia leaks.
- Wall must resist: static pressure (0.3 bar, 300 ms), impact of heavy fragments/projectiles (e.g., 150 kg valve at 50 m/s, 0.25 m^2 impact area), and heat radiation of 10 kW/m^2 from surrounding fires.
- Penetrations below max liquid level must be liquid-tight and cold-resistant.
- New builds: At least two escape routes. Existing: May deviate based on risk assessment.
- Manholes/doors allowed if meeting protection criteria.

M31: Finishing and insulation (P)

- Thermal insulation must be non-combustible (EN ISO 1182) and not promote fire spread (EN 13501-1).

M32: Construction form of existing atmospheric storage tanks (C)

- Existing tanks must be at least double-walled storage tanks (double containment).
- Both inner and outer tanks designed to contain the stored liquid and withstand cold shock in case of leaks.
- In case of inner tank failure, liquid remains within the structure; limited gaseous ammonia may be released.
- Penetrations through walls allowed only for pump suction line and drain line, protected from external impact.
- No other connections permitted up to max filling level unless welded manholes or nozzles for maintenance.

- Containment facility is provided for leakage scenarios considering pipe bursts and valve closing times.
- Roof is self-supporting and welded to inner tank wall.
- Use of perlite insulation is prohibited.

M33: Design foundation of existing atmospheric storage tanks (C)

- Existing tanks may have a heating system in the foundation to keep temperature above 0°C.
- Heating system should have redundancy so if one system fails, temperature control is maintained.
- Heating controlled by at least two temperature controllers monitoring bottom plate with alarms.
- Temperature controllers are monitored in the control panel and control room.

2.3 Safety Systems and Instrumentation

Scope: Control systems, monitoring, protective devices, alarms, and safety instrumentation

M34: Instrumentation and protection (C)

- Ensure the atmospheric storage tank and its associated systems have instrumentation and safeguards to guarantee safe and reliable commissioning, operation, decommissioning, and maintenance.
- Provide sufficient redundancy, particularly for pressure, temperature, and level measurement (duplicate level measurement by two independent methods), with readings displayed in the control room or to the operator.
- Maintain all instrumentation and safeguards during tank operation.
- Include a temperature measurement and pre-alarm on the supply line, with values visible to the operator.

M35: High-level protection (C)

- Install a high-level protection system in the storage tank, in addition to independent overfill protection (per M36 and M78).
    - Set a pre-alarm to activate at a level that provides at least 15 minutes to intervene before overfilling can occur.
- Independent high-high level switch (physically separate from primary level transmitter) triggers automatic pump shutdown and inlet valve closure.

M36: Instrumental safeguards (C)

- Equip the storage tank with independent instrument safeguards:
    - Overpressure protection with SIL 3 classification, stopping supply near the tank inlet (preferably with automatic stopping/tripping of loading), based on pressure measurement, set to prevent activation of pressure relief valves.
    - Overfill protection with at least SIL 2 classification, stopping supply near the tank inlet, based on level measurement.

  - Underpressure safety device (SIL 2), stopping discharge near the tank inlet (preferably with automatic stopping/tripping of discharge), set to prevent pressure relief valves from activating.
  - Backflow prevention to avoid hot ammonia flowing back into the tank, comprised of two check valves in series with periodic monitoring and an independent instrumented backflow preventer (SIL 2) that stops backflow if pumps fail.
- Safety Instrumented System (SIS) designed, installed, and maintained per IEC 61508/61511.
- Proof test intervals: SIL 3 systems tested minimum annually, SIL 2 systems tested minimum every 2 years.
- All SIS components designed for safe failure (fail-safe design: valves fail closed, alarms fail to alarm state).

M37: Pressure relief and pressure control valves (C)

- Equip the storage tank with the following safeguards for excess pressure:
  - A pressure regulating valve discharging to a flare installation (EN-ISO 25457 compliant), set to prevent outdoor air discharge activation; flare must have support gas, backup, and prevent oxygen backflow to the tank.
  - Pressure relief valves that discharge to the outside air at a safe location; valves must be of the 'pilot operated' type (EN-ISO 4126-4).
- Calculate the number of relief valves needed based on maximum expected pressure buildup.

M38: Design pressure relief and pressure control valves (C)

- Configure relief inlets to pass through the suspended roof to prevent cold vapors from entering the warm space between the outer and suspended roof during pressure relief.
  - This design ensures faster pressure relief and prevents damage to the hanging roof.

M39: Low pressure protection (C)

- An atmospheric storage tank is protected against a pressure lower than the minimum allowable operating pressure using vacuum relief valves.
- The vacuum relief valves are of the weight-loaded type.

- The number of vacuum relief valves required is calculated based on the total air inflow and the specified set point values, as per EN-ISO 28300.

M40: Redundancy due to maintenance (C)

- In addition to M37 (overpressure protection) and M39 (vacuum protection), at least one additional overpressure and one additional underpressure relief valve must be installed for maintenance and inspection.
- The valves associated with the pressure relief valves are interlocked so that only one safety can be removed at any given time. A change-over valve can be used, which prevents more than one connection being closed simultaneously during maintenance.

M41: Preventing outflow (C)

- For existing tanks using external pumps to limit outflow, several valves are installed in the annular space:
  - Hand valve placed against the primary tank wall.
  - Automatic safety valve (ESD valve) placed after manual valve.
  - Additional automatic safety valve (ESD valve) shortly after penetration through concrete outer wall.
- These valves allow inspection and maintenance and provide safety via pipe burst detection.
- Gas detection combined with camera monitoring is used to trigger emergency stops if leaks detected.

M42: Grounding and lightning protection (C)

- Effective lightning protection must be provided for the storage tank.
- Both the inner and outer tanks must be earthed using grounding electrodes with a dispersion resistance not exceeding 2.5 Ohms.
- Earthing points are evenly distributed along the tank perimeter (max. 20 m apart) and made of the same material as the tank wall.
- Stainless steel is used for electrode connections; copper parts require additional protection against ammonia degradation.
- Earthing must comply with EN-IEC 62305-3.

M43: Instrumentation and protection systems (P)

- Provide reliable, redundant instrumentation for pressure, oxygen, temperature, and level (two independent level methods).
- Measurements must be visible in control room or operator station.
- Supply line: Temperature measurement with pre-alarm visible to operator.
- Existing tanks may be exempt from structural modifications for temperature sensors.
- Oxygen measurement not required for stainless steel tanks.

M44: High-level protection (P)

- Install high-level pre-alarm activating before independent overfill protection triggers.

M45: Instrumental safeguards (P)

- Independent overpressure protection (SIL 1): Stops supply at tank inlet, pressure-based.
- Independent overfill protection (SIL 2): Stops supply at tank inlet, level-based.
- Exceptions if continuous gas discharge mitigates consequences (SIL/LOPA study required).
- Applies to both new and existing installations.

M46: Pressure relief valves (P)

- Equip tanks with pressure relief valves discharging to safe location, preferably to ammonia gas processing network, not atmosphere.

M47: Redundancy for maintenance (P)

- Install at least one redundant pressure relief valve for maintenance; ensures continuous protection.
- Valves interlocked so only one can be removed/isolated at a time (use change-over valves if needed).

M48: Grounding and lightning protection (P)

- Effective lightning protection according to location risk.

- Grounding electrodes with earth dispersion resistance ≤2.5 Ohms; connection parts stainless steel (copper protected if used).
- Earthing points distributed ≤20 m apart.
- Earthing in accordance with EN-IEC 62305-3.
    - Risk analysis determines required protection class (EN-IEC 62305 series).

2.4 Product Handling and Transfer Systems

Scope: Piping, loading/unloading equipment, material compatibility, and transfer operations

M49: Prohibition of threaded connections (C+P)

- Threaded connections are prohibited in the primary containment system.
- Instrumentation may have threaded connections (max 20 mm) only if a flanged or welded valve is installed between instrumentation and primary system.
- For existing pressure storage tanks with threaded connections, risks are addressed via Risk Based Inspection (RBI).

