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Advancing safety and economics in the global ammonia trade – A focus on open sea terminals and floating storage

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ABSTRACT

The urgency of achieving global decarbonization demands innovative strategies, particularly within the emerging Clean Hydrogen Economy. A pivotal facet of this transformation lies in the projected tenfold surge in ammonia trading through maritime routes in the forthcoming decades. This paper proposes a critical examination of safety concerns and economic implications associated with this evolving trend.

Firstly, the safety implications of ammonia trading are scrutinized, given its notorious toxicity, emphasizing the significant risks during storage and transfer, particularly in densely populated or high-traffic regions such as busy ports. This analysis strongly advocates for conducting these operations at a safe distance from such areas to effectively eliminate - instead of mitigating - potential risks.

Addressing the economic aspect, the challenges of establishing new ports or jetties for large-scale ammonia trading are reviewed. Traditionally capital-intensive and hindered by protracted permitting processes, a paradigm shift towards open sea terminals is proposed. These not only enhance safety by distancing from populated areas but also present a cost-effective alternative to conventional port infrastructure.

In the context of Ammonia Export and Import, various scenarios are closely examined, including import parcel sizes, frequency, environmental considerations, and traffic proximities. Special emphasis is placed on open sea solutions, highlighting their inherent safety and economic benefits. Leveraging proven technologies from the oil and gas industry, these solutions facilitate fluid cargo transfer in open waters, eliminating the need for new harbors or expensive jetties.

The paper features two case studies, illustrating ammonia export challenges with extended pipelines due to flat bathymetry and import complexities in highly populated areas with onshore storage limitations. Introducing the Floating Storage Terminals concept as a flexible solution for selected Ammonia Export and Import projects aligns with the Inherently Safer concept, offering advantages such as reduced permitting time, enhanced project economics through lower capital expenditures, and expedited delivery.

In conclusion, as the global community moves toward decarbonization, the paper underscores the key role of innovative trading solutions for commodities like ammonia. By employing existing technologies, safer and more economically viable approaches are advocated, emphasizing the ongoing need for innovation and collaboration in this crucial field.

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.
This paper is following up on our white paper "Ammonia Shipping : what is new ?", ref.[1], that gives the main elements that will change between the past 30yr and the coming next 30 yr. From the economic and then technical standpoints with safety as the redline, ultimately the larger use of ammonia is for the sake of better world: safer & less carbonated.

To help industry decision-makers to foster the energy transition, the focus of this paper, still centered on the transfer of Ammonia from/to the carrier to/from the shore (export or import), but now show casing the overall cost optimization of the value chain with larger battery limits. The concept of "virtual pipeline – from production (excluded) to consumption (excluded) – introduces the notion of tariff. The tariff is the minimum revenue in USD per ton of ammonia that amortizes the various pieces of infrastructure over the project duration - i.e. integrating all the cost elements to compare the economic performance of the various concepts that guarantee the safety, the non-negotiable element of each project.
Organized in four chapters, this paper ambitions to consolidate the main relevant input from the various stakeholders of the Ammonia value chain.

1. The battery limits of the "virtual pipeline" to be optimized from project economics perspective: identify the key drivers and their interaction in terms of sizing therefore economics.
2. The technical aspect: various concepts and technologies for Ammonia transfer.
3. The two specific case studies.
4. The overall picture from off-taker's, insurer's and investor's perspectives which aims at a wise balancing between investment and return on investment addressing safety dimensions. This updates and adds to section 4 of ref.[1].

The overarching conclusion is given as summary of all these elements illustrating the main point: Ammonia jetty-less terminals transfer systems will be a key contributor to the Hydrogen Economy & Strategy by enabling safe and cost-effective infrastructure for ammonia transfer in off-the-shore with minimum impact infrastructure.

1. the “virtual pipeline” battery limits: key drivers for project economics

As explained in ref.[1], figures 1 to 3, the shipping of Ammonia is not new but will increase by an order of magnitude - say by potentially a factor 20 - in the coming decades. The Ammonia carriers cargo capacity will increase by a factor 4 to 5, so the flow rate during loading or offloading, consequently the leak size and resulting toxic cloud in case of accident. The frequency of loading or offloading will also increase potentially by similar factors, consequently the end probabilty of accident/leaks. Figure 1 illustrates the net effect of these increases the Quantitative Risk Assessment (QRA) that is required to demonstrate that populated area are not within the reach of a toxic cloud. Indeed the “population” is defined by people who are not trained to react properly if exposed to ammonia released in the atmosphere. A factor 10 on the through put of an existing ammonia terminal – say from 0.1 to 1 MTPA (Million Ton Per Annum) – due to larger leak size and higher frequencies (leading to more severe scenarios: e.g. stronger wind and/or in more rare wind direction) the extend of the toxic cloud could now reach populated area. Consequently a terminal that suited for 0.1 MTPA ammonia through put may no longer be suited for a 1 MTPA through put. A solution to such a problem is to increase the distance of the most likely source of the leak (connection at the midship manifold of the ammonia carrier) – this can be achieve in cost effective way by using jetty-less solutions – which will be listed in the next section.

