

SHIPPING OF AMMONIA: WHAT IS NEW?

Rev. 2.0 – Feb-24

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TRUE.
BLUE.
TRANSITION.

ABSTRACT

The decarbonization of the World will need many paradigm changes. Among others, in the Clean and/or Green Hydrogen economy, the trading of Ammonia by ships will grow significantly.

The objective of this paper is to address the safety aspects of this trend to come and how to address them.

First, the problematic will be analyzed. Indeed Ammonia is not new: its toxicity is well known and there is about 40 years of experience in Ammonia shipping. So how this relevant experience can be used to address safely – at concept level – the order of magnitude increase to come in volume and frequency of large Ammonia cargo transfer between the onshore storages and carrier vessels. Instead of being mitigated, should the risk of a toxic cloud be eliminated and kept away from populated areas, such as busy ports ? How can this be done ? What will be the impact on project economics ?

Other types of cargo have similar safety constraints. To create new ports or jetties dedicated for large scale Ammonia trading would be unduly CAPEX intensive, requiring long permitting process. This paper will review the various technologies available for fluid cargo transfer from onshore storage to gas carriers in open sea, in other words, without the need of new harbor nor expensive jetty.

To adapt a proven solution, Imodco will complete - by Mid of 2024 - the qualification for Ammonia application of Single Point Mooring (SPM) terminals, used for fluid cargo transfer in open sea, validated by over 470 systems delivered since 1958 for fluid transfer in open sea.

As matter of fact, the safety records with jetty-less systems are good and guaranteed by the well documented regulations and guideline/recommendations for oil transfer (e.g. OCIMF). Gas Carriers are regulated by other codes (SIGTTO and IGC code), the paper will give recommendations for good practices for transfer of Ammonia in open sea, using SPM terminals.

Finally, Jetty-less Terminals not only ensure intrinsically safe operations but also enable significant improvements in project economics by providing optimum CAPEX/OPEX/Uptime combination to secure the required safety level.

INTRODUCTION

Enhanced by the current crisis, the Energy Industry has many challenges to overcome, often summarized as an Energy Transition. Within the various Hydrogen Carrier molecules, Ammonia is one of the most affordable and has one the highest energy density. This makes Ammonia a good candidate for long haul transport of clean and/or green fuels.

The presented work focus on shipping of Ammonia, first looking what will change between the past 30yr and the coming next 30 yr: from the economic and then technical standpoints with safety as the redline as ultimately the larger use of ammonia is for the sake of better world: safer & less carbonated. The technical focus will be centered on the transfer of Ammonia from/to the carrier to/from the onshore storage. Organized in four chapters, this paper ambitions to consolidate input from the various stakeholders of the Ammonia value chain.

1. The macro economical aspect: various uses and traded volumes, focusing on the part shipped by various types of gas carriers.
2. The technical aspect: various technologies for Ammonia transfer.
3. The safety discussions reviewing the main risks and their elimination or mitigations.
4. The overall picture from insurer's and investor's perspectives which aims at a wise balancing between investment and return on investment addressing safety dimensions.

The overarching conclusion is given as summary of all these elements illustrating the main point: Ammonia SPM terminals transfer systems will be a key contributor to the Hydrogen Economy & Strategy by enabling safe and cost-effective infrastructure for ammonia transfer in open sea. As an opening for further work, a status is given on recommendations for good practices and regulations for transfer of Ammonia in open sea, using SPM terminals.

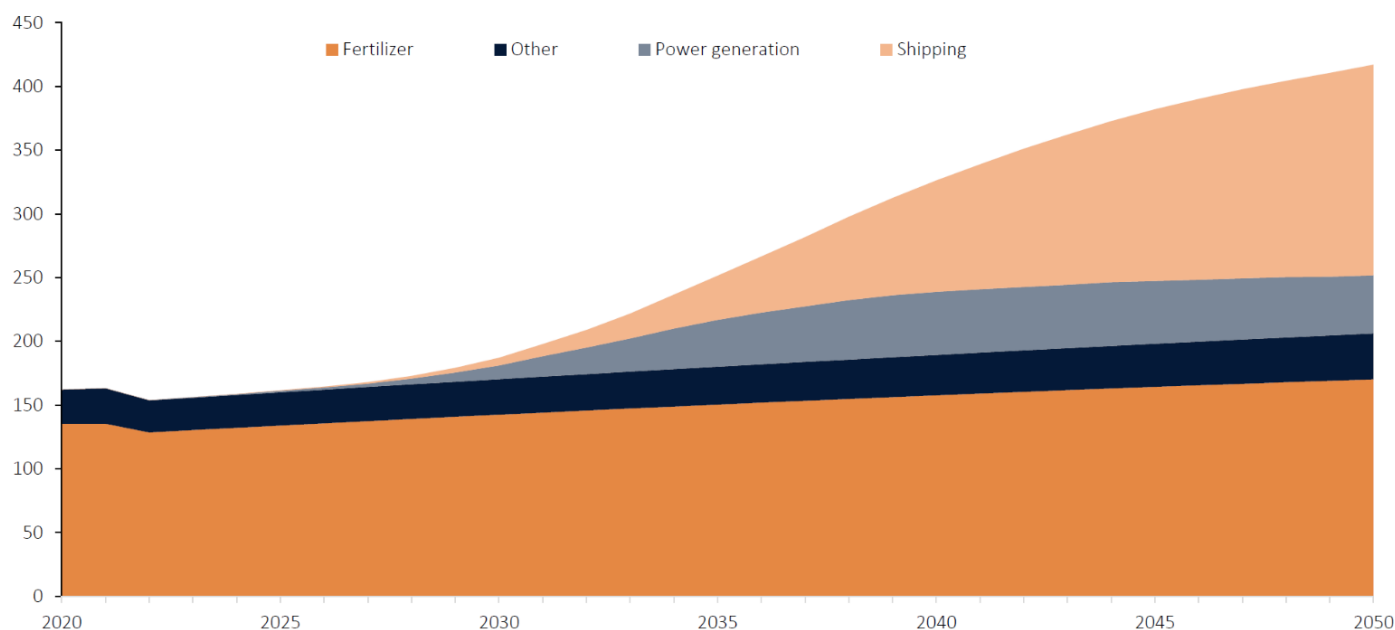
1. Shipping of Ammonia: “over the last 30yr” versus “in the next 30yr”