M50: Location of connections tank (P)

- All connections of pressure storage tanks are made through the top (inlets, outlets, vapor discharge, safety devices, instruments).
- An exception is a bottom outlet for liquid discharge and a drain is permitted.
- All filler connections have check valves unless other devices provide equivalent safety.
- Take-off lines ≤ 20 tons/hour have flow restrictors or safety devices near the tank.
- All connections have hand valves for maintenance, except for instruments penetrating the tank.
- For existing tanks, installing oxygen or temperature measurement nozzles can be done via manholes if needed.

M51: Material of product lines (C+P)

- Pipes, valves and fittings transporting ammonia shall be resistant to ammonia:
  - Cold-resistant carbon steel pipes are kept between -33°C and -12°C by circulating liquid ammonia continuously, except during maintenance;
  - Stainless steel piping allowed between -33°C to ambient temperature, at least RVS 316L for uninsulated pipes or 304L for insulated pipes with vapor barrier.

- Coatings are applied to prevent external corrosion; corrosion under insulation (CUI) is prevented by avoiding temperature cycling.

M52: Segmentation of ammonia pipelines (C+P)

- Segmentation limits for overhead ammonia pipes depend on diameter:
  - ≤ 10": max segment length 1000 m
  - >10": diameters have shorter max segment lengths as per table

Nominal Pipe Diameter	DN (mm)	Max. Segment Length	Max. Segment Volume
≤ 10"	≤ DN 250	1,000 m	50 m^3
12"	DN 300	700 m	50 m^3
14"	DN 350	520 m	50 m^3
16"	DN 400	400 m	50 m^3
18"	DN 450	315 m	50 m^3
20"	DN 500	255 m	50 m^3
24"	DN 600	175 m	50 m^3
> 24"	> DN 600	Based on 50 m^3 limit	50 m^3

Table 2: Maximum Segment Length for Overhead Ammonia Pipelines

Note: Maximum segment volume of 50 m^3 is the governing criterion for larger diameters.

- Segmentation methods include: remote-controlled shut-off valves and gas locks >3 m high (only for cold ammonia pipes).
- Gas locks accumulate gas to form break points that prevent liquid flowing out of pipeline segments.
- Isolation valves or powered shut-off valves are recommended at site or plant boundaries and at pipeline elevations exceeding gas lock limits.

M53: Pressure relief product lines (C)

- Product lines that can be blocked have thermal relief valves (TRVs) venting without release to atmosphere.

- If fire is a scenario, an additional or second TRV with slightly higher set pressure may be installed for fire protection.

M54: Leak detection system for product lines (C+P)

- Product lines with design flow ≥ 20 t/h must have leak detection installed.
- System must automatically detect leaks, stop pumps, and isolate the affected line.
- Use mass flow measurement (in/out) plus at least one additional method: acoustic, fiber optic thermal, infrared, vibration, or local/site gas detection.
- Beware: Vapor bubbles in ammonia lines may cause false alarms; lines must be pressurized or cooled before measurement starts.

M55: Location of product lines (C)

- Lay product lines in gutters with rainwater drainage where possible.
- Where gutters are not feasible (e.g., pipes on scaffolds), provide separate collection at loading arms.
- If product lines share gutters with flammable hydrocarbon lines, take additional measures to exclude heat radiation (M4).
- New builds: Prefer separate routing; existing sites: supplementary cooling or thermal relief valves if separation not possible.

M56: Location of connections (P)

- All connections (inlets, outlets, vapor discharge, safety devices, instruments) made through the top of the pressure storage tank.
- Exception: bottom outlet allowed for complete liquid ammonia discharge and drain (see M57).
- All filler connections have a check valve (or equivalent protection).
- Take-off lines ≤20 t/h: flow restrictor or instrumental safety device directly at/in the pressure storage tank.
- All connections: at least one hand valve for maintenance; exceptions for instrument penetrations (e.g., temperature tapes).

M57: Drain connections (P)

- Complete emptying: drain through tank bottom permitted for new tanks (max DN50, robust, sealed with valve + blind plate).
- Existing tanks: larger drains possible (max DN200).

M58: Preventing liquid outflow (P)

- For liquid ammonia discharge: at least one hand valve at tank wall; two automatic safety valves, e.g. emergency shutdown (ESD) valves, after hand valve, first ESD valve as close as possible inside safety wall.
- ESD valves automatically close by a line break or pressure drop in discharge line is detected, triggered by the safety control system (SIL 2 according to EN-IEC 61508/61511 standards) to quickly stop flow and prevent any liquid release.
- Additional: gas detection as alarm with camera for manual ESD activation.

M59: Emergency Shutdown at Pressure Tank Inlet (P)

In addition to M58 an automatic inlet ESD valve must be installed to prevent uncontrolled pressure or temperature buildup:

- Location: On the main ammonia supply line at or within 2 meters of the tank inlet
- Trigger conditions: Automatically closes when:
  - Pressure exceeds design pressure + 10% (SIL 2 transmitter-based)
  - Temperature rises above max. design temperature (SIL 2)
  - Overfill condition detected (level sensor, SIL 2)
- Design: Pilot-operated solenoid-controlled, normally closed (fail-safe)
- Backup: Manual block valve upstream; one additional relief valve remains active during maintenance
- Testing: Annual functionality test; response time ≤200 ms documented

M60: (Emergency) provision emptying containment facility of safety wall (P)

- For jet spray scenario: penetration through bottom of safety wall (max DN100) for emergency liquid ammonia discharge; valve + blind plate; pumps/hoses on site for transfer.
- Rainwater drainage: separate drain, closed by default, opened only after visual/pH check.
- Emergency plan (M130) defines handling of collected ammonia.

M61: Pressure relief product lines at pressure storage (P)

- Blocked-in product lines equipped with non-atmospheric thermal relief valves (TRVs).
- If fire is a credible scenario: TRV capacity explained for this purpose, or second TRV with higher set pressure for fire scenario.

M62: Location of product lines at pressure storage (P)

- Product + flammable lines in same gutter: additional measures against heat radiation (see M4).
- Product lines identification per ISO 20560
- If separation not possible in existing infrastructure: additional cooling or thermal relief valves for fire scenario.

M63: Safe loading/unloading facility design (C+P)

- Loading/unloading system designed to minimize human error during coupling/uncoupling and loading.
- Examples: different vapor/liquid connections, dedicated system.

M64: Loading installation – connection of loading arms (C)

- Only fixed loading arms for liquid; hoses allowed for vapor return.
- Remote-controlled valves as close as possible to loading arm connection; check valve for loading to higher-pressure transport.
- Loading arm ends: valves + emergency break coupling; vapor space of transport not in communication with storage tank (vapors to separate vapor treatment).
- Draining facility at loading/unloading site; no draining with hot ammonia gas from ship after cold loading.
- Nitrogen flush for inerting before loading.
- Ship loading arms: remote-controlled quick-connect/disconnect (QC/DC), mechanically protected against unintentional opening; foot valve (product valve) as close as possible to loading arm.

M65: Loading installation – connection of loading arms at pressure storage (P)

- Only fixed loading arms for liquid; hoses allowed for vapor return.
- Remote-controlled valves as close as possible to loading arm connection; backflow preventer for loading to higher-pressure transport.
- Loading arm ends: valves + emergency break coupling; vapor space of transport not in communication with storage tank during loading; during unloading, vapor connection allowed if backflow preventer present.
- Vapors from transport to separate vapor treatment, not BOG system.
- Gas detector in discharge line stops unloading if gas detected.
- Draining facility at loading/unloading site; no draining with hot ammonia gas from ship after cold loading.
- Nitrogen flush for inerting; piping not under ammonia conditions inertized.
- Ship loading arms: remote-controlled QC/DC, mechanically protected against unintentional opening; foot valve (product valve) as close as possible.
- Existing facilities using hoses in transition period: depressurize by releasing vapors to vapor treatment; do not purge with nitrogen or air.