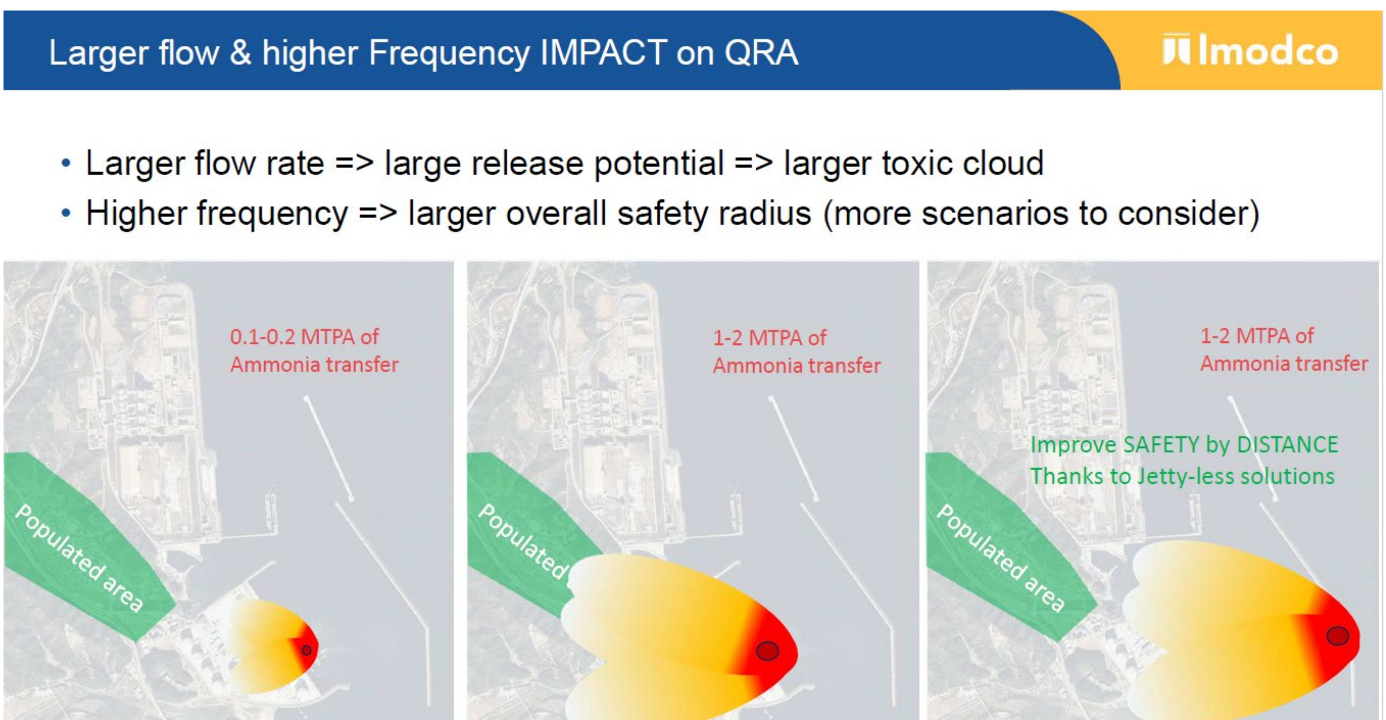

Figure 1: impact of a factor 10 in through put on Quantitative Risk Assessment (QRA)

For more detailed discussion on safety, please refer to section 3 of ref.[1]. In Summary, ammonia is highly toxic at high concentration, therefore for ammonia transfer the key subjects are :

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

A cloud of high ammonia concentration could either kill or severily harm people within an area in order of a few hundred meters (up to km – see Figure 2) – dependings on the released amount, the weather (humidity, temperature, wind,…).

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 (see Figure 2 - Ammonia Leak Mejillones Chile) 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 – thanks to 2 facts:

- Sufficient distance off-the-shore
- Wind blowing in the good direction.

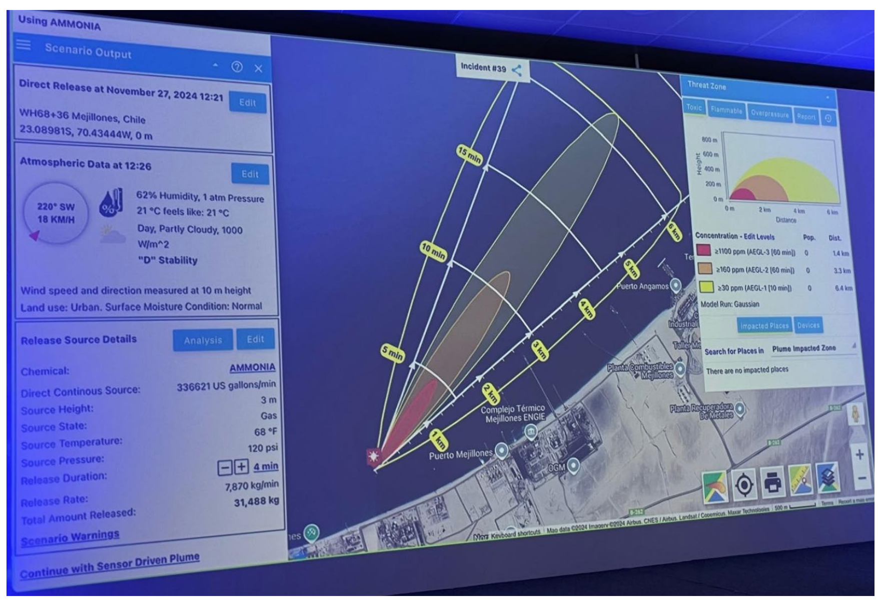

Figure 2: reach of cloud from Mejillones Ammonia release – the show case of safety QRA

Safety QRA (Quantitative Risk Assessment) studies are compulsory to identify and evaluate the possible scenarions of Toxic Cloud consequent to large (accidental) releases:

- Unplanned rupture of transfer system connections (loading arm/jumper, release coupling, flanges...): At large flow rate, the release can be significant
- 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.

Once the Safety requirements are well established, the optimization of the project economics should be carried out with the overall picture – battery limits, as futher explained below.
Figure 3 illustrates the low carbon energy transport for long haul distances which calls for ammonia shipping. The analogy of "virtual pipeline" is used mainly to introduce the notion of "Tariff" which is the revenue - in USD / ton of Ammonia using the pieces of infracture required to transport the ammonia from the production (excluded) to the consumption (excluded) - to amortize the overall system (break even of the NPV for a given through put in MTPA over a number of years with a given Internal Rate of Return). This overview is particularly relevant for the new uses of Ammonia as carrier of low carbon energy, typically produced far away from where it will be consumed. Indeed the transportation cost adds to the production cost but can be optimized independtly from the production cost. The main parameters are distance and throughput (MTPA) which drives the selection of the Ammonia carrier size for the project. All the pieces of infrastructure are sized against the cargo capacity of the offtaker ammonia carrier:

- the storage capacity is typically 1.5 times the offtaker capacity,
- the pipeline between storage and offtaker carrier is sized for the flow to transfer the offtake cargo in typically 24 hr
- the quay, Jetty or jetty-less system is also sized agains the size of the offtaker carrier.

Consequently, once the various concepts (quay/jetty/jetty-less) are screen against safety considerations (as illustrated in Figure 1), the next criteria for the "best for project" concept selection is the economic KPI (Key Performance Indicator) of the tariff in USD/ton of ammonia transported from production (excluded) to consumption (excluded).

Figure 3: recommended battery limits to optimize the ammonia value chain

In the future, new ammonia production site could also be Floating Production Storage and Offloading (FPSO) platform. In such a case the battery limit is modified to account for the fact that Storage and Offloading functionalities are integrated. Figure 4 shows the SBM Offshore concept for Ammonia FPSO described in Ref.[2].

Figure 4: Ammonia FPSO concept (courtesy of SBM Offshore)

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. The various concepts and technologies for Ammonia transfer

Over the last 30 yr, Ammonia cargo transfer has almost exclusively been performed in habors, 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 5: Ammonia Carrier at quay side

Note (1): one of the perceived size constraints for the future ammonia carriers is the existing quay side lengths and availability, this constraint disappears once the jetty-less terminal concept decision is made as these can be designed to any size of vessels.

Existing ports/jetties may have buzy traffic/actitivies, port authorities may also see the possibility of jetty-less systems as an opportunity to extend their business while overcoming these practical and physical limitations.

Jetty-less systems with ONSHORE Storage:

Figure 6 illustratesthe principle of ONSHORE Storageconnected via a subsea pipeline to jetty or jetty-less terminal. Figure 7 shows the evolution of terminals from jetty to jetty-less: reducing Life Cycle Cost while increasing Uptime thanks to the weathervaning functionality.

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 65 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.