The shipping of Ammonia is not new. Over the last 30 years, some Ammonia have been transiting as maritime cargo. Most of these shipments were onboard LPG carriers of relatively small cargo capacity (say less than 25,000 t – 38,000 m³) able to carry Ammonia at -33 deg. C and close to ambient pressure (ie. Onboard the so-called refrigerated cargo gas carrier). Ammonia shipping represents today 15-20 MTPA of the 180-200 MTPA world wide ammonia production/use, as most of today ammonia is produced and used locally.

The production/use of ammonia will grow drastically in the coming 30 years, by probably a factor 3 as illustrated in Figure 1.

Ammonia demand remains on trac to grow 3-fold

Ammonia demand by demand segments to 2050
Million tonnes



Source: Rystad Energy HydrogenCube

Figure 1: extract from Rystad Energy's presentation at World Hydrogen Summit, Rotterdam May-23

As illustrated in Figure 2, most of the new Ammonia production will mainly come from the most economical hydrogen production hubs such as Australia, Chile and Arabian Gulf (as other areas well exposed to sun and wind are unfortunately less stable politically or less conveniently located) and will be exported to importing areas such as Asia and Europe.

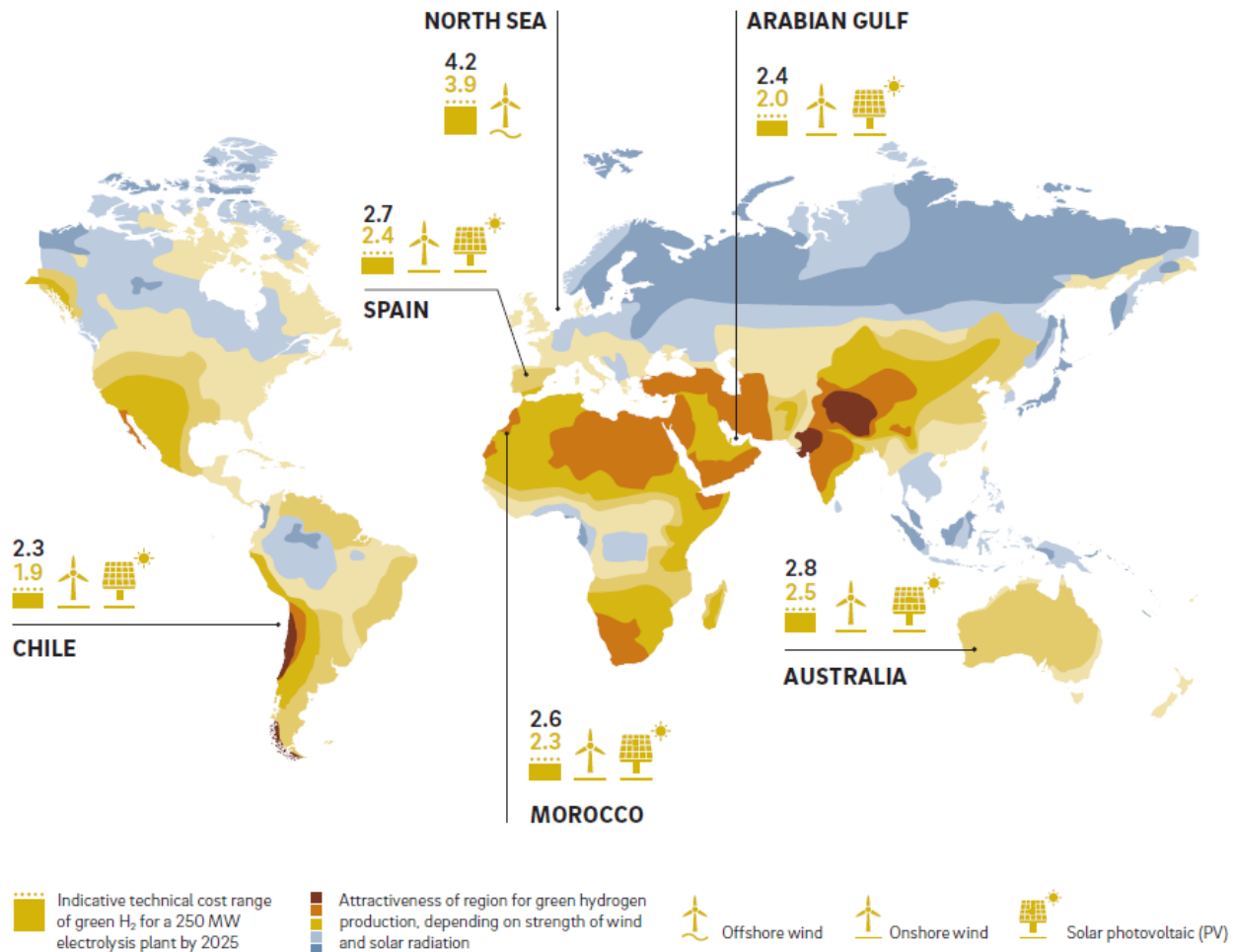


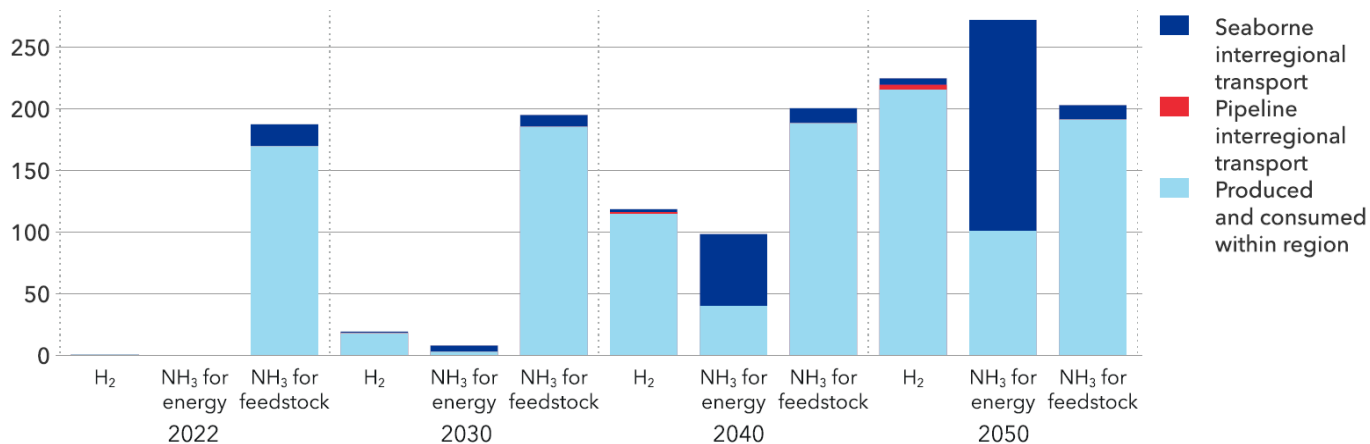
Figure 2: Cost competitive renewable electricity and green hydrogen production hubs are typically located distant from demand centers (Eur/kg) – source: [roland-berger-hydrogen-transport.pdf](https://roland-berger.com/hydrogen-transport.pdf)

So most of the new ammonia production will be transported over long haul distances therefore by ships. For transport by ship, the Ammonia is liquid, typically at or close to -33 degrees Celcius when transported on carriers with refrigerated tanks. Indeed for large cargo volumes, it is more cost effective and safer to transport the ammonia close to atmospheric pressure. At that pressure, ammonia is liquid at -33deg C.

As most of new production and new consumption will be at long haul distances from each other, it results that Ammonia shipping will increase in volume and/or in frequencies by at least an order of magnitude. Depending on the sources (summarized as low and high bound estimates), the ratio is close to a factor 20, as explained in Figure 3.

Transport of hydrogen and ammonia

Units: Mt/yr



All numbers displayed in mass terms: Mt of H₂ or Mt of NH₃. The mass of ammonia converted from H₂ is approx. 5-6 times the mass of H₂.

Above graph Source: DnV Energy Transition Outlook 2023

| Ammonia volumes | today (low) | 2050 (low) | increase Ratio (low) | today (high) | 2050 (high) | increase Ratio (high) |