M66: Loading and unloading lines (C+P)

- Lines resistant to maximum pressure and thermal expansion.
- All ammonia piping color-coded per ISO 14726 or local equivalent: typically yellow base with “AMMONIA - TOXIC” labels at maximum 3-meter intervals.
- Flow direction arrows displayed at all valves and branch connections.
- Piping identification includes: product name, hazard class, flow direction, maximum operating pressure, and emergency contact information.

M67: Loading installation marine and inland vessels – emergency break coupling (C+P)

- Emergency break coupling disengagement (or excessive deflection/drift): automatic close of remote safety valves + stop loading.
- Pre-alarm and second alarm ensure flow stops before break coupling disengages.
- DN150+ ship loading arms: hydraulic emergency break coupling.
- All travel distances included in envelope calculation (terminal specification, M74).

M68: Loading installation tank cars/rail tank cars – loading and unloading arms (C+P)

- Loading/unloading arms include: gland connections, balanced suspension, locking system, cut-off, separate liquid/gas arms, drainage, stowed position switch, flow restrictor (≤150% nominal, or safety valve on overcapacity), emergency break coupling (<1 kg ammonia loss in incident).
- Optional: connection check instrument, emergency release, filter.

M69: Loading and unloading area – roadway protection (C+P)

- Technical devices prevent tanker/rail tank car from moving away while connected.
- Mechanical handling equipment for rail cars locked to loading/unloading equipment.

M70: Tank car/rail tank car loading and unloading area – 'containment' (C+P)

- Secondary containment for spill prevention: weighbridge basement, sloped/raised-edge sewer, or other system; prevent mixing with water.
- Containment size based on spill scenario (type, cause, location, outflow rate, pressure, response time, % flash, calculation).

M71: Material of fittings (C+P)

- All materials used in fittings resistant to ammonia.
- Copper, silver, zinc, and their alloys prohibited.
- Contact between mercury and ammonia not allowed.

M72: Design of fittings and gaskets (C+P)

- All fittings pre-checked for suitable ammonia-resistant materials.
- All valves pretested for leak tightness with helium test (EN-ISO 15848).
- Only closed pumps without mechanical seals used; mechanical seals with leak detection allowed for compressors.
- Gaskets non-explosive and low emission (e.g., spiral wound with solid outer ring).

M73: Fire-tested valves (C+P)

- Valves exposed to heat load >10 kW/m^2 must be fire tested.

- Manufacturer's certificate demonstrating compliance required.

2.5 Operational Procedures and Controls

Scope: Operating procedures, training, process control, and quality management

M74: Terminal Specification (C+P)

- The terminal specification consists of detailed documentation on storage and transport modes within the hazardous substances storage and handling area.
- It covers: connection and transport requirements, pressure and temperature limits, inert and water content requirements, geometry, load rates, pump pressures, connection details, Material compatibility requirements, Emergency shutdown procedures and systems, Vapor handling and recovery systems, Refrigeration system specifications (for atmospheric tanks), Safety instrumentation requirements (alarms, sensors, interlocks), Sampling and quality control procedures, Grounding and bonding requirements, Communication protocols during loading/unloading, Environmental monitoring requirements, Personnel qualification and training requirements
- Also includes requirements for restraint systems, calculations/drawings for loading arm reach, and operational details related to ensuring safe loading/unloading.
- For pressure tanks, the maximum received temperature is limited to 80% of the temperature corresponding to the design pressure.
- For atmospheric tanks, the maximum temperature to be received is set by the tank's design minus additional safety margins.

M75: Addressing safeguards and operating outside design conditions (C)

- When safeguards such as those in M35, M36, M37, and M39 are activated (triggered), this is treated as an undesirable event and recorded and analyzed (incident investigation into cause, effect, and preventive measures).
- Any operation outside the tank's design conditions is similarly treated as an undesirable event, analyzed, and approved by an independent expert for ammonia storage tanks.

M76: Addressing safeguards and operating outside design conditions (P)

- Activating safeguards (e.g., M44, M45, M46) is considered an undesired event and must be recorded and analyzed.
- Any operation outside the specified tank design parameters must be documented and investigated as an adverse event. This includes identifying root causes, assessing impacts, and defining corrective and preventive measures. The investigation and its findings must be reviewed and approved by an accredited independent inspection body.

M77: Operational procedures (C)

- Maintain procedures for commissioning/decommissioning, all phases of normal operation (including testing, maintenance, inspection), action on deviations, maintenance during production.
- Procedures address (temporary) safety measures.
- Written operating procedures maintained at all operator stations covering: normal operations, startup/shutdown sequences, abnormal situation response, emergency procedures, and routine maintenance activities.
- Procedures reviewed and updated minimum annually and within 30 days after any incident, near-miss, or process change.
- Pre-startup safety review (PSSR) required before initial startup and after any modification or extended shutdown (>30 days).

M78: Control of storage conditions (C)

- Continuously monitor pressure, temperature, and level in atmospheric storage tank.
- Settings allow intervention before overfill or overpressure protections trigger.

M79: Operational procedures for commissioning and decommissioning atmospheric storage (C)

- Before commissioning: tank and lines cleaned, dewatered, flushed with nitrogen until O_2 <4%, then with ammonia until O_2 <0.5%.
- Cooling filled by controlled ammonia supply, bottom temp decreased at <1°C/hour to –33°C.

- Ammonia analyzed for water content (≥0.2 wt%, <0.5 wt%) within 1 week after filling.
- Decommissioning: empty as far as possible, slowly evaporate remaining ammonia (<1°C/hr), flush with nitrogen then air.

M80: Water content (C)

- Water content in ammonia storage must be at least 0.2 wt% and lower than 0.5 wt%
- A certain water content is required in ammonia to prevent stress corrosion cracking and to protect storage tank integrity.
- Checked at least 24 hours after filling via sample from circulating pump.

M81: Prevent/reduce oxygen entry (C)

- Nitrogen for purging contains <5 ppm O_2.
- Limit entry of inerts, prevent ammonia return to tank during product loading.
- BOG compressor suction equipped with vacuum relief device.
- Oxygen content measured monthly and after maintenance.

M82: Operational controls (C)

- Visual leak inspection on all plant components related to atmospheric storage at least every 8 hours.

M83: Lifting operations (C+P)

- Procedure for lifting/hoisting above ammonia-carrying parts: no hoisting unless part emptied and depressurized, unless risk analysis demonstrates sufficient protection.
- Risk analysis includes:
  - minimum lift height
  - double securing of load
  - load suitability
  - infrastructure protection
  - lifting supervisor in radio contact
  - operations limited to good visibility and wind (not above force
  - approved lifting plan

- o clear plant overview attached to permit.

M84: Modifications and repairs (C)

- Modifications and repairs to the ammonia storage facility require approval from an independent expert or accredited inspection body in accordance with national implementation of the EU Pressure Equipment Directive (PED 2014/68/EU).
- Requirement does not apply if the work concerns designated pressure equipment subject to separate national regulations for pressure equipment modifications.

M85: Training and education (C)

- Training program for all operational staff on the ammonia plant is in place.
- Mandatory training topics: process safety, ammonia release risks, hazardous process aspects, and procedures for commissioning/decommissioning.
- - Operator training curriculum includes: ammonia physical and chemical properties, toxicity and health effects including regulatory exposure limits (EU-OEL: 20 ppm 8-hour TWA, 50 ppm 15-minute STEL; IDLH 300 ppm per NIOSH), proper use of respiratory protection (Self-contained breathing apparatus (SCBA) and escape respirators), spill response procedures, first aid for ammonia exposure (eye/skin contact, inhalation), and emergency evacuation procedures.
- Refresher training conducted minimum annually with documented competency assessment (written test and practical demonstration).
- All personnel working in ammonia handling areas must complete facility-specific safety orientation before unescorted access is granted.
- Training records maintained for duration of employment plus minimum 5 years.

M86: Operational Control – Availability of Procedures and Instructions (C+P)

- Loading operations may only occur when written procedural documentation and work instructions are in place.
- These procedures must clearly state the conditions to be met during all phases of the loading operation.
- Applicability: All loading/unloading activities for both new and existing installations.

