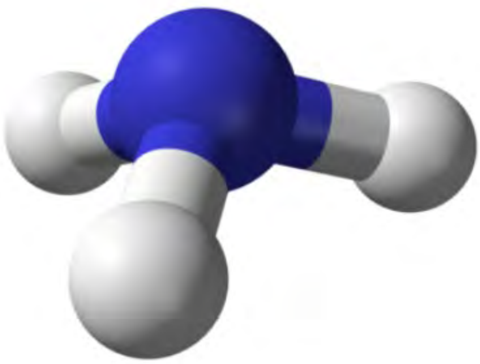
Green Shipping Programme

Report for pilot “Ammonia as Fuel”



Green Shipping Programme

Content

Revision	Date	Description
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Foreword

This report is made as a result from the pilot work carried out under Green Shipping Programme (GSP).

The work in this pilot had not been possible without the great contribution from the partners in the pilot, each contributing with competence within their field of competence. GSP is a public-private partnership, aims to advance the Norwegian government's maritime strategies and plans. The program's vision is to develop and strengthen Norway's goal to establish the world's most efficient and environmentally-friendly shipping.

The pilot had very high aims, where the pilot vessel is certainly not seen as the simplest for introduction of ammonia as fuel. But the work has shown that even for this type of vessels with bunkering within Oslo, ammonia could be possible to utilize. This should be a potential door opener also for a lot of other potential concepts.

Participants in the pilot work

A total of 24 companies have joined the work with this pilot. Thanks to all the contribution from them, the pilot study has been successful, and a lot of new competence is gained.

Green Shipping Programme

Summary

Norway is committed through the Paris Agreement to cut greenhouse gas emissions. IMO has an ambition to reduce the CO2 emissions by 40% in 2030. Through the action plan for green shipping /1/, the government aims to halve emissions from Norwegian shipping and fishing by 2030, and as part of this, incentivize zero- and low-emission solutions in all vessel categories.

Color Line has a relatively young fleet and see retrofit of existing fleet to be probable to meet the targets. The purpose of this pilot study is to shed light on the possibility to utilize ammonia as a blend-in fuel for the vessel “Color Fantasy” in order to meet the IMO target of 40% CO2 reduction in 2030.

The tremendous cooperation to gain insight in the potential of utilizing ammonia as fuel through this pilot has shown that it could be possible to do this, even for a passenger vessel bunkering in Oslo Havn despite of all the challenges and hazards. Due to the distinctly pungent, suffocating odor and the toxicity, extremely high focus on the safety aspects are however needed.

Further studies into the bunkering aspect, onboard solutions, handling and safety procedures, the economics in such a retrofit and the continuous research and development in technology is needed to realize the project.

Karl Wisløff
karl.wisloff@colorline.com
Technical Manager – Color Line AS

Erlend H. Nervold
erlend.h.nervold@dnv.com
Principal Engineer – DNV

1. Information about ammonia

Background

The key information about ammonia is presented in this chapter, where most of the information is obtained from the white paper “Ammonia as a marine fuel” from DNV GL /2/.

What is ammonia

Ammonia (NH_3) is a colorless gas under ambient conditions with a lower density than air. The boiling point is -33.3°C and hence by applying a moderate pressure it can be handled as a liquid at room temperature. At pressures above 8.6 bar at 20°C, ammonia is a liquid with a density of 0.61 t/m^3. At the boiling point, the density is 0.68 t/m^3. The heating value for ammonia on a lower heating value basis is 18.6 MJ/kg. Thus, compared to MGO the energy content is less than half on a mass basis and about 30% on a volume basis in liquid state. Comparison of density, lower heating value and volumetric energy density between Ammonia, LPG and MGO is shown in table 1.

	Ammonia	***LPG***	***MGO***
Density (t/m^3)	0.61	0.49	0.835
LHV (GJ/t)	18.6	46	42.7
GJ/m^3	11.4	22.6	35.7
Volume (m^3/GJ) normalized	3.14	1.58	1

Table 1: Comparison of volumes required per energy unit on lower heating value basis for ammonia compared to LPG and MGO

Usage

The global production of ammonia was 170 million tonnes in 2018, and some 11% of global ammonia production, or 18.5 million tonnes, is traded as ammonia. Most ammonia is used for fertilizers (some 80%). But some of it also is utilized for variously form of explosives, plastics, synthetic fibres and resins, refrigerants, and chemicals like nitric acid. Anhydrous ammonia is transported in gas carriers designed for ammonia transportation. Ammonia can be transported by three different ship types, depending on how the cargo is stored:

- refrigerated, typically at -50ºC at close to ambient pressure
- semi-refrigerated, typically at -10ºC and 4-8 bar pressure
- under pressure, typically at 17 bar, corresponding to the vapor pressure of ammonia at about 45ºC

In addition to handling of ammonia as a cargo, some ships have refrigeration systems with ammonia as refrigerant. This implies that handling of ammonia in the marine industry is not unknown. Similarly, handling of ammonia in many other industries is well known.

Production

Most ammonia is produced by the Haber-Bosch process, which combines nitrogen gas and hydrogen gas at high pressures and elevated temperatures to form ammonia. Today the most common source is natural gas. Another source of hydrogen for the Haber-Bosch process is by electrolysis of water based on renewable energy. The efficiency for such a process at large scale would typically be 68%. Nitrogen is obtained from an air separation unit. For the entire process from electricity to ammonia, the efficiency is reported to be approximately 52%. As a third possibility, hydrogen for the Haber-Bosch process may also be thermochemically produced through the sulfur-iodine cycle from for instance nuclear power. Another approach, that is under development by Haldor Topsøe, is a combination of solid oxide electrolysis cell (SOEC) and Haber Bosch process. In this concept, the SOEC separates the oxygen from the air/steam mixture, such that an air separation unit would not be required.

Typically - CO_2 emission-free ammonia from renewable electricity is labelled green ammonia, whereas ammonia from fossil sources like natural gas and coal is labelled brown ammonia. Ammonia from fossil sources with carbon capture and storage (CCS) is labelled blue ammonia.

Environmental footprint

The GHG emissions from the different potential sources of ammonia varies significantly, both depending on the process utilized as well as the CO_2 emission (CO_2 equivalents) from the power mix used in the production. Another potential contribution to global warming is the possibility that N_2O is produced during the process of utilizing ammonia in the power producer. N_2O is having a Global Warming Potential over 100 year of almost 300 times as much as CO_2. The focus on GHG in the industry is today strong, and it is expected that the technology development will have this in focus.

Some ideas about the CO_2-equivalent (GWP 100 years) for different sources of ammonia is found for well to tank in the table below:

	Green ammonia	Blue ammonia from natural gas – shifted syngas CCS	Blue ammonia from natural gas – all flue-gas CCS	Brown ammonia from natural gas	Brown ammonia from coal
Anticipated efficiency in production:	52%	64%	60%	66%	44%
EU power mix 2019	2732 kg CO_2-equivalent/ tonne	760 kg CO_2-equivalent/ tonne	194 kg CO_2-equivalent/ tonne	1600 kg CO_2-equivalent/ tonne