|-------------------------------------|-------------|------------|----------------------|--------------|-------------|-----------------------|
| Overall production - MTPA | 150 | 450 | 3 | 200 | 600 | 3 |
| Local consumption - MTPA | 135 | 150 | 1.11 | 180 | 200 | 1.11 |
| Ammonia shipping - MTPA | 15 | 300 | 20 | 20 | 400 | 20 |
| Typical cargo size in kT (1) | 10 | 100 | 10 | 25 | 150 | 46 |

Figure 3: Ammonia Shipping increase by factor 20 between today and 2050 projections

Note (1): one of the perceived size constraints for the future ammonia carriers is the existing quay side lengths, this constraint disappear once the jetty-less terminal concept decision is made.

The next section presents the various technologies available for ammonia cargo transfer from onshore storages to gas carriers. The third section will reflect from a safety standpoint on the increase by more than order of magnitude in volume and/or frequencies.

2. Ammonia cargo transfer – from/to carrier to/from shore

Over the last 30 yr, Ammonia cargo transfer has almost exclusively been performed in harbors, at quay side, with the carrier hardly moving relatively to the fixed ground/quay: the motions are slow (“quasi-static”, in opposition to “dynamic” resulting from large waves) either due to tidal variations or some residual swell diffracting within the port. As only a few Ammonia carriers were in operation, so far none was involved in ship collision. Ship collisions risk may increase with increased vessel traffic.



Source: <https://newsroom.portofantwerpbruges.com/storage-of-ammonium-nitrate-under-very-strict-safety-conditions-in-port-of-antwerp>

Figure 4: Ammonia Carrier at quay side

The fluid transfer used is either loading arms or flexible hoses – as further detailed below:

- Similar to LNG loading arms – the loading arm is an articulated piping (see Figure 5 extract from Kanon loading arm brochure) designed to accommodate a pre-defined maximum envelop of relative positions.

MARINE LOADING ARMS

Characteristics:

- Sizes 4" to 24" diameter
- Materials: carbon, stainless and low temperature steels, with PTFE or rubber linings and other special alloys
- Temperature range –200° C to + 300° C

All KANON arms, including manually operated models, can be provided with a **virtually** non-spill Emergency Release System.

This ensures, that, in the event of an emergency, the liquid and vapour lines are both sealed after disconnection. Once the emergency sequence commences, the arm automatically rises and returns to its parked position, allowing for immediate departure of the tanker if necessary.