M87: Control Conditions Ammonia for Unloading (C)

- The unloading procedure must explain how incoming ammonia is tested and compared with the terminal's specification.
- Key tests include water content (wt%), temperature, and temperature/pressure ratio.
- Ammonia is not transferred to the storage tank if the temperature is higher than specification or if the water content is below 0.2 wt%. If the latter, steps must be taken (such as inline blending) to raise water content before filling.
- Deviations in the pressure/temperature ratio may indicate inert gases (e.g., nitrogen or oxygen); these must be removed before unloading.

M88: Procedure for Loading (C)

- Loading must follow internal, pre-established written procedures, covering:
  - Personal protective equipment (PPE) requirements.
  - Ensuring transport containers hold only ammonia or inert, non-flammable gases with compliant oxygen levels.
  - Verifying all pathways are appropriately routed for safe transfer.
  - Confirming there is sufficient space in the receiving tank to avoid overfilling.
  - Vapor returns must connect to a vapor treatment system.
  - Tankers must have proper grounding; loading cannot commence otherwise.
  - Use of a deadman's switch for tanker loading/unloading.
  - Automatic locks for railcar bottom valves.
  - Periodic checks for leaks and process progress during loading.

M89: Operational control – loading and unloading area general (C+P)

- Regular transshipment activities only take place at specially equipped and identifiable loading/unloading sites.
- As soon as a tank wagon or rail tank wagon is connected, the area is closed off with a physical blockade (e.g., barrier).
- No other vehicles (except ammonia transport) may be present at the site.

M90: Mooring of tankers (C+P)

- Tankers are moored to prevent excessive stress or damage to connected cables or loading arms during loading/unloading.

M91: Load and unload tank cars and rail tank cars – prevent runaway (C+P)

- During coupling/uncoupling or transshipment, tank cars/rail tank wagons are immobilized (e.g., with hand brakes, wheel chocks) to prevent movement.

M92: Operational control – supervision during loading (C+P)

- During loading, at least one trained company official is present at a safe location to intervene if necessary.
- During ship loading, a designated person is also on board to intervene; effective communication is ensured.
- Camera surveillance with gas detection is permitted as an alternative if immediate action is possible from the control room.

M93: Filling control during loading (C+P)

- For loading tank cars/rail tank cars, overfilling is prevented by two independent methods:
  - 1st method: Flow measurement stopping loading at calculated maximum.
  - 2nd method: Choice of vapor return with liquid detection, infrared camera for level, or weighbridge check.
- Both methods have a pre-alarm for early intervention and automatic stop for high-high alarm.

M94: Control of storage conditions (P)

- Continuously monitor pressure, temperature, oxygen content, and level in the tank.
- Settings are configured to allow timely action before safety devices are triggered.

M95: Operational procedure for commissioning and decommissioning (P)

- Commissioning: remove water/oil, leak test with nitrogen, flush with nitrogen (<0.5% O_2), flush ammonia gas, cool gradually with liquid ammonia, measure O_2 and remove if detected.

- Decommissioning: empty to minimum, evaporate remaining ammonia, verify tank is ammonia-free, flush with nitrogen (<2% NH_3), then air (>19% O_2), remove oil, collect/dispose emissions via vapor treatment.
- Similar steps for product lines.

M96: Training and education (P)

- Training/education for all staff involved covers: process safety, ammonia release risks, hazardous process steps (see M98), commissioning/decommissioning procedures (M95).

M97: Prevent/reduce oxygen amount tank (P)

- Nitrogen gas used to make the storage tank inert must have a very low oxygen content, < 5 ppm, to prevent any reactions that could cause corrosion or safety risks.
- During product loading, measures must be taken to prevent unwanted gases from entering the tank, and to avoid any ammonia gases from flowing back into the storage tank.

M98: Discharge of oxygen and inerts (P)

- Oxygen detected above the threshold is immediately purged via BOG or vapor processing plant.
- O_2 measurement has alarm/recording; continuous logbook is maintained.
- 250 ppm O_2 in gas phase = operation outside of design conditions (per M76).

M99: Discharge of oxygen and inerts (P)

- If oxygen is detected above the detection limit in a pressurized storage tank, it must be immediately removed via a BOG processing system or vapor processing plant.
- The oxygen measurement must be equipped with alarm and recording systems. A logbook is maintained to demonstrate continuous recording of oxygen content.
- If more than 250 ppm oxygen is detected in the gas phase of the pressurized storage tank, this is considered "operating outside design conditions" and must be documented and analyzed in accordance with relevant safety standards. The appropriate national authority or accredited inspection body must be notified as

required by the national implementation of the Seveso Directive (2012/18/EU) or equivalent regulations.

- For facilities with continuous gas discharge systems capable of effectively removing oxygen, immediate notification may not be required, provided that the oxygen removal system functions properly and oxygen levels return to acceptable levels within a defined timeframe.

M100: Contents and filling rate (P)

- Pressurized storage tanks are filled to a maximum of 80% by volume.
- A higher fill level is permitted only if the minimum filling temperature as stated in the table below is maintained and there is a functioning temperature safety device.

filling temperature [°C]	fill level [%]
-33	80,0
-30	80,5
-25	81,2
-20	82,0
-15	82,8
-10	83,6
-5	84,5
0	85,4
5	86,3
10	87,3
15	88,3
20	89,4
25	90,5
30	91,7
35	92,9
40	94,2
45	95,5
50	97,0

Table 3: Maximum fill level of pressure storage tanks at different filling temperatures

M101: Control conditions ammonia for unloading (P)

- The unloading procedure for pressure storage must specify that incoming ammonia is evaluated against the terminal specification (M74), which includes at least: water content (wt%), temperature, pressure/temperature ratio.
- Ammonia must not be transferred to the pressurized storage tank if the incoming temperature exceeds the terminal specification.
- The pressure/temperature ratio must agree with the ammonia vapor pressure curve; if there is a deviation (indicating inerts/oxygen), these are removed before transfer, usually through a vapor processing plant.

M102: Procedure for loading (P)

- Loading is conducted only according to written, internal procedures addressing at least:
  - Proper PPE and escape masks where necessary;
  - Means of transport contains only ammonia or nitrogen or a non-flammable/inert gas with allowed oxygen content;
  - Equipment is arranged to ensure product flow only to intended place before pumping begins;
  - Sufficient free space in the receiving containment is confirmed and overfilling prevented;
  - Vapor return, if used, is connected to a vapor handling facility or protected by a backflow preventer;
  - Demonstrable effective grounding for tankers, with loading not started unless grounding is verified;
  - Use of deadman's switch by the driver during loading/unloading;
  - Automatic locking system engaged on bottom valve of rail tank cars;
  - Regular checks for leaks and loading progress.

M103: Temperature protection (P)

- The temperature of ammonia introduced into the pressure storage tank does not exceed the maximum temperature stated in the terminal specification.

2.6 Detection and Monitoring Systems

Scope: Gas detection, leak detection, environmental monitoring, and alarm systems

M104: Overflow and leak detection (C)

- No overflow is allowed on atmospheric storage tanks.
- The annular space (between inner and outer tanks) must have detection systems with alarms to identify both condensate and liquid ammonia presence.
- When liquid is detected in this space, it must be immediately removed using a specific device described in M24.

M105: Loading and unloading bay – alarm system (C+P)

- Audible/visual alarm operable from multiple positions.
- Ammonia gas detector (M111) stops loading on leak detection.

M106: Loading and unloading bay – emergency stop (C+P)

- Remote-controlled shut-off/ESD valves also closable from supervised location + ≥2 safe positions; preferably near escape routes.

M107: Overflow protection flash vessel (C+P)

- Independent SIL 1 overfill protection on flash vessel for cooling hot ammonia; stops supply, prevents liquid entering gas outlet.

M108: Version heat exchanger for heating liquid ammonia (C+P)

- Heat exchanger designed to prevent leakage to heating medium (e.g., double spiral exchanger).
- Intermediate medium recommended (e.g., ammonia).