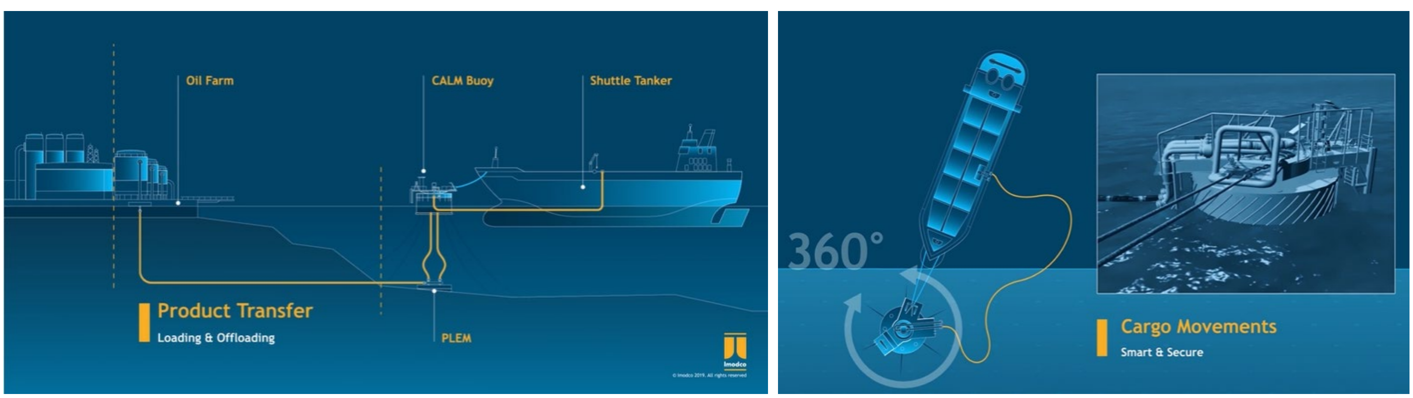

Figure 6: Typical architecture of CALM terminal (Single Point Mooring – SPM)

As illustrated in Figure 6, 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)](https://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 guarantied when adhering to the well documented regulations and guideline/recommendations (e.g. OCIMF – ref.[6]). 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 6.

Figure 7: 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, …).

Regarding qualification of the well known concepts for the new application “ammonia transfer”: Imodco has completed Ammonia swivel qualification and are validated subsea Ammonia ESDV. Compared to jetty, the Jetty-less solutions requiring longer and more dynamic ammonia hoses (being qualified by Trelleborg and Continental Industry/Contitech): qualification certificate will be available by end of 2025.

The technical segmentation of the jetty-less offering is has two main families of concepts:

- **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 – in most scenarios - the best, safety wise, as further away from populated areas: the ammonia cargo transfer being performed in open sea.

So, as illustrated in Figure 8, from a descriptive view point:

- Segment 1: Protected Sites - allowing <u>fixed heading jetty-less solutions</u> - using <u>only floating flexible hoses</u>. When feasible & operationally safe & good uptime, this is the simplest solution.

- Segment 2: Protected Sites - allowing <u>fixed heading jetty-less solutions</u> - using <u>subsea pipeline</u>. 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 <u>weathervaning jetty-less solutions</u> (SPM for <u>Single Point Mooring</u>). 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).

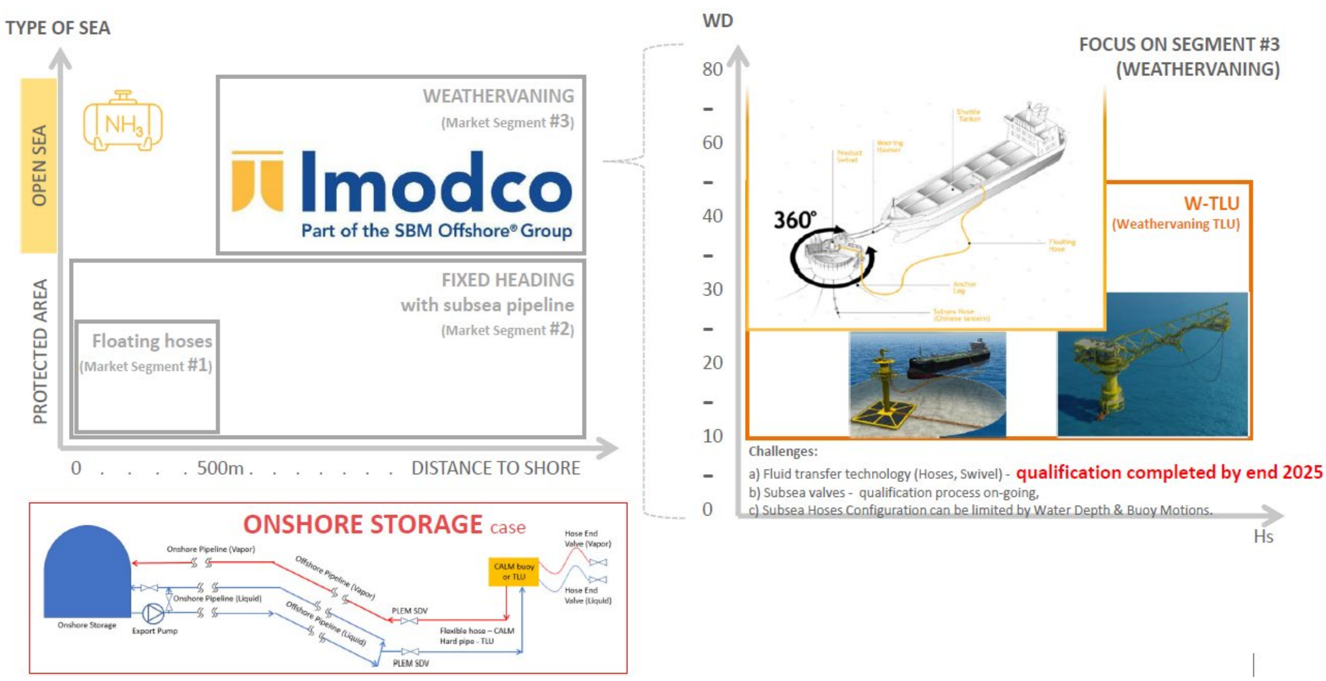

Figure 8 : Technical Segmentation for Ammonia Jetty-less solutions with ONSHORE Storage

<u>Jetty-less systems with OFF-the-SHORE Floating Storage:</u>

There are **3 typical motivations for FSO** (Floating Storage & Offloading terminal)**:**

- **<u>Flow Assurance :</u>** cost of pipeline and pumping & cooling system.

  Large Ammonia cargos need to arrive in the Ammonia carrier tanks within the temperature specification of the tanks (close to -33deg.C). If/when the ammonia arrival temperature is too high, three options:
  - either reduce the flow so that the required cooling remains within the capacity of the offtaker ammonia carrier (sized as a minimum to compensate the heat ingress of its tanks during sailing).
  - Or have a vapor return line to send back to shore the heat (in form of vapor) that cannot be managed onboard the offtaker when loading at full flow.
  - Or anticipate the heat ingress by sub cooling the ammonia below target arrival temperature so that the anticipated temperature increase is managed upstream.

  As explained above and illustrated in Figure 9, in the case of onshore storage, the system (from storage, cooling, pumping and pipeline) needs to be sized so that the heat ingress in that system is overall compensated. For long pipeline length, the heat ingress may lead to large CAPEX and OPEX that may result in non economical tariff, especially if the through put is too low to amortize a large CAPEX. Indeed projects with modest through put will typically favor a project financial profile with less CAPEX and more OPEX that can be made more proportional to the the through put.

  The second case study given in section 3 illustrates such a project scenario where the FSO (floating storage) enables the project economics by reducing drastically the CAPEX associated to the onshore storage.