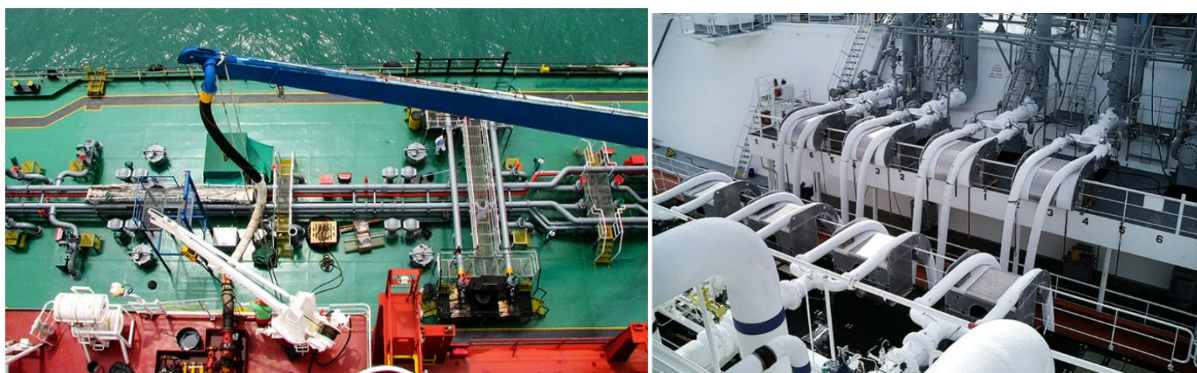
Source: <https://kanon.nl/wp-content/uploads/2021/06/Kanon-Loading-Equipment-brochure-en.pdf>

Figure 5: typical loading arm

Similar to bonded hoses used for dead crude oil transfer, the bonded hoses are steel wire reinforced rubber structures (comparable to car tyre technology). For the Ammonia, the focus on chemical compatibility leads to the use of different grades of rubber.

In both cases, the system has typically 3 levels of positions: allowable positions for safe fluid transfer, warning mode positions where the fluid transfer must be stopped to prepare for disconnection and extreme positions beyond which there is a risk of damage. If the position monitoring system reaches that latter level, the loading arm disconnects by activating its (Powered) Emergency Release Coupler.

The Emergency Release system when using hoses, it is either designed to release beyond a given load level or also actively disconnected triggered by a position monitoring system similar to the one used for loading arms (see Figure 6).



Sources:

left picture: <https://www.continental-industry.com/en/solutions/fluid-handling/renewable-energy-solutions/ammonia-hoses-for-bunkering>

right picture: <https://www.trelleborg.com/en/fluidhandling/products-and-solutions/industrial-hoses/oil-petroleum/gutelling-lpg-white>

Figure 6: typical current use of ammonia hoses in quasi-static application

Jetty-less systems:

In process of qualification, few Jetty-less solutions requiring longer and more dynamic ammonia hoses (being qualified by Trelleborg and Continental Industry/Contitech) will be available in 2024, both for:

- **Protected Sites:** as further explained below there are two sub-segments (1 & 2 as function of the distance from shore) in protected or/and directional environment.
- **Open Sea Sites:** which are the best, safety wise, as further away from populated areas: the ammonia cargo transfer being performed in open sea.

Such open sea offloading systems, called SPM terminals (for Single Point Mooring – allowing carrier vessels to weathervane during the fluid transfer) have been invented over 60 years ago mainly for large oil tankers which would not fit in the existing harbours or which would need to load or offload oil (or oil derivative) from a refinery away from existing infrastructures. For some large development projects, heavy and long term investments were made into large jetty systems to receive these large vessels. Over the years, the experience of these large projects indicates that Jetty systems typically are not only expensive but also have long delivery schedule. This is mainly due to the nature of jetty systems, especially those with breakwater, requiring many studies of the impact on the environment and the consequently time consuming associated permitting process. Jetty-less systems have a more straight forward permitting process and shorter overall schedule, as the simplicity of the overall system enables a virtuous spiral of simplification and cost efficiency: Jetty-less systems are conceived from day one with a view of minimum impact on the environment, including possible site reinstatement. This eases the permitting process, reduces the number of required impact studies, finally a shorter schedule and simpler system have combined and significant positive effect on the overall CAPEX.



Figure 7: Typical architecture of CALM terminal (Single Point Mooring – SPM)

As illustrated in Figure 7, the carrier vessel heading can be adjusted any time to site conditions to ensure a safe approach, berthing, loading, disconnection and sail away, leveraging on over 60 years of operating experience of SPM terminals illustrated in this video [Catenary Anchor Leg Mooring \(CALM\) Terminal \(vimeo.com\)](#).

Part of the experience gathered over these many years of SPM operations, the safety distance to account for safe maneuvering of the approaching vessel. As per ABS rules, the terminal (SPM or fixed heading) location should be at least three times the vessel length from the

bathymetry line of minimum allowable water depth for the largest vessels planned to use this terminal.

The safety records with SPM systems are good and guaranteed when adhering to the well documented regulations and guideline/recommendations (e.g. OCIMF). For most products that are in liquid form at ambient temperatures, the captains of carrier vessels are generally used to berth, load/offload, unberth from jetty-less systems. This is a testament to the fact that jetty-less systems are widely used for simple reasons: it works and it is cost effective (best Net Present Value for all scale projects), as summarized in below Figure 8.



Figure 8: Summary of 60 yr experience with Jetty-less solutions

Once far enough from populated areas (main selection criteria), the choice of jetty-less solution depends on the flow rate, the ability to manage Boiled-Off Gas (BOG), traffic related risks and other parameters (pressure drop, ...).

So, as illustrated in Figure 9, from a descriptive view point:

- **Segment 1:** Protected Sites - allowing fixed heading jetty-less solutions - using only floating flexible hoses. When feasible & operationally safe & good uptime, this is the simplest solution.
- **Segment 2:** Protected Sites - allowing fixed heading jetty-less solutions - using subsea pipeline. When required (i.e. segment 1 solutions not working), this could be considered but once the pipeline cost is absorbed, the remain delta cost between segment 2 and segment 3 is relatively small.
- **Segment 3: Open Sea Sites** - requiring weathervaning jetty-less solutions (SPM for Single Point Mooring). For the Liquid Ammonia, Methanol and LOHC, two types of SPM systems are available:
 - CALM terminals (Catenary Anchor Leg Mooring buoy), by default, unless not enough water depth for a submarine hose configuration or too harsh operational environment.
 - TLU Terminals (Tower Loading Unit) for more challenging projects where the CALM concept does not meet the project requirements (either harsh survival environment, safety or uptime).