M109: Instrumentation and protection for heat exchangers for heating liquid ammonia (C+P)

- Heat exchanger equipped with continuous temperature, pressure, and level monitoring.
- Overpressure protection present, with relief not discharging to the atmosphere.

M110: Heat exchanger leak detection system (C+P)

- Detection system installed to identify ammonia leakage into the intermediate medium.
- System also detects leakage from intermediate medium into heating medium.
- Detection method can be pressure, pH, or conductivity measurement, matching the medium.

M111: Continuously operating gas detection system (C+P)

- Ammonia gas detection system installed and active in all relevant facility locations.
- Minimum detection locations: annular space of double containment tanks, inside/outside safety wall of pressure tanks, compressors, flash vessel, heat exchanger, pumps, vapor processing plant, loading/unloading areas, control rooms, shelters.
- At loading/unloading: pre-alarm at 30 ppm, loading stops at 198 ppm.
- Number and position of detectors based on scenario analysis in Safety Design Dossier (SDD)

Note: According to the following norms: EN 50270, EN 50402 and IEC 62990-1

Self-Diagnostic and Testing Requirements:

- Each ammonia gas detector must have built-in self-diagnostic capability to detect hardware/sensor failures.
- Alarm must be raised (visual + audible) if detector fails or goes offline.
- At minimum, one automated bump test per detector per 24 hours.
- Fixed ammonia detectors installed at: tank dome connections, pump seals, compressor shaft seals, loading/unloading stations, control room HVAC air intakes, and facility boundaries (downwind based on prevailing wind).

- Detector specifications: measurement range 0-500 ppm minimum, response time T90 <30 seconds, accuracy ±10% of reading or ±5 ppm (whichever is greater).
- Alarm setpoints: Low alarm 25 ppm (investigate and ventilate), High alarm 50 ppm (evacuate non-essential personnel, prepare for emergency), High-high alarm 150 ppm (initiate emergency shutdown, full evacuation).
- Portable ammonia detectors available for maintenance personnel; units capable of detecting 0-100 ppm with audible/visual alarm using calibration gas (0.5% ammonia in nitrogen, ±10% accuracy).
- If bump test fails, detector must automatically switch to alarm state and notify operator.
- Fallback: Manual override available — if automated system fails, manual gas testing (portable detector) can be performed by qualified personnel within 4 hours.
- Failure to restore detector functionality within 24 hours requires: (a) activation of substitute detector at same location, or (b) operational restriction (e.g., no loading until detector restored).

M112: Safety Design Dossier for ammonia gas detection (C+P)

- Safety Design Dossier (SDD) for ammonia gas detection submitted to competent authority for approval.
- SDD must be positively assessed by accredited inspection body before approval.
- the SDD contains at least the following information:
    - The results of a scenario analysis showing the expected scenarios (nature and magnitude) for each installation/activity;
    - Where, given the scenario analysis, which substances are going to be detected;
    - The specification of the type of detector/detection principle;
    - the alarm values;
    - the intended actions and controls based on the alarm values;
- SDD describes scenarios, substances to detect, detector types, alarm levels, control actions, inspection, testing, maintenance.

M113: Implementation and inspection of ammonia gas detection per SDD (C+P)

- Gas detection systems built according to approved SDD.
- Independently inspected on delivery and at least annually by accredited type A inspection body.

- System not operated unless proven fully operational with positive inspection report.
- If SDD amended, resubmission and approval required before modification.

M114: Five-year assessment of the gas detection SDD (C+P)

- SDD should be reassessed every five years by accredited inspection body.
- Assessment includes differences in standards, new requirements; report available to competent authority.

2.7 Inspection, Maintenance and Testing

Scope: Periodic inspection requirements, maintenance programs, and testing protocols

M115: Inspection of fire water network and hydrants (C+P)

- The fire water network and all hydrants are visually inspected periodically.
- Functionality of hydrants, fire water monitors, stationary and semi-stationary water supply is tested at least annually.

M116: Testing of emergency power supply (C+P)

- The emergency power supply (used for critical safety systems) is tested monthly; full system (under load) is tested annually.

M117: Testing of stationary vapor dispersion prevention facilities (C+P)

- Stationary devices (e.g., water curtains, monitors) for vapor dispersion prevention are inspected every month and fully tested annually.

M118: Loading installation – periodic inspections (C+P)

- For good reliability, at least once a year, the condition of the loading and unloading installation is checked by:
  - Visual external inspection of pipes for external deterioration, correct location, and support.
  - Visual external inspection and reliability check of valves, instruments, and safeguards.

M119: Loading installation – recording of inspection results, modifications, and repairs (C+P)

- A record system shall be kept for all inspections, modifications, and repairs performed on the loading and unloading installation.
- The modification/repair data and the findings from tests, maintenance, and inspections are recorded in this system.

M120: Periodic inspection (C)

- Annually:
  - Visual inspection of the concrete wall for deterioration, damage, or loss of integrity.
  - Visual external inspection of pipes for deterioration, location, and support.
  - Visual external inspection and operability check of valves, instruments, and safeguards.
- Once every four to six years:
  - Visual inspection of the foundation.
  - If concrete corrosion is evident (discoloration, surface spalling >5 mm depth), reduce inspection interval to every 2 years.
- Concrete Corrosion Management:
  - Corrosion in ammonia environments is primarily due to nitrogen oxide formation. If corrosion rate exceeds 1 mm/year or structural integrity is questioned, engage structural engineer and competent authority for assessment.

M121: Independent Inspection Oversight and Reporting (C+P)

- All critical inspections needs to be conducted by an accredited Type A Inspection Body or independent expert qualified per applicable standards (EN-ISO 17020, PED, Seveso III).
- Inspection reports should be in line with national regulations.
- All reports must include minimum information:
  - Tank/Equipment identity (ID, materials, installation year, design specs)
  - Inspection date and interval since last inspection
  - Scope of inspection (methods, standards applied, areas covered)
  - Findings (defects, non-conformities, degradation, SCC evidence)
  - Corrective action plan with remediation timelines
  - Inspector certification and signature

- Critical defects (non-compliances affecting safety) must be reported to the competent authority within 24 hours. Plant operation must cease until defects are remedied and re-inspection confirms compliance.
- All inspection records and supporting documentation must be archived for minimum 10 years and remain accessible to the competent authority at all times.
- Annual Compliance Summary Report aggregating all inspection findings and corrective actions must be provided to the authority by year-end.

M122: Inspection and maintenance program (C)

- The ammonia storage facility and all installation parts are inspected and maintained according to an approved inspection and maintenance program.
- Approval comes from a designated inspection body or independent expert as appropriate.
- Documentation of inspections and maintenance is required before returning to service.

M123: Testing safety devices and instrumentation (C)

- Safety devices, including over/under-pressure protection, are tested at least annually or as per the inspection and maintenance program.
- Instrumentation (for example: level, pressure, temperature, oxygen content) is functionally tested annually to ensure correct function and alarm capability.

M124: Cooling facility and devices to prevent/limit vapor dispersion – control and maintenance (C)

- Inspection and maintenance of cooling and vapor containment facilities are conducted per documented maintenance plans and applicable technical standards.
- A records system of the inspections performed is established and maintained.
- Registration includes new construction, modifications, periodic inspections, maintenance, failures, and relevant safety events.

M125: Periodic inspection (P):

By performing periodic inspections, in addition to checking for leaks as described in M96, the reliability of the ammonia storage facility is monitored. The required periodic inspections are:

Annually:

- A visual inspection of the security wall for deterioration, damage, and maintenance of integrity;
- A visual inspection of the pressure storage tank support structure for deterioration, damage, and maintenance of integrity;
- A visual external inspection of the pipes to check for external deterioration, location, and support. For insulated piping, a visual inspection of the insulation is sufficient. The insulation shall be removed only in those places where it is necessary for conducting investigations or where, based on the visual external inspection, there is reason to do so;
- A visual external inspection and verification of the functionality of valves, instruments, and safeguards.