  This CAPEX and OPEX optimization is project specific and driven by pipeline length, ambiant temperature, flow rate (derived from offtaker carrier size, derived from overall project through put/production and distance between production and consumption) …

  In contrast, for ammonia export projects with long pipeline, the FSO solution reduces drastically the pipeline, pumping and cooling system costs (CAPEX & OPEX) as the ammonia is cooled down onboard the FSO (no need for pipeline insulation and no need for pipeline recirculation line) and the pipeline is sized just for the project production (114 t/hr corresponds to about 1 MPTA) typically an order of magnitude (factor 10) less than the flow rate in the onshore storage case.

  In between offloading, the pipeline inventory is kept cold thanks to a recirculation loop to avoid demurrage on the visiting carrier (due to the time it would take to cool down such a large inventory). In the case of FSO, there is only one small pipeline for the continous flow of ammonia production that will be cooled down onboard.

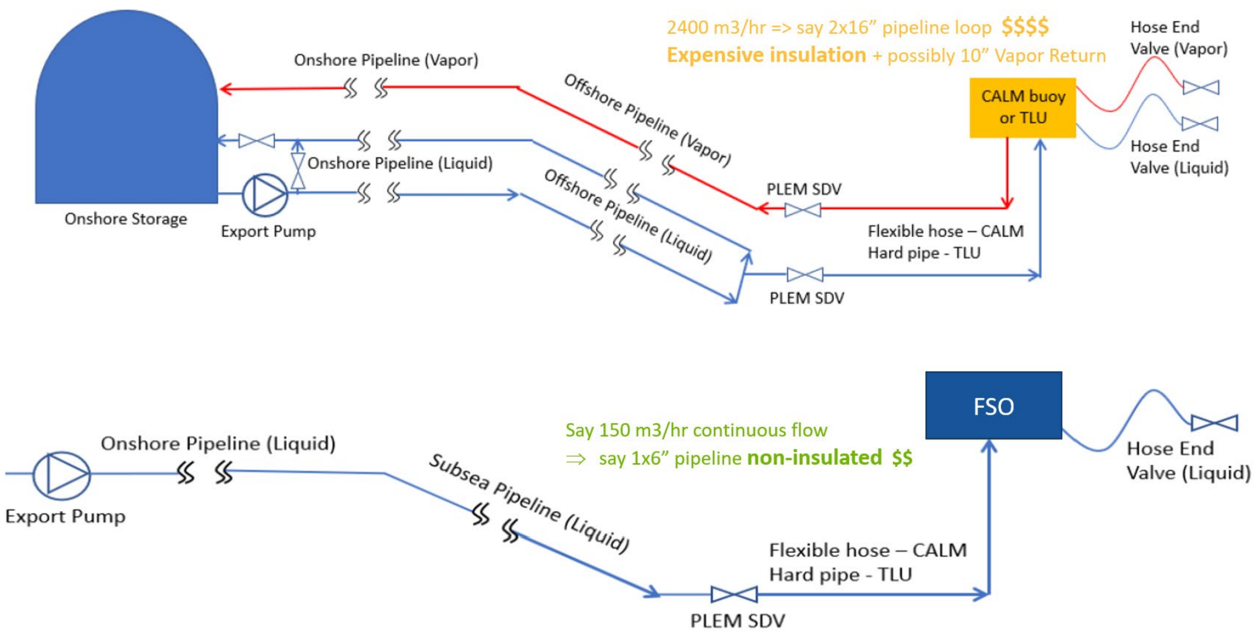

Figure 9 : Comparative Cold Gas Flow Assurance scenarios : onshore vs floating storage

- **Lack of Space onshore :** either congested areas or too close to population (see Figure 1), typically such scenario may be on the import side of value chain, for example in Korea or in Japan. In such a case, the likely relevant concept is a FSO located in spot that is:
  - Either Protected by an existing breakwater (as illustrated in Figure 1 and Figure 10), where the footprint of the mooring system is important to avoid interference with existing trafic/activities. The proposed Short Footprint Buoy Mooring (SFBM) system has a minimum footprint (the length of the FSO veseel plus say 40 m in front and astern) with the ability to receive visiting carriers in side-by-side (to either offload or refill a FSO, or refill a FSRU). In Figure 11, the footprint comparison between shallow water spread mooring system (which mooring lines could interfer with passing by vessels therefore the need for a large exclusion zone) and SFBM.
  - Or in open sea, where the environment can come from any direction typically requiring a weather-vaning FSO to minimize mooring loads and maximize operational uptime - especially for loading or ofloading that can be then

performed in tandem as illustrated in Figure 12.

- **Project Phasing / de-risking :** reduce initial CAPEX until project development phases are better known/validated, the OPEX side (main element is the lease rate of the FSO) can be adjusted to the phased production rate as in both cases weather-vaning or fixed heading FSO, the same jetty-less system can be designed to receive first a small FSO and then later a lager one. This project flexibility may reduce the risk profile of the project and therefore enable the Final Investment Decision (FID) at least of the first phase of the project. Then the project have some revenue in order further optimize the second phase – overall this improves the project economics, public perception and permitting.

As explained above, the use of FSO can help the economics or permtitting of some projects. In terms of qualification of the jetty-less systems, the same technology bricks are used than for CALM terminals: flexible hoses, ESDV, Swivels,… In addition, from a vessel operation perspective, as Liquid ammonia and LPG are similar in density and temperature, the relevant experience is LPG FSO which are in production for over few decades (e.g. N'Kossa LPG FSO operates since Nov-1996). Liquid ammonia and LPG being similar in terms of density and temperature, one third the LPG carriers can be used as Ammonia carriers, these vessels could be used as Ammonia FSO.

Figure 10 : Fixed heading jetty-less system for DIRECTIONAL environment or PROTECTED site

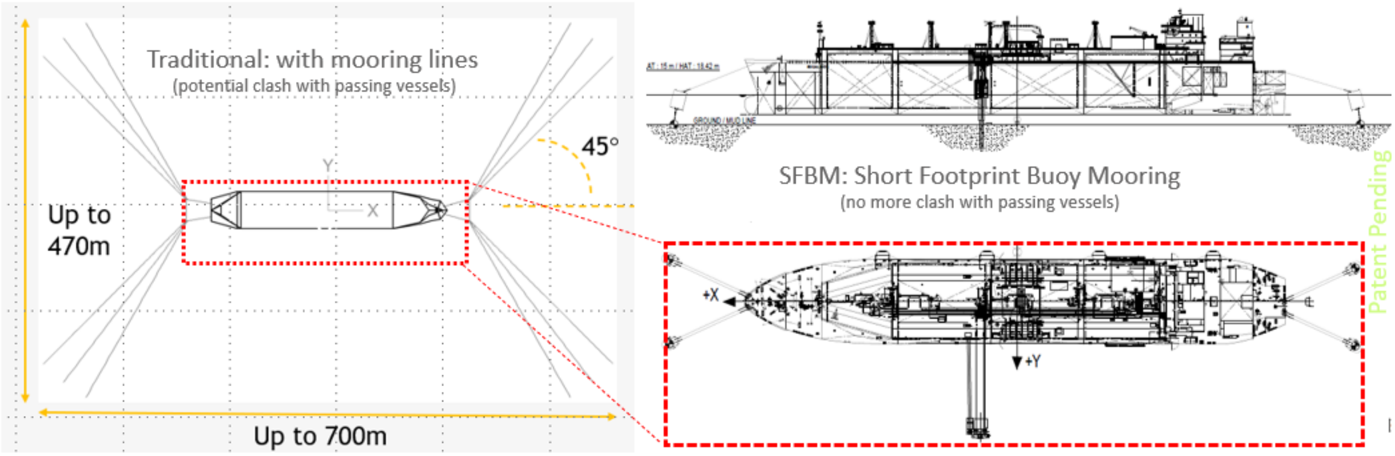

Figure 11 : Fixed heading jetty-less system FOOTPRINT comparison: mooring lines vs SFBM

Figure 12 : weathervaning jetty-less system for OMNIDIRECTIONAL environment in open sea

3. The two specific case studies

Two cases studies both using the logic that Safety requirements are not negotiable, the economic performance should be compared only between concepts enabling similar safety level, at least at the minimum required (ALARP).