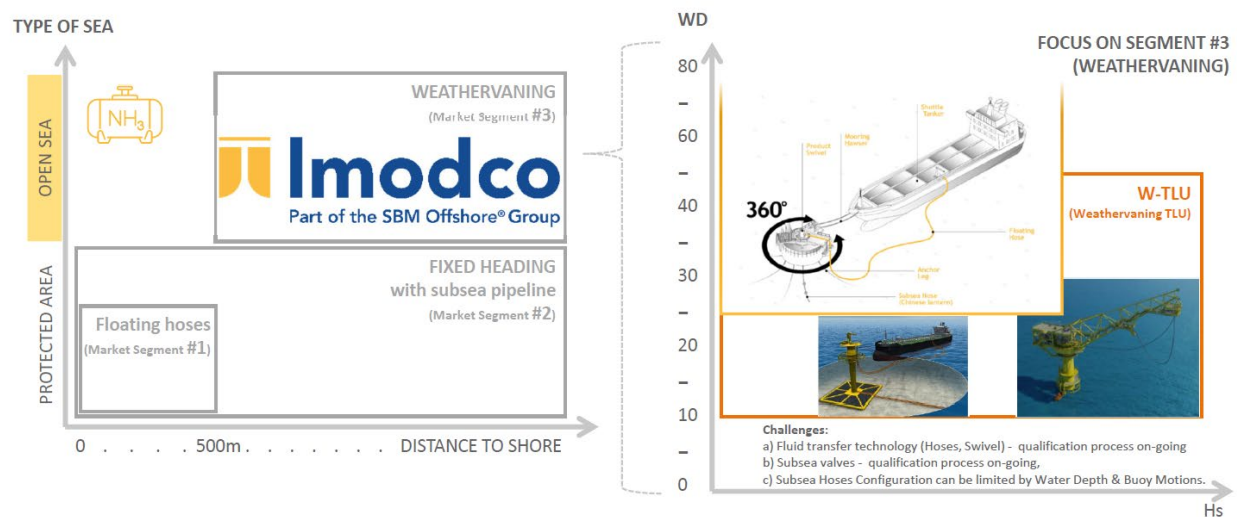


Figure 9 : Technical Segmentation for Ammonia Jetty-less solutions

3. Safety discussion: mitigations vs elimination of the main risks

As we saw in the previous sections, Ammonia shipping is not new and will increase by well over a factor 10, which from a Safety perspective calls for stepping back and revisiting what was done so far.

Ammonia is well known and as per this table comparing with other fuels, the main risk is changing of nature: more toxicity than flammability. Ammonia (NH₃) TOXICITY largely depends on concentration (ppm), duration of exposure, and individual sensitivity. From 2 ppm of NH₃, there is a unique & bad smell, which is useful for safety (especially compared to H₂ that has no smell). As further detailed in below table higher NH₃ concentrations can seriously impact health up to fatality. Ref.[4] gives detailed factsheets comparing various alternative fuels for shipping and below table about Ammonia toxicity levels:

| Substance | Health | Flammability | Reactivity |
|--------------------------------|--------|--------------|------------|
| Ammonia | 3 | 1 | 0 |
| Hydrogen | 0 | 4 | 0 |
| Gasoline | 1 | 3 | 0 |
| LPG | 1 | 4 | 0 |
| Natural Gas | 1 | 4 | 0 |
| Methanol | 1 | 3 | 0 |
| 0=No hazard ; 4=Severe hazards | | | |

FIGURE 55: AMMONIA TOXICITY EXPOSURE LEVEL

| Concentration / Time | Effects |
|--------------------------------|---|
| 10,000 ppm | Promptly lethal |
| 5,000 – 10,000 ppm | Rapidly fatal |
| 2,500 – 4,500 ppm / 30 minutes | Fatal |
| >1,500 ppm | Pulmonary oedema, coughing, laryngospasm |
| 700 – 1,500 ppm | Immediate eye and throat irritation |
| 500 ppm / 30 minutes | Upper respiratory tract irritation, watering eyes |
| 134 ppm for 5 minutes | Watering eyes, eye irritation, nasal irritation, throat irritation, chest irritation |
| 140 ppm for 2 hours | Severe irritation, need to leave the exposure area |
| 100 ppm for 2 hours | Eye and throat irritation |
| 50 – 80 ppm for 2 hours | Perceptible eye and throat |
| 20 – 50 ppm | Mild discomfort, depending on whether an individual is accustomed to smelling ammonia |

Source: Hafnia

The safety discussion for Ammonia Export/Import is therefore mainly about the risk of exposing people to toxic clouds (especially “general population” that is not aware nor trained about ammonia toxicity).

What are the scenarios leading to ammonia releases large enough to be a threat to population ? Should trained and untrained populations be considered differently ? These scenarios have now to be revisited with the new context in mind: factor 10 or more on probability of events simply because of the increase of frequency of the operations and also the size of the potential release

increases with the volume of the ammonia cargo parcel therefore the flow rate of the ship to/from shore transfers.

In other words, the efficiency of the mitigations used in the last 30 years may no longer be good enough to keep the risk level below acceptable level from a simple statistical analysis standpoint (impact of the factor 10 or more). Exhaustive studies of various plume scenarios are a “must do”.

While large rupture – as the one which took place in Chile a few years ago – can not be excluded despite all design efforts to reduce its likelihood, increased safety distance away from the potential releases is typically the soundest solution. The large release event in Chile (about 50 t in min 2 min – see below picture - Ammonia Leak Mejillones Chile - 24-Nov-2016) had no major consequences as it was enough away in open sea with favorable wind direction, the released ammonia had the space to dilute in air to non toxic concentrations and also to dissolve in sea water.