M126: Inspection and testing safeguards at pressure storage (P)

- Inspection and testing of safeguards are carried out at the pressure storage installation.
- The test frequency of instrumental safeguards (such as those referred to in M45 and M58) follows from the SIL verification.
- Ensure that all relevant safeguards are included in the testing program and that documentation of tests and results is maintained.

M127: Consideration of periodic inspection for pressure storage (P)

- The relevant environmental/Seveso permit of storing pressurized ammonia must ensure that, during the mandatory testing, maintenance, and inspection as required under the Pressure Equipment Directive (PED), the corrosion mechanism SCC is explicitly examined by the responsible inspector.
- All relevant failure mechanisms shall be determined and assessed using internationally recognized standards, such as EN 13445-5 (Damage Mechanisms Affecting Fixed Equipment in the Refining Industry), or equivalent national/international technical codes and standards.

M128: Loading equipment – checking for proper operation (C+P)

- The loading and unloading installation is periodically tested for operability of the valves and proper functioning of the alarm and security systems.
- When abnormalities are found, corrective action is taken immediately.
- Regularity is based on the frequencies recommended by the manufacturer.

M129: Inspection and maintenance program of existing ammonia storage facility in atmospheric storage (C)

- For parts of the facility covered by the Pressure Equipment Directive (PED), the inspection program must be reviewed and approved by a notified body or accredited inspection organization, in line with national implementations of the PED.
- For components not subject to the PED (such as atmospheric refrigerated ammonia storage tanks), the inspection program should be approved by an independent ammonia storage tank expert and the responsible national environmental authority.
- The independent expert must supervise or review all periodic and extraordinary inspections conducted.
- After maintenance or inspection with tank out of operation, recommissioning is only permitted with formal approval by an independent expert.
- For existing double containment atmospheric storage tanks, the interval for major in-service inspections should not exceed 12 years (or a shorter interval determined by a risk-based inspection (RBI) approach).
- In-service inspection must ensure accessibility (inspection ports, annular gaps, etc.) of all relevant welding seams, tank base and roof, as specified in recognized guidance.
- Out-of-service inspections should be carried out according to the intervals determined by RBI methodologies.
- If in-service NDT (e.g. robotic or remote inspection, pulse-echo, etc.) is not possible for specific areas due to obstacles, an out-of-service inspection of these areas shall be conducted at appropriate intervals.
- Robotic and non-destructive inspections (NDT) using state-of-the-art techniques are recommended to evaluate weld integrity and detect cracks (incl. SCC).

2.8 Emergency Preparedness and Response

Scope: Emergency plans, protective equipment, firefighting, and crisis management

M130: Emergency plan (C+P)

- The emergency plan, as required by the Seveso Directive and the national occupational health and safety legislation, shall include specific concerns for ammonia:
  - Exposure to ammonia in liquid and gaseous form.
  - Evacuation (at elevation and ground level).
  - Fire combined with toxic gas cloud from ammonia and emission of nitrogen oxides during fire.
  - Salvage and cleanup of an ammonia pool.
  - Procedure for managing a primary tank leak.
- The emergency plan must be submitted to the competent authority under the applicable environmental and major-accident legislation for approval.
- Emergency Response Plan includes toxic release scenarios with pre-calculated evacuation zones based on dispersion modeling for various release rates and weather conditions.
- Coordination procedures with local emergency services, hospitals (for ammonia exposure treatment), and neighboring facilities documented. Joint emergency exercises conducted minimum annually.
- Public notification procedures established for releases that may impact areas outside facility boundary.

Note: Large ammonia releases may require evacuation of areas up to 1.6 km downwind depending on release rate, duration, and atmospheric stability. Initial isolation zone minimum 100 m in all directions per ERG Guide 125 or equivalent European guidance (e.g., ERI-Cards, national emergency response guidelines).

M131: Work Platform Evacuation (C+P)

- The emergency plan must describe how to evacuate persons from work platforms on top of the tank.
- Fire department assistance (e.g., with high rescue vehicles) requires prior positive advice from the regional emergency management authority or Fire Department.

M132: Operating Installation in Emergency Situations (C+P)

- The ammonia storage installation must remain operable during emergencies for a limited time.
- Provisions must allow the plant to be secured safely within that limited time.

M133: Shelter Locations (C+P)

- A shelter-in-place must be present at loading/unloading sites, or PPE must be provided to reach a shelter or safe zone.
- Shelter must offer at least 8 hours of protection and comply with EEMUA Publication 186 or equivalent standards.

M134: Wind Bag or Wind Vane (C+P)

- A wind bag or wind vane must be installed near the ammonia storage component.
- It must be clearly visible in the dark.

M135: Loading and Unloading Area – Personal Protective Equipment (C+P)

- Breathing masks or full-face masks with ammonia filters and special clothing must be available near the loading/unloading area.
- Operators must wear this protective equipment when coupling or uncoupling transport connections.
- Sufficient escape masks must be present with unobstructed access.
- A frost-free safety shower with eye showers (compliant with EN 15154).
- Minimum PPE for routine ammonia operations: chemical splash goggles or face shield, ammonia-resistant gloves (butyl rubber minimum 0.35 mm thickness or neoprene), long-sleeved clothing, and safety footwear.

- Full-face air-purifying respirator with ammonia cartridge (minimum protection factor 50) required when ammonia concentration may exceed 20 ppm (EU-OEL) but remain below 300 ppm.
- SCBA with minimum 30-minute capacity required for: emergency response, concentrations exceeding 300 ppm or unknown, confined space entry, and any IDLH atmosphere.
- Emergency escape respirators (minimum 15-minute capacity, hood-type preferred) available within 15 meters of all ammonia handling areas; minimum one escape unit per two workers.
- Full chemical-resistant suit (Level B minimum) required for spill response and decontamination activities.
- A (15–37 °C) must be available at the loading/unloading bay.

M136: Fire Extinguisher at Loading/Unloading (C+P)

- At least one portable fire extinguisher (43A/233B) must be present at the loading/unloading bay.
- The extinguisher must meet EN 3-7 and be maintained according to EN
- It must be freely accessible and always ready for use.

M137: Vapor Dispersion Control During Loading (C+P)

- A stationary system, automatically activated by ammonia detection, must be installed at loading locations.
- If using a water curtain, it must fully enclose the site and meet a minimum capacity of TNC / V = 33 (Total Nozzle Capacity/Volume).
- If using water monitors, at least two must be present per bay, each with ≥ 2000 l/min flow and remote operation from a secure location.

M138: Vapor Dispersion Control at Other Plant Components (C+P)

- Vapor control must be installed at components like the heat exchanger, flash vessel, and BOG system.
- This may include:
  - Two remote-controlled water monitors (≥ 2000 l/min), or
  - A water curtain enclosing the entire site (TNC / V = 33).

M139: Cooling Facilities (C+P)

- If used to reduce heat radiation (≥10 kW/m^2), cooling facilities must provide:
  - ≥ 2 l/min/m^2 for heat radiation
  - ≥ 10 l/min/m^2 if exposed to direct flame
- This must be detailed in the SDD.

M140: Safety Design Dossier for (Semi)Stationary Facilities and Cooling Water Supply (C+P)

All (semi)stationary installations (e.g., water curtains, monitors, cooling systems, and fire-fighting water systems) for ammonia handling must comply with a standardized SDD.

- The SDD must be approved by an accredited notified body (Notified Body under EU directives) or by the competent port or environmental authority in the relevant Member State.
- The SDD follows a standardized format and must include:
  - Scope and boundaries of the system
  - Description of the facility and its environment
  - Process descriptions
  - Risk and scenario analyses
  - Safety provisions, structural and organizational measures
  - Reference to relevant European and international laws and standards, including justified deviations
  - Technical drawings, design choices, and documentation on inspection and certification
- If formal certification from an accredited inspection body is not feasible, compliance may be demonstrated by a Declaration of Conformity supported by a formal risk assessment prepared by a qualified independent party.