- CBM vs CALM for large ammonia cargo transfer: the Oman case. Actually, the two systems are not at the same safety level (CBM has lower System Integrity Level than CALM + a more complex marine operations), so the economic comparison should not even be necessary. The case study is to demonstrate small CAPEX saving may be a sub-optimal decision in the overall economics.
- Onshore Storage vs FSO: the North Brazil case illustrates the scenario of a long pipeline where the FSO concept improves significantly the project economics.

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

Referring to section 4 of ref.[1], the importance of the ammonia carrier size selection is the starting point of the optimization of logistics economics.

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 transporation 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. In the previous section, the 3 potential motivations for FSO were detailed.

3.1 CBM vs CALM for large ammonia cargo transfer: the Oman case

In Oman, less than 9 months weather conditions could be seen as compatible with the fixed concept called CBM (Conventional Buoy Mooring) which - at first glance – looks attractive by it relative simplicity. But looking closer the CBM concept is not at the same System Integrity Level (SIL) for the control of the subsea valves on the PLEM (PipeLine End Manifold that interfaces the subsea pipeline and the submarine hose configuration. The control system reliability is important for safety, if any issue in the subsea configuration, the ESDV (Emergency Shut Down Valves) will isolate the pipeline inventory from the issue/leak. In addition, in case of cold gas such as ammonia these PLEM valves need to be activated a few times per loading operations. The operations can be controlled and activitated via a short umbilical (with minimum response time and high reliability) from the CALM buoy instead of via a long and exposed umbilical to shore in the case of a CBM (with longer response time and lower reliability).

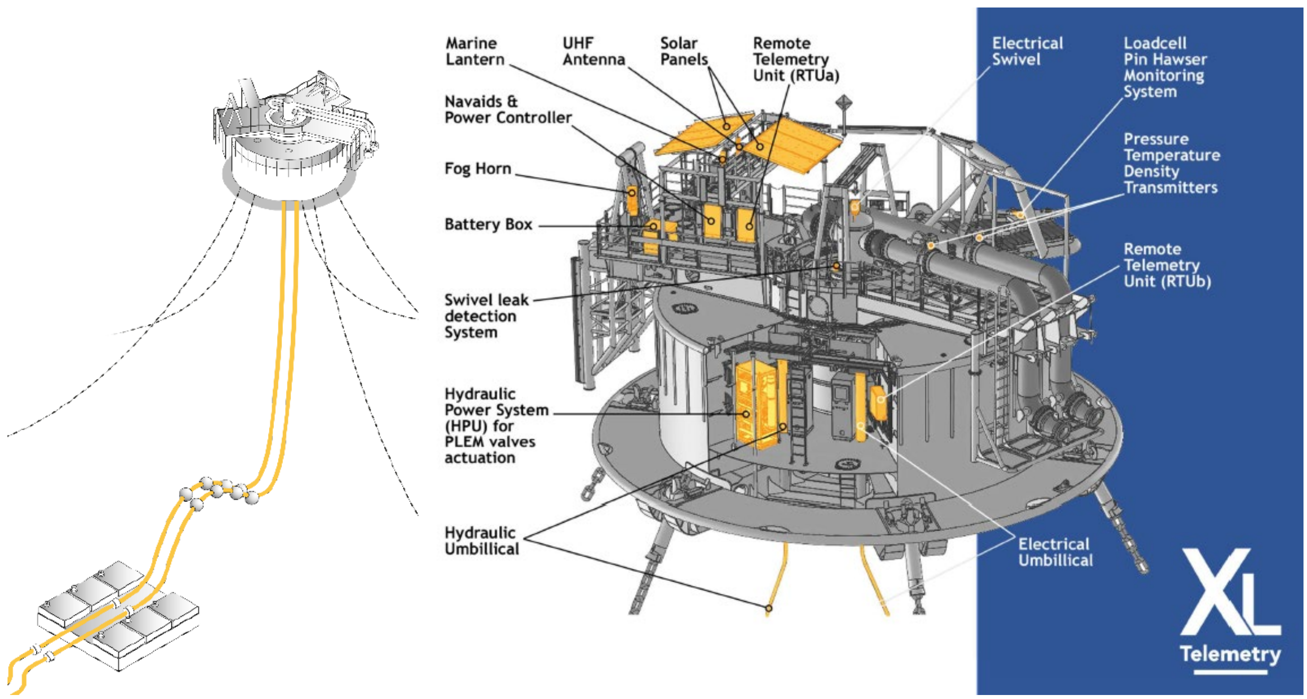

Figure 13: High System Integry Level (SIL) of telemetry/control hosted on CALM buoy

To compensate for the lower SIL, the ESDV on SBM PLEM can be of “Fail Safe” design in case of any issue along the few km long umbical up to the onshore control room. In case of failure, the overall export terminal will be down for potentially a long period of time – the time to search, find the issue and then fix it along the few km long control umbilical, either burried or below protection matresses (difficult access for repair).

The other issue with selecting the CBM concept in Oman is the need for 2 off Azimuthal Stern Drive (ASD) Tugs to assist the CBM connection operations during the Khareef season. The availability of these tugs was not confirmed by brokers, so this implies large mobilization costs, which according to estimates from the same broker would match in value the delta CAPEX between CALM and CBM. The CALM marine operations are intrinsiquely safer therefore do not need such high spec tugs, hence a large OPEX relative saving resulting in overall lower USD/t of ammonia to be safely exported. Figures 14 and 15 illustrates the above comparison of CAPEX, OPEX and resulting Tariff.