Toxic Cloud may be consequence of large (accidental) releases:

Unplanned rupture of transfer system connections (loading arm/jumper, release coupling, flanges...): At large flow rate, the release can be significant (e.g. about 50 t in 2 min in Chile: picture)

Collision between Vessels could lead to even larger release
=> Exhaustive studies of various Plume scenarios are compulsory, especially if close to populated areas or within areas with Simultaneous Operations.



The main risk is related to the connection/disconnection between the pipeline and the ammonia carriers, that is why the connection of the Ammonia transfer system to the carrier vessel necessarily has an Emergency Release Coupling (ERC) system that is either designed to release beyond a given load level (passive ERC) or to actively disconnect (powered ERC) when triggered by a position monitoring system. See next page for explanatory images gathered under Figure 10.

The purpose of such ERC is two folds: prevent from escalation of an unplanned event by protecting the asset (avoid tearing off the fluid transfer system by a controlled disconnection/weak point) and minimize the release of the inventory contained in the fluid transfer system. In unplanned disconnections, there is a release of Ammonia which has to be managed somehow.

As ammonia is highly toxic at high concentration, for ammonia transfer the key subjects are :

- How much liquid is released in such an un-planned (and rare) event ?
- Where this released liquid ammonia and associated vapor go ?

Indeed in populated areas, a small cloud of high ammonia concentration could either kill or severely harm people within an area in order of a few hundred meters – dependings on the

released amount, the weather (humidity, temperature, wind,...). In Europe, over the last 30 yr, no such catastrophic event has happened, but it is important to analyze what is behind this good track record in order to re-validate whether this will remain applicable for the coming 30 yr where the volume and/or frequency of ammonia transfer will be multiplied by at least a factor 10.

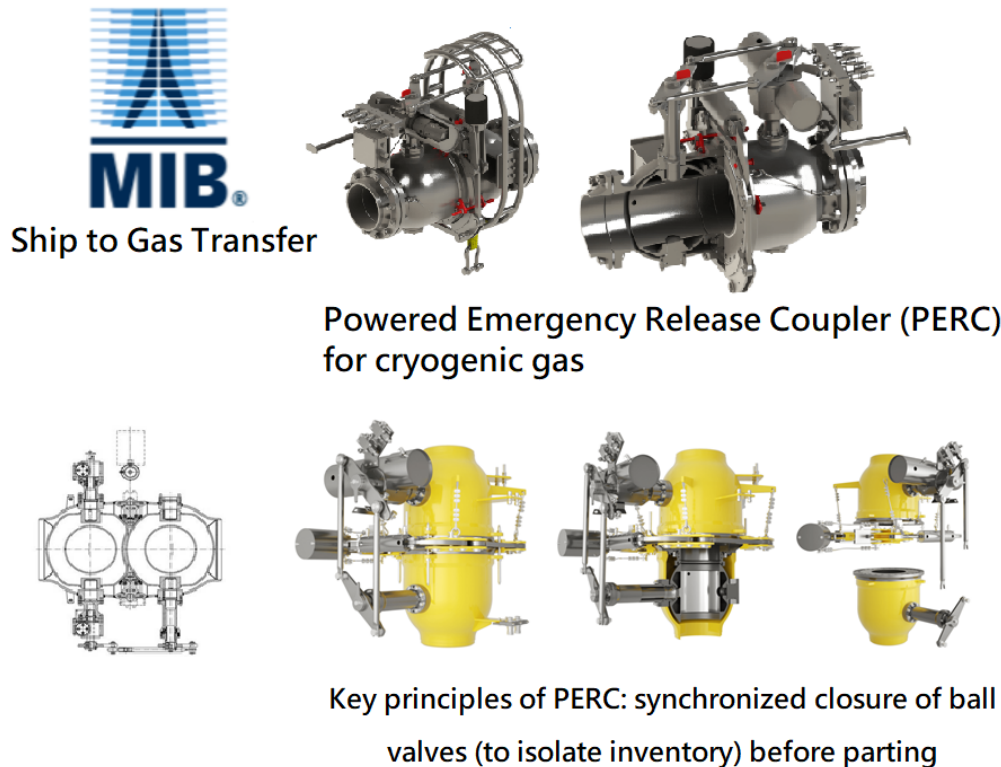


Figure 10: typical Emergency Release Couplers (ERC) – (here Powered version so PERC)

Below images are MIB courtesy: <https://www.mibitaliana.com/product-emergency-release-system/>

Typical mitigations against creation of toxic cloud:

- Strict vessel traffic management to prevent from vessel collision into Ammonia carriers.
- Minimize the released volume : in case of emergency (i.e. when no time for an automatic purge of the piping to a safe location) typically the volume contained between the two ball valves that are automatically closed during the release – this is proportional to the square of the valve diameter. MIB have developed a (P)ERC design that minimizes this volume. (bottom image in figure 10)
- Water spray: to mix the liquid ammonia with water this minimize the formation of toxic cloud. The resulting contaminated water is drained to avoid dumping it into the harbor water.
- Exclusion zone during ammonia transfer: stop all activities within a safety/exclusion zone (dependent on project conditions) of several hundreds of meter. In busy ports, this operational mitigation can be a severe constraint for the surrounding businesses.

As illustrated in Figure 11, the principle of inherently safer design is to first try to eliminate the identified risk before to mitigate it.