M141: SDD Approval, Assessment, and Ongoing Inspection (C+P)

- Prior to submission, the SDD and any addenda must be assessed by an accredited notified body or equivalent Type A inspection body with expertise in fire protection and ammonia handling systems.
- The application for SDD approval must include the inspection body's assessment report.
- Upon delivery of (semi)stationary systems, an initial conformity inspection by the accredited body is mandatory to demonstrate compliance with the approved SDD.

- Annual inspections must be conducted to verify ongoing conformity.
- Any non-conformities detected must be reported promptly to the competent port or environmental authority, together with a corrective action plan.
- The SDD and the associated system should be reviewed and reassessed at least every five years by a competent SDD coordinator and the accredited inspection body, with any required updates submitted for approval.
- If standard certification is not achievable, a Declaration of Conformity, supported by a comprehensive risk assessment, may be used to demonstrate regulatory compliance.

M142: Design of Fire Protection and Cooling Facilities (C+P)

- (Semi-)stationary fire protection facilities (measures M137, M138, M139), the (cooling) water system, and fire hydrants shall be designed according to EN 12845 (fixed firefighting systems – sprinkler systems) or equivalent standards approved by the competent authority.
- The (cooling) water network must be a loop system with block valves. The block valves are positioned so that, even if part of the fire water network is out of service, enough (cooling) water remains available for every part of the ammonia storage facility.
- A legible, up-to-date, to-scale drawing of the (cooling) water network must be available. It must show at least:
    - Locations of firewater pumps and cooling facilities
    - Locations and diameters of pipelines
    - Locations of block valves
    - Locations and numbers of fire hydrants and water monitors
- System capacity and pressure for the firewater pumps and cooling facilities must be documented at the system level and be available during emergency response.
- The applicable European standards shall be chosen based on the design choices taken by the operator. The SDD must record these choices and specify which standards are followed. The SDD is part of the facility operating permit application (in accordance with Seveso III requirements where applicable).

M143: Capacity and pressure of firefighting/cooling water network (C+P)

- The fire/chilled water network and pumping system are designed to deliver the minimum amount of water required for the maximum scenario.
- The amount of water is tailored to both prevent or limit the spread of an ammonia vapor and to cool facilities where a heat radiation load greater than 10 kW/m^2 may occur and where escalation is possible.
- The pumping system (together with the (cooling) water network) is dimensioned for the maximum expected pressure required at every location within the ammonia storage facility.
- The required dynamic (working) pressure is determined for each (semi-)stationary facility. For above-ground fire hydrants, a minimum dynamic pressure of 1 bar (100 kPa) is required. This requirement does not apply to monitor combinations.
- Firewater pumps can be started from a safe location. The maximum required time to manually start the firewater pumps is tailored to the scenarios to be distinguished.

M144: Minimum duration of water supply (C+P)

- Ensure the required amount of water is available for at least 4 hours under all circumstances.
- Deviations from the 4-hour minimum can be approved by the relevant safety authority based on detailed scenarios.

M145: Reduced pump system availability (C+P)

- In case of reduced availability of the pump system (e.g., during maintenance or repair):
  - Provide at least 100% of required capacity for cooling and water screens.
  - Provide at least 75% of capacity for fire hydrants.
- Alternative pumping capacity must be available, e.g., spare pumps, fireboat connection, or interconnection with a neighboring facility's water system.
- Locations and capacities of alternative pumping facilities and operation instructions must be documented.

M146: Taking out of service part of firefighting/cooling water network (C+P)

- When part of the firefighting/cooling water network is taken out of service, determine alternative water supply means for that portion.

- Cooling water must be available at least halfway down the eligible street and on at least two sides of a facility.
- Temporary changes longer than 2 hours must be communicated to the regional emergency management authority or company fire department.
- Include changes such as stationary facilities no longer powered, semi-stationary facilities used or fed by the fire department, or changes in mobile combat aspects.

M147: Matching firefighting/chilled water system to firefighting vehicles (C+P)

- Coordinate the connections and operation of the firefighting/cooling water system to ensure compatibility with firefighting vehicles.
- Ensure delivery pressure is suitable for firefighting deployment needs.

M148: Fire hydrants (C+P)

- A sufficient number of above-ground fire hydrants and fire hydrant/monitor combinations are installed on the firefighting/cooling water network.
- Fire hydrants comply with EN 14384 or an equivalent standard.
- The required number depends on the site's fire and toxic risk scenarios.
- Fire hydrants are spaced 50 to 80 meters apart, except on open undeveloped land.
- Fire hydrants are protected from freezing.

M149: Fire hydrants - connections and identification (C+P)

- Each fire hydrant has at least two connection options equipped with valves of at least 67 mm passage diameter and storz coupling with standard ridge distances.
- If fire hydrants have valves with a 100 mm passage, the coupling ridge distance is 115 mm.
- Reducer couplings are available on site for different dimensions.
- Fire hydrants have a unique number clearly marked nearby.
- Hydrants can be opened using a commonly used hydrant key or fixed controls like a handwheel.

2.9 Modern Requirements

Scope: Cybersecurity, climate resilience, physical security threats, and sustainability

M150: Industrial Cybersecurity for Control Systems (C+P)

- Industrial control systems (SCADA, DCS, PLC) and safety instrumented systems protected per IEC 62443, NIS2 Directive (Art. 21) or equivalent.
- Network segmentation:
  - Operational technology (OT) separated from information technology (IT)
  - Firewall at OT/IT boundary
  - Safety systems (SIS) isolated from process control where practical
- Access control:
  - User authentication and role-based permissions
  - Multi-factor authentication for remote access
  - VPN required for external connections
  - Session logging maintained
- Physical security of control hardware:
  - PLCs, servers, networking equipment in locked cabinets or control room
  - Access logging for control room and equipment areas
- Security maintenance:
  - Regular security updates and patches per vendor recommendations
  - Vulnerability assessments annually minimum
  - Security incidents investigated and documented
- Backup systems:
  - Control configurations backed up offline (not network-connected)
  - Backups tested quarterly
  - Recovery procedures documented

Recommendation:

- Encrypted wireless protocols and key rotation are strongly recommended, particularly if wireless links are operational.
- A documented cybersecurity incident response plan specific to industrial control systems should be maintained and regularly tested.

M151: Cybersecurity - Emergency Control Independence (C+P)

- Critical safety functions independent of control systems:
  - Manual emergency shutdown pushbuttons (hardwired, not through PLC)
  - Manual valve operation capability (handwheels on critical valves)
  - Backup manual level indication (sight glasses, dip sticks)
- Cybersecurity incident response:
  - Procedures for control system compromise
  - Manual operation capability until systems restored
  - Emergency shutdown independent of compromised systems
- Personnel training on cybersecurity awareness: phishing recognition, password security, suspicious activity reporting.

M152: Climate Resilience - Design Parameters (C+P)

- Facility design accounts for climate change projections (IPCC AR6):
  - Facility robustness per EN 1990
  - Temperature extremes: design for +10°C above historic maximum and -10°C below historic minimum
  - Wind loads: 150% of current local design wind speed standards (EN 1991)
  - Precipitation: drainage systems sized for 100-year storm plus 25% margin
- Flood protection (if facility in projected 100-year flood zone):
  - Critical equipment elevated above projected flood level
  - Waterproof barriers for below-grade infrastructure
  - Emergency drainage capacity with backup power
- Sea level rise (coastal facilities):
  - Long-term planning accounts for 0.5-1 meter sea level rise over facility lifetime
  - Critical infrastructure elevated or protected accordingly
- Climate risk assessment updated every 5 years or after severe weather events.