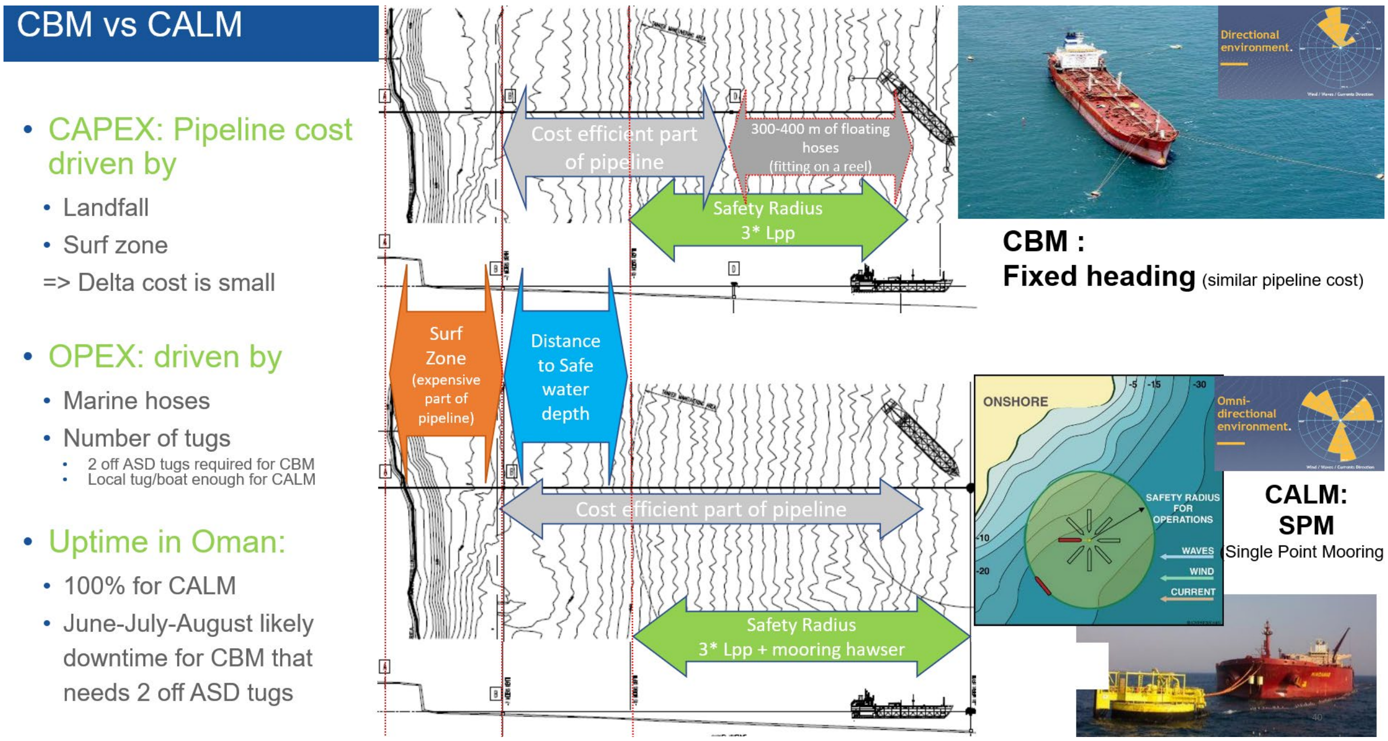

Figure 14: CBM vs CALM – pipeline cost comparison: relatively small delta CAPEX

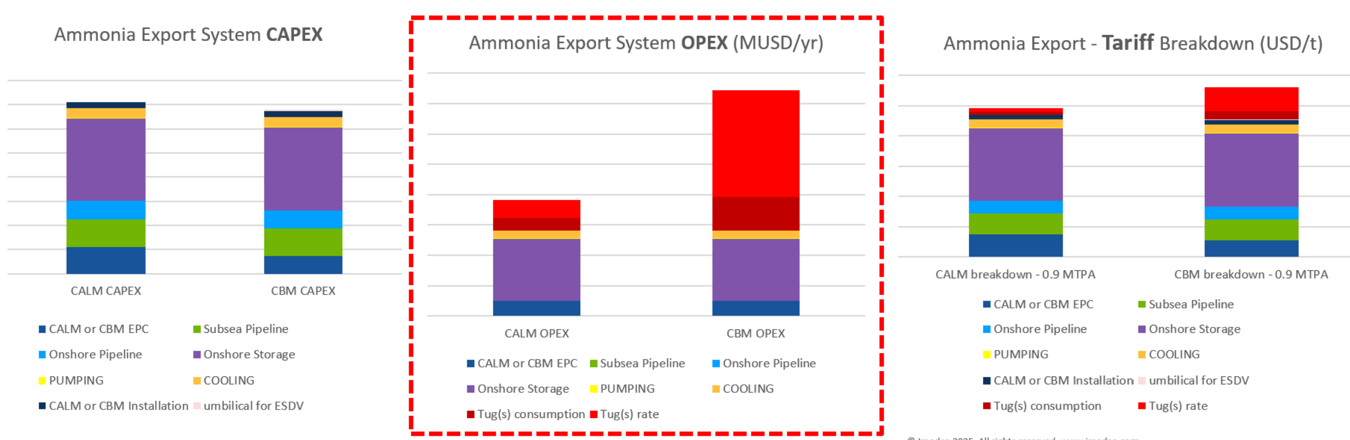

Figure 15: CBM vs CALM – economics comparison (with high ASD tug mobilization cost)

3.2 - Onshore Storage vs FSO: scenario with long pipeline that favors FSO

In northern Brazil, a large green ammonia project is facing the issue of flat bathymetry resulting in the need to have about 25 to 30 km of pipeline to reach sufficient water depth to receive the deep draft ammonia carriers that will collect the ammonia produced for export. As illustrated in Figure 9, the Flow Assurance largely influence the project economics that impacted by above budget CAPEX and the significant amount of energy (OPEX) wasted to compensate the various sources of heat ingress: heat from the pumps to push the ammonia against the pressure drop induced by friction along the pipeline and the heat still passing through the thick insulation. Sizing the system (storage, pumping, cooling, pipeline diameter and insulation and resulting energy consumption) so that the Ammonia is within the offtaker carrier receiving temperature capacity at full flow, the CAPEX and OPEX are then estimated resulting a tariff comparison between "Onshore Storage with CALM" vs "FSO" shown in Figure 16.