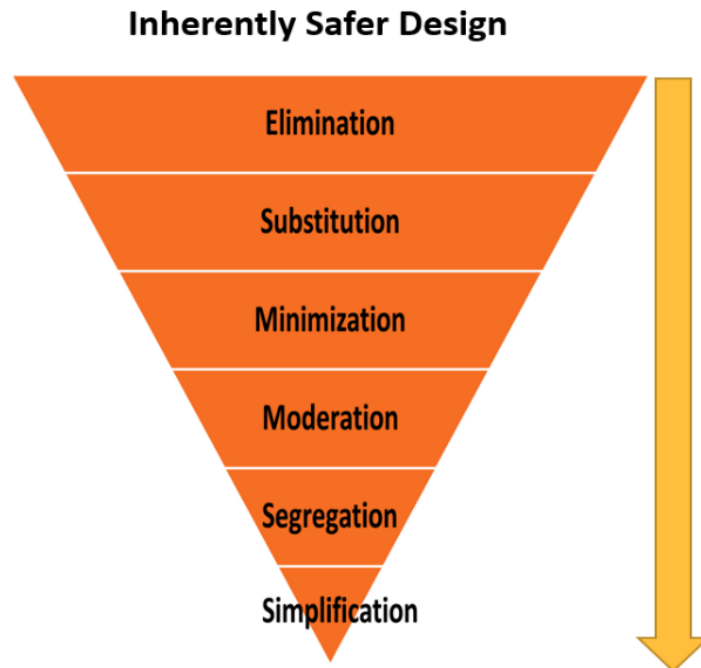


Figure 11: the principle of safety in design

This principle also applies in the project definition, as illustrated in Figure 12, the operational safety performance is drastically impacted by the concept selection and further project definition: despite best operational efforts, a sub-optimal concept cannot lead to the best safety performance of the optimum concept selection.

Figure 12 illustrates the relative safety performance of the same project with 4 scenarios splitted in two cases:

the red curve: the main risks are only mitigated as concept level.

the blue curve: the main risks are eliminated as concept level.

For instance, the risk of a toxic cloud in populated area can be minimized using the above proposed mitigations (the red curve in Figure 12) or eliminated using a SPM terminal in open sea (the blue curve in Figure 12).

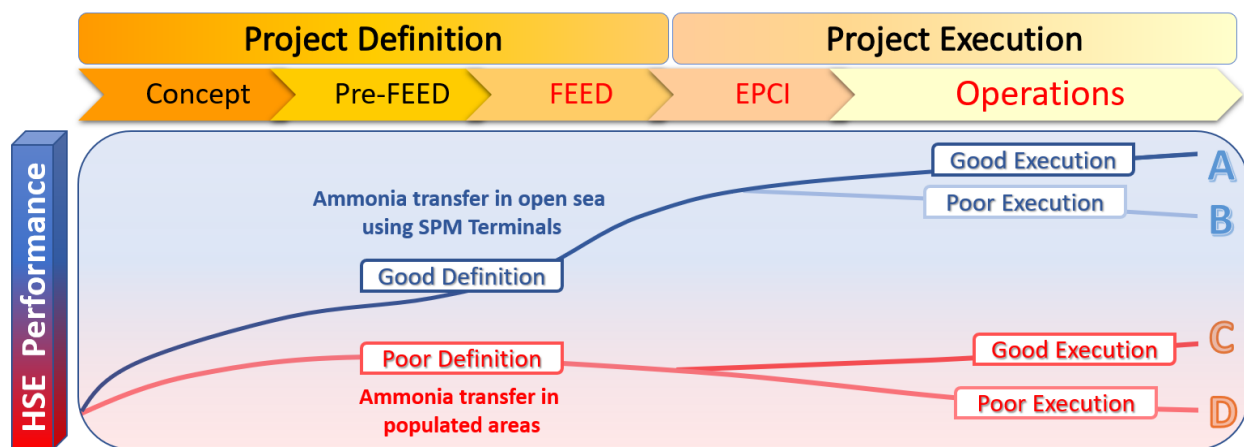


Figure 12: Safety in Design from project concept to delivery – impact on operations

For large and frequent ammonia transfers, therefore with a higher likelihood of an unplanned disconnection and therefore release of ammonia, it is recommended to make at concept selection the decision to eliminate (instead of minimizing) the risk of a toxic cloud in populated area by moving offshore – in open sea - the operations of connecting to and disconnecting the carrier to the fluid transfer system. Also, a contribution factor is the wider forum of personels & crews involved in Ammonia transfers among which the proper training level may no longer be as uniformly high enough as it used to be over the last 30 years without accidents: this is typically the possible degradation from good to poor execution, as illustrated in Figure 12.

4. Overall picture - Insurer's & Investor's perspectives - balancing investment and return on investment while addressing safety dimensions

The section lists the key subjects/questions to address when making the concept decision for projects which will eventually rely on large and frequent ammonia export for their economics.

Project Economics: how important is the Ammonia export revenue stream ? if it had to stop along the project life, what would be the impacts ?

Below we only address the reasons of why the Ammonia export could be either stopped or at least significantly less than planned, assuming the “red curve” scenario of Figure 12 (the main risks are only mitigated instead of eliminated). A few scenarios are considered, where SIMOPS stands for management of Simultaneous Operations:

- a. The main mitigation is at SIMOPS level: SIMOPS stands for Simultaneous Operations management defining what operations can be carried in parallel or not. During an Ammonia transfer operation, all activities within the design/original safety/exclusion zone are stopped. Either the *port activities are picking up* and this constraint becomes so large that the arbitration turns in favor of reducing the frequency and/or duration of the Ammonia exports, hence overall a significant reduction of the associated revenue.
- a. The main mitigation is at SIMOPS level: all activities within the design/original safety/exclusion zone are stopped during an Ammonia transfer operation. Unfortunately, for some reasons, there has been an event where the release of Ammonia was larger/longer than assumed in the definition of the safety/exclusion zone. As a consequence,
 - at the best, there was no victim, but the safety/exclusion zone has been increased impacting more activities, and similarly to above scenario a), the arbitration results in significant reduction of the ammonia revenue for the project.
 - at the worse case, there has been victims, in addition to above the project is now facing major legal and financial issues.
 - If the project economics require the highest protection of the ammonia export revenues, then such a project should make the choice at concept selection to eliminate the risks associated with ammonia transfer in populated area: shift away that risk offshore, in open sea, using SPM terminals (the “blue curve” scenario of Figure 12).

Project Economics: how important are the Ammonia storage and transportation costs ?