M153: Extreme Weather Preparedness (C+P)

- Severe weather monitoring and response:
  - Weather alert system providing real-time warnings
  - Pre-storm procedures: secure loose items, verify backup power, test emergency systems

    - Operations curtailment criteria defined (wind speed thresholds, storm warnings)
- Post-storm inspection:
    - Facility inspected for damage before resuming operations
    - Structural integrity, tank stability, piping, electrical systems verified
- Extended power outage preparedness:
    - Emergency generator fuel supply for 72 hours minimum
    - Manual monitoring procedures for extended outages
    - Alarm systems connected to security response

M154: Physical Security - Critical Infrastructure Protection (C+P)

- Control room hardening:
    - Backup control capability at separate location if control room compromised
    - Emergency systems (ESD, fire suppression) protected and redundant
- Drone countermeasures (optional, for high-risk facilities):
    - Drone detection systems (radar, RF, visual)
    - Response protocols for unauthorized drone activity
    - Coordination with local authorities
- Personnel security measures:
    - Visitor registration and escort in operational areas
    - Access control cards or keys tracked and controlled
    - Contractor access limited to authorized areas and supervised
- Emergency lockdown capability:
    - Procedures for security threats
    - Secure access control at all entry points
    - Communication capability to alert personnel and authorities

M155: Sustainability Assessment and Life Cycle Considerations (C+P)

- Major infrastructure projects subject to sustainability assessment per EU Taxonomy requirements:
    - New storage tanks or significant modifications
    - New loading/unloading infrastructure
    - Projects seeking EU green financing or public funding
- Carbon footprinting per ISO 14067 or EN 17472:
    - Scope 1: Direct emissions from facility operations
    - Scope 2: Indirect emissions from purchased energy

    - Scope 3: Embodied carbon in materials, transport, construction
- EU Taxonomy environmental objectives considered:
    - Climate change mitigation (primary)
    - Climate change adaptation
    - Circular economy (material reuse, recycling)
    - Pollution prevention
    - Water and marine resource protection
- Construction and demolition waste (CDW):
    - Minimum 70% reuse or recycling of non-hazardous CDW per EU Taxonomy
    - Material recovery plan documented before construction
- Material selection informed by environmental assessment:
    - Recyclable materials prioritized where technically feasible
    - Environmental Product Declarations (EPDs) per EN 15804 requested from suppliers for major components
    - Results documented and considered in design decisions
- Assessment documentation retained for facility lifetime; updated for major modifications.

Note: Full Life Cycle Assessment (LCA) per ISO 14040/14044 and EN 17472 recommended for projects >€5 million or where required by funding conditions, environmental permits, or corporate ESG commitments.

3 References

- ABS: Requirements for Ammonia Fueled Vessels
- ABS: Ammonia Bunkering – Technical and Operational Advisory
- ATEX Directive 2014/34/EU: Equipment for Explosive Atmospheres
- DNV: Alternative Fuels for Containerships (Guidance Paper)
- DNV: Ammonia in Shipping – Tracing the Emergence of a New Fuel
- DNV: Gas Fuelled Ammonia Class Notation
- DNV: Safe Introduction of Alternative Fuels – Ammonia and Hydrogen as Ship Fuels (White Paper)
- DNV-RP-0699: Competence Related to the Use of Ammonia as Fuel
- EEMUA Publication 186
- Green Shipping Programme: Ammonia Safety Handbook
- IACS UR H1: Control of Ammonia
- IGC Code: International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk
- IGF Code: International Code of Safety for Ships Using Gases or Other Low-Flashpoint Fuels
- IMO MSC.1/Circ.1687: Interim Guidelines for the Safety of Ships Using Ammonia as Fuel
- IMO Resolution A.1050(27): Recommendations for Entering Enclosed Spaces Aboard Ships
- IPCC AR6: Sixth Assessment Report of Climate Change
- ISO 7105: Anhydrous Ammonia for Industrial Use
- Lloyd's Register: Rules for Ships Using Gases or Other Low-Flashpoint Fuels
- Maritime Technologies Forum (MTF): Guidelines for Developing and Implementing a Safety Management System for Ammonia-Fuelled Ships
- EN 3-7: Portable Fire Extinguishers
- EN 10028: Flat Products Made of Steel for Pressure Purposes
- EN 13445: Unfired Pressure Vessels
- EN 13501-1: Fire Classification of Construction Products and Building Elements
- EN 14384: Pillar Fire Hydrants
- EN 14620: Design and Manufacture of Site Built Steel Tanks for Refrigerated Liquefied Gases
- EN 50270: Electromagnetic Compatibility – Gas Detection Apparatus

- EN 50402: Functional Safety of Gas Detection Systems
- EN-IEC 61508: Functional Safety of Electrical/Electronic/Programmable Electronic Safety-Related Systems
- EN-IEC 61511: Functional Safety – Safety Instrumented Systems for the Process Industry
- EN-IEC 62305-3: Protection Against Lightning
- EN-ISO 4126-4: Safety Devices – Pilot-Operated Safety Valves
- EN-ISO 7010: Graphical Symbols – Safety Signs
- EN-ISO 9606: Qualification Testing of Welders
- EN-ISO 14001: Environmental Management Systems
- EN-ISO 15614-1: Specification and Qualification of Welding Procedures
- EN-ISO 15848: Industrial Valves – Fugitive Emissions Testing
- EN-ISO 25457: Flare Details for Petroleum and Natural Gas Industries
- EN-ISO 28300: Venting of Tanks for Petroleum and Natural Gas Industries
- EN-ISO 45001: Occupational Health and Safety Management Systems
- IEC 62990-1: Gas Detectors – Performance Requirements
- ISO 20560-1: Safety Information for the Content of Piping Systems
- NIS2-Directive (2022/2555)
- NPR 7910: Hazardous Area Classification (ATEX Zones)
- Perplexity.ai, Claude.ai: As a summary tool; The content reflects the project's activities. AI were used for the generation of the cover page, and no personal data was used for this purpose.
- PED 2014/68/EU: Pressure Equipment Directive
- PGS 12: Dutch national guideline for ammonia storage and transfer
- Seveso III Directive 2012/18/EU: Control of Major-Accident Hazards Involving Dangerous Substances
- SOLAS: International Convention for the Safety of Life at Sea
- Statista: Carbon dioxide emissions from international shipping worldwide from 1970 to 2023
- STCW Code: Seafarers' Training, Certification and Watchkeeping

4 Abbreviations and Acronyms

- ALOHA: Areal Locations of Hazardous Atmospheres
- BLEVE: Boiling Liquid Expanding Vapor Explosion
- BOG: Boil-Off Gas
- (C): Cold Storage (Atmospheric)
- (C+P): Measures for cold and pressurized ammonia
- CCPS: Center for Chemical Process Safety
- CUI: Corrosion Under Insulation
- DCS: Distributed Control System
- DN: Diameter Nominal
- EN: European Standard
- ERG: Emergency Response Guidebook
- ESD: Emergency Shutdown
- ESG: Environmental, Social, Governance
- GHS: Globally Harmonized System
- HVAC: Heating, Ventilation and Air Conditioning
- IDLH: Immediately Dangerous to Life or Health
- IEC: International Electrotechnical Commission
- IGC: International Gas Carrier (Code)
- IGF: International Gas Fuel (Code)
- IoT: Internet of Things
- IPCC: Intergovernmental Panel on Climate Change
- ISA: International Society of Automation
- ISO: International Organization for Standardization
- IT: Information Technology
- LCA: Life Cycle Assessment
- LOPA: Layer of Protection Analysis
- MTF: Maritime Technologies Forum
- NDT: Non-Destructive Testing
- OEL: Occupational Exposure Limits
- OT: Operational Technology
- (P): Pressurized Storage
- PED: Pressure Equipment Directive
- PHAST: Process Hazard Analysis Software Tool

- PLC: Programmable Logic Controller
- PPE: Personal Protective Equipment
- PSSR: Pre-Startup Safety Review
- PWHT: Post-Weld Heat Treatment
- QC: Quality Control
- RBI: Risk-Based Inspection
- SCADA: Supervisory Control and Data Acquisition
- SCBA: Self-Contained Breathing Apparatus
- SCC: Stress Corrosion Cracking
- SDD: Safety Design Dossier
- SIL: Safety Integrity Level
- SIS: Safety Instrumented System
- SOLAS: Safety of Life at Sea
- STEL: Short-Term Exposure Limit
- TNC: Total Nozzle Capacity
- TRV: Thermal Relief Valve
- UPS: Uninterruptible Power Supply
- VPN: Virtual Private Network
- wt%: weight percent