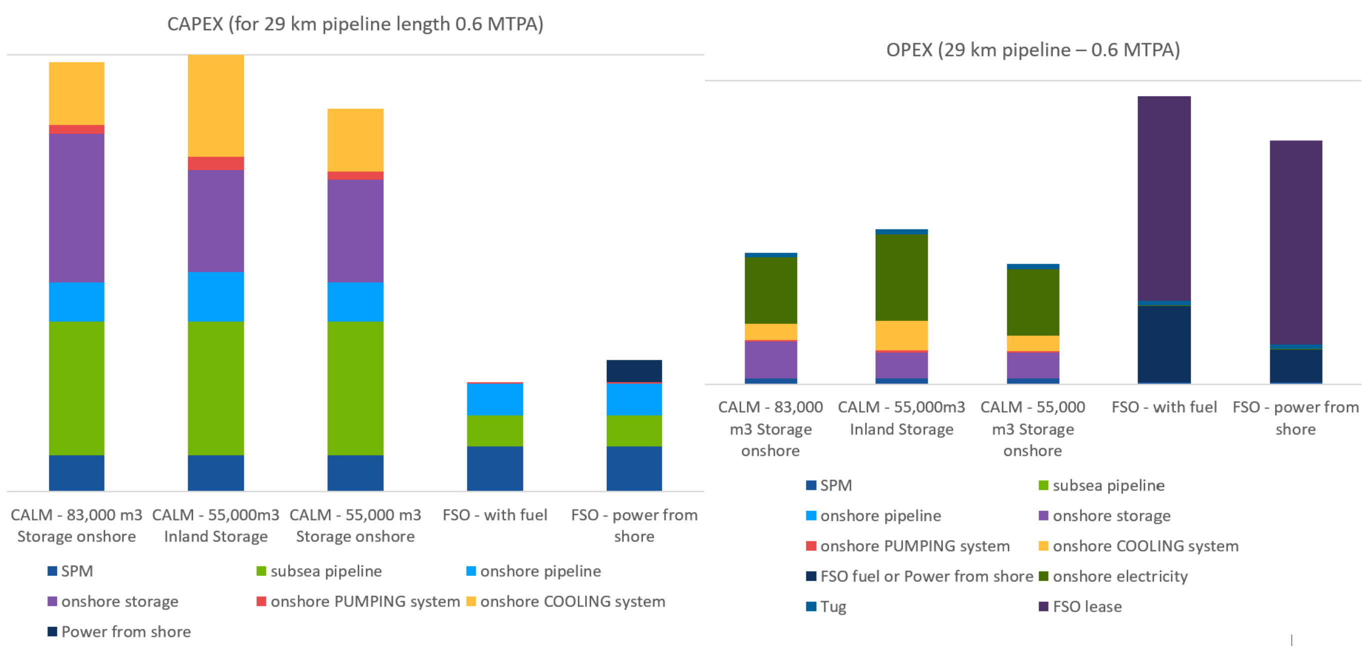

Figure 16: Onshore storage with CALM vs FSO – economics comparison – CAPEX and OPEX

As the "Tariff" is highly dependent on the through put, which can be growing in phases, as the revenue in USD / ton of Ammonia using the pieces of infracture required to transport the ammonia from the production (excluded) to the consumption (excluded) to amortize the CAPEX and OPEX of the overall system (i.e. the tariff is the NPV break even revenue per ton of ammonia for a given through put in MTPA over a number of years with a given Internal Rate of Return). In this case study, the Phase 1 production is 0.6 MTPA while Phase 2 could go up to 0.9 MTPA, which would reduce the tariff by one third. Also storage size and overall length of pipeline (including onshore pipeline) have a direct impact on economics, as illustrated in Figure 17.

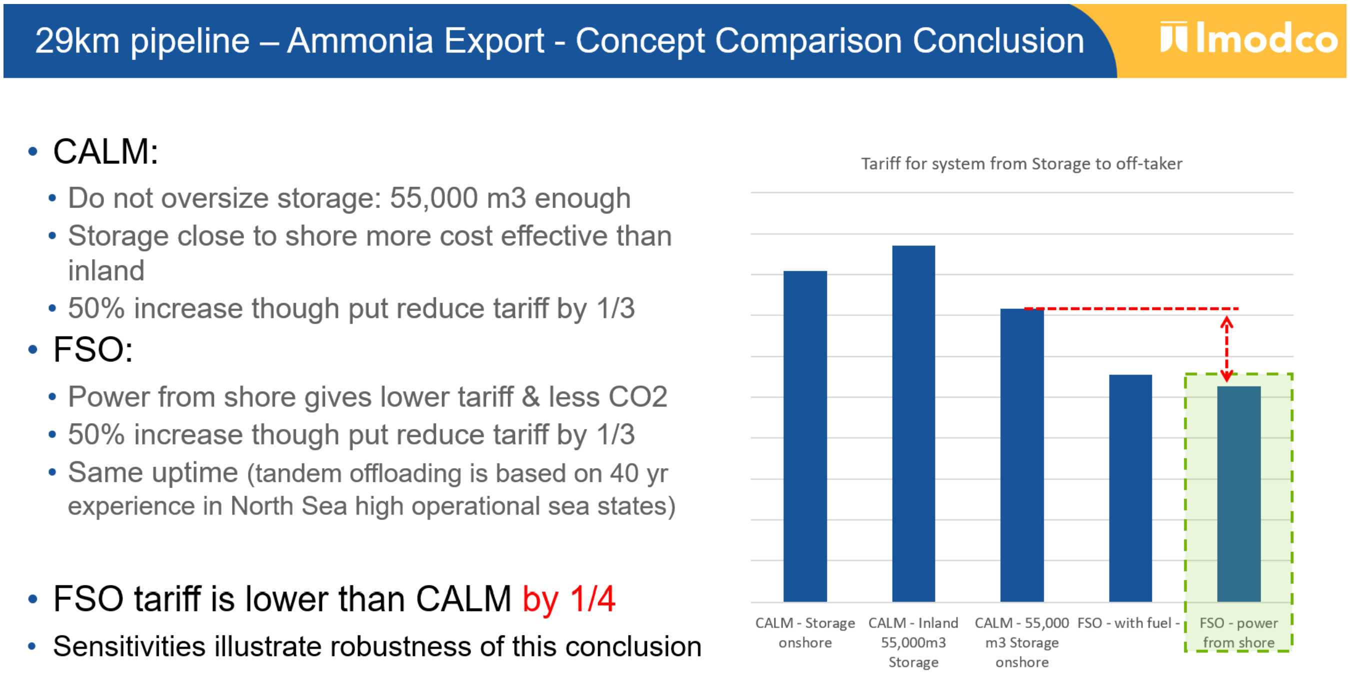

Figure 17: Onshore storage with CALM vs FSO – economics comparison– tariff (USD/t of NH3)

Based on this concept comparison with Tariff as KPI, this project has selected the FSO concept and now focused on the FSO cost optimization for this ammonia export project with long pipeline.

This conclusion in favor of FSO is project specific and not applicable to other projects which could have other heat ingress and through put conditions that lead to different CAPEX and OPEX profiles and resulting tariff. Each project should run its own comparative study : comparing – from an economic perspective - the various concept with the required level of safety performance.

4. Overall picture from off-taker's, insurer's and investor's perspectives: the best return on investment addressing safety dimensions

The section refers to section 4 of ref.[1] which 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 ?

This question naturally ends up with the minimum safety requirements to be validated at concept level to avoid the non-affordable risks of export reduction (largely degrading the economics) or - even worse - stopping of the export/import, therefore writing off the project and impacting reputation. Refer to ref.[1] for details.

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

Public perception is key for the fate of ammonia projects and associated economy.

The golden circle of Why the need for Ammonia, How to safely manage Ammonia, What are the practical tools (safety, carbon intensity certification, technologies,…) and investments are the various subjects fostered in the Ammonia Energy Association (see Figure 18).