- a. what is the optimum ammonia carrier size, what would be the impacts ? Economy of scale typically calls for larger cargo, within the SPM terminal concept, the ammonia carrier size/length has no limitation: indeed being offshore, the jetty-less systems can easily be adapted to any carrier sizes: either designing a stronger mooring capacity during the project definition or reducing the operational conditions when receiving larger carrier sizes than originally planned.
- b. Part of the transportation costs, especially for large volume and/or high frequency of using the loading or offloading infrastructure, the reduction of port calls and optimization of sailing durations - both resulting from the jetty-less terminal concept decision - can significantly improve the overall project economics, leading to better return on investments.
- c. Finally, once the concept decision of keeping offshore the ammonia carriers, the project economics can be further optimized by evaluating the next conceptual decision: Onshore vs Floating Storage. Indeed, depending on the project characteristics, the floating storage unit (FSU) can enable the economics of the first phase of a large and/or challenging project by enabling earlier revenue thanks to shorter permitting (e.g. lack of space onshore for storage), easier implementation (e.g. smaller pipeline system, easier to install). The later and larger phase of such projects may either increase the FSU size or eventually implement onshore storage with a SPM terminal. In such a scenario, the FSU can be leased - instead of bought – just for that phase of the project, the FSU pipeline can either be recovered or used a vapor return line for the phase 2 SPM terminal.

Public perception and future of ammonia as clean and/or green fuel:

In case of major problem on one project consequence on other projects may lead be:

- Increase of insurance premium
- Longer permitting process (or worse: permit not granted) due to “Not In My Back Yard” push-back (the so-called “NIMBY effect”).

Impact on environment:

While it is clear that going offshore eliminates the risk of a toxic cloud in populated area, one could ask whether this would increase the overall risk to the environment:

- Ammonia release within “closed” water of a port: while the release amount can be probably better reduced (e.g. shorter flexible hoses) the dilution will be less effective.

- Ammonia release in open sea: while lacking of scientific data so far, it is known ammonia dilutes well in water therefore the relative concentration will quickly reduce to level below long term severe impact. According to EDF study comparing to oil (for which there is 60 yr of SPM operational experience and which ammonia would attempt to progressively replace as a fuel), the impact on environment is globally similar to Marine Gas Oil but it is lower in “deep sea” in other words in “open sea” - see Figure 13.

Source: [Environmental Defense Fund \(EDF\), LR, and Ricardo launch report examining ecological impact of ammonia as a shipping fuel across diverse habitats and receptors | Environmental Defense Fund \(edf.org\)](#)

<< A joint study released by Environmental Defense Fund (EDF), Lloyd’s Register (LR) and Ricardo PLC, examines the potential marine environmental impacts of ammonia spills during its use as a shipping fuel. Ammonia generated from renewable energy is considered a sustainable alternative to fossil fuels as the shipping industry decarbonises.>>

Table 15 Summary of comparison of ammonia with marine gas oil for environments

| Habitat | Ammonia | MGO |
|----------------|---------------|---------------|
| Rivers | Medium Impact | High Impact |
| Wetlands | High Impact | High Impact |
| Estuaries | High Impact | High Impact |
| Coastal Waters | High Impact | High Impact |
| Coral reefs | High Impact | High Impact |
| Mangroves | High Impact | High Impact |
| Deep sea | Low Impact | Medium Impact |
| Polar regions | Low Impact | High Impact |

Key

| | |
|---------------|---------------|
| Low Impact | Low Impact |
| Medium Impact | Medium Impact |
| High Impact | High Impact |

Figure 13: extract from EDF report comparing impact of Ammonia vs Marine Gas Oil

Summary and Conclusions

The pitch of this paper is to look at the overall Health, Safety, Security and Environment (HSSE) impacts of Ammonia transfers from/to carrier vessels.

Organized in four chapters, this paper has consolidated input from various stakeholders of the Ammonia value chain to make the following conclusions:

1. The macro economical aspect: the traded volumes of shipped Ammonia will at least grow by factor 10 or more in the coming 30 years.
2. The technical aspect: various technologies for Ammonia transfer are well known, the key subject is “where is the transfer performed ?”:
 - a. Within populated areas such as ports – mitigating the risks related to high toxicity of Ammonia.
 - Or
 - b. Offshore – using SPM terminals – being qualified for Ammonia application – eliminating the risks, shifting them away from populated areas
3. The safety discussions reviewing the main risks and their elimination vs mitigations. The order of magnitude change in volume and frequency of Ammonia transfers calls for changing paradigm from risk mitigation to risk elimination.
4. The overall picture from insurer’s and investor’s perspectives - which aims at a wise balancing between investment and return on investment addressing safety dimensions – confirms and gives business back-up to this strong recommendation – for large Ammonia export and import projects - to use SPM terminals enabling Ammonia transfers offshore away from populated areas.

The overarching conclusion: in a similar way than for Oil shipping, the Ammonia SPM terminals transfer systems will be a key contributor to the Hydrogen Economy & Strategy by enabling safe and cost effective infrastructure for ammonia transfer in open sea. Consequently, further work has started to adapt and recommend good practices and regulations for transfer of Ammonia in open sea, using SPM terminals, which will be relevant to many of the future exporting Clean and/or Green Hydrogen projects.

As opening, the jetty-less terminals can also be a jetty-less Floating Storage Unit (FSU) enabling to further optimize the economics of ammonia export/import projects.

This paper was presented at Green Hydrogen Summit Oman (GHSO) in Dec-24, ref.[6].

ACKNOWLEDGEMENTS

The authors would like to thank Imodco and SBM Offshore for permission to publish this paper.

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Ref.[4] – BV white paper – Alternative fuels outlook for shipping – Sept-2022

Ref.[5] - Environmental Defense Fund (EDF), LR, and Ricardo : “Ammonia at sea: studying the potential impact of Ammonia as shipping fuel on marine ecosystems”

Ref.[6] – Imodco presentation at Tech2 Talks of Green Hydrogen Summit Oman – Dec-2023