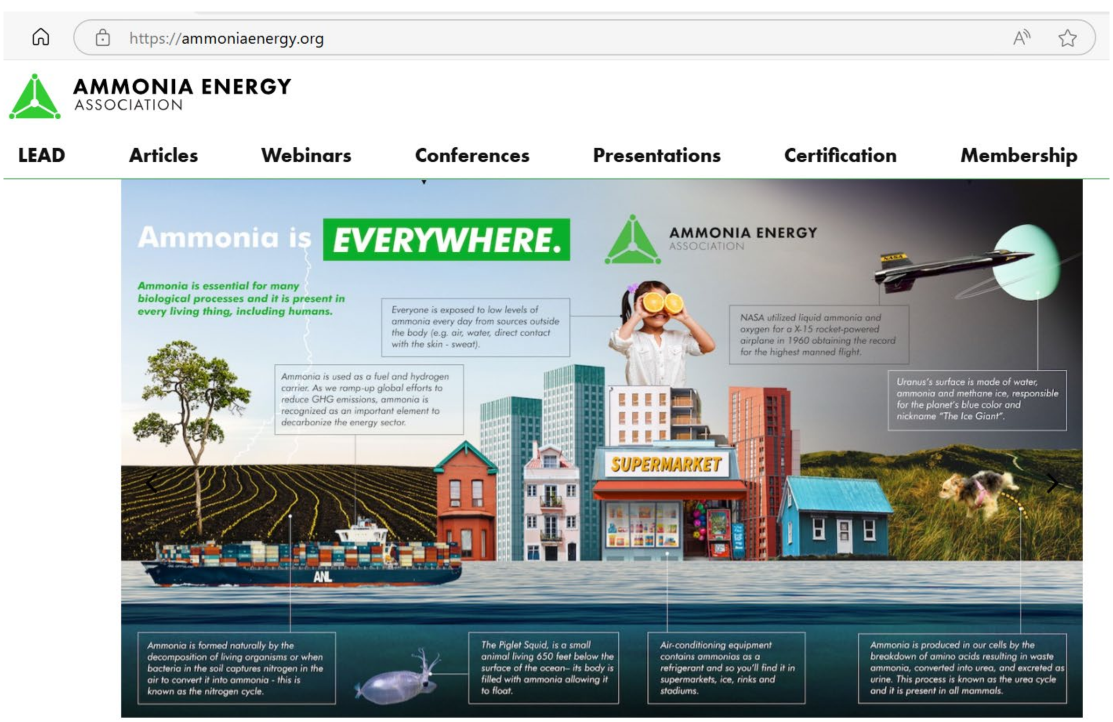

Figure 18: Ammonia Energy Association – effort to towards public perception

Other initiatives are also contributing to the safe and cost effective development of Ammonia contribution to the Energy Transition as promising vector of low carbon energy.

- Port of Rotterdam will be a large ammonia hub for Europe and are working on Ammonia public awareness among other supports to various worlwide projects.
- The ARISE (Ammonia Response In Sea Emergencies) is a research partnership to advance ammonia transport technologies. www.arise-partnership.org

- SIGTTO and OCMIF also further extend their covering of the Ammonia bulk shipping. OCIMF will update the SMOG – ref.[6] – the 2026 revision will cover ammonia application.

These combined efforts will manage the perceived risks and the actual risks associated with Ammonia so that:

- insurance premium are adjusted accordingly
- permitting process are compatible with the required pace for the energy transition.

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) but 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 19.

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.>>

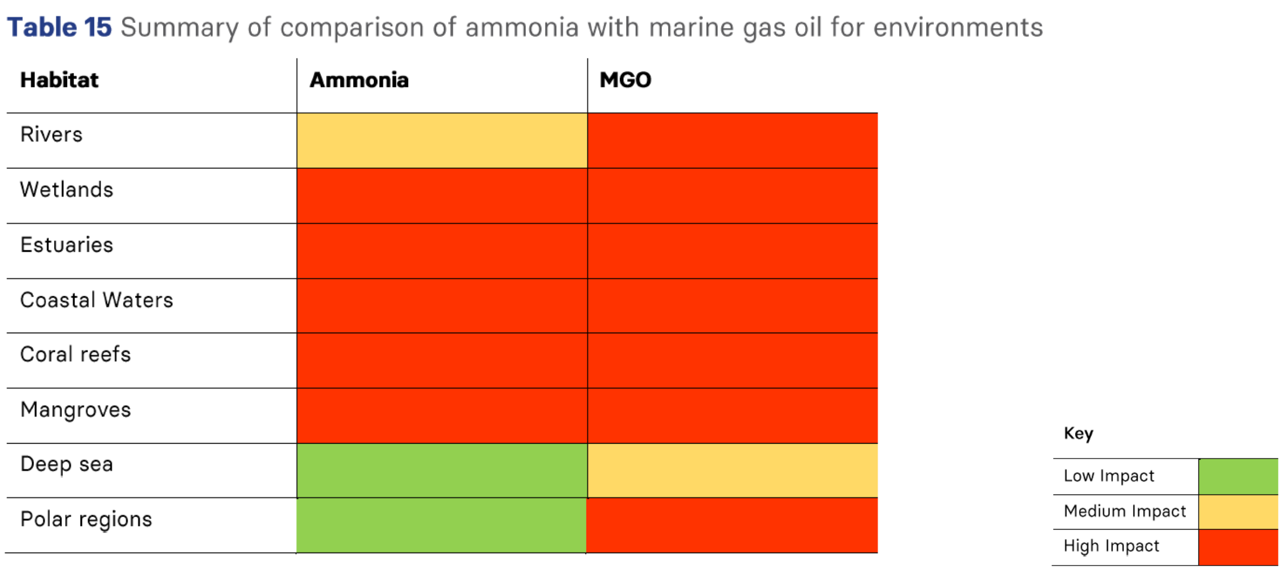

Figure 19: extract from EDF report comparing impact of Ammonia vs Marine Gas Oil

Summary and Conclusions

As a follow-up of our white paper "Ammonia Shipping : what is new ?", ref.[1], the pitch of this paper is to look at the overall cost efficiency once the Safety requirements are secured by proper study of 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. As the two or three new folds of ammonia production will be far away from the new consumers, the cost of Ammonia bulk transport will have a significant share in the overall cost of low carbon ammonia. Hence the need to optimize this cost with an overall picture of the ammonia transport value chain: from production (excluded) to consumption (excluded).
2. Beyond the safety aspects (i.e. once Safety is properly addressed): the various jetty-less technologies for Ammonia transfer can also improve the economics of project:
    a. Lighter infrastructure (i.e. lower CAPEX and shorted schedule) compared to jetty/harbor (new or extension).
    Or / and
    b. Easier Permitting (i.e. better schedule) thanks to easier decommissioning and further away from population
3. Within the jetty-less solutions, either in protected site or in open sea, the Floating Storage Offloading (FSO) can also enable some project economics so FID for more low carbon energy projects to further contribute to the Energy Transition.
4. Eventually the jetty-less solutions bring flexibility to project executions, enabling a phased approached allowing to de-risk a project which economics depend on a to-be-proven market.

The overarching conclusion: in a similar way than for Oil shipping, the Ammonia jetty-less terminals will be a key contributor to the Low Carbon Energy Economy & Strategy by enabling safe and cost-effective infrastructure for ammonia transfer from production (excluded) to consumption (excluded). Most of these jetty-less solutions for FSO can also be used for LNG: FSU, FSRU. These are a first step toward the energy transition as LNG is the cleanest fossil fuel and could evolve to e-LNG made out of renewable energy.

Key take-away: The SAFETY and Life Cycle Cost efficiency for large Ammonia Export/Import transfer systems start at concept selection when jetty-less solutions should be considered.

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- Ref. [2] – SBM Offshore – Ammonia FPSO presentation
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- Ref.[4] – BV white paper – Alternative fuels outlook for shipping – Sept-2022
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- Ref.[6] – OCIMF – Single Point Mooring Maintenance & Operations Guidelines (SMOG) – 3rd edition 2015 (latest revision , new edition cover ing Ammonia is planned for 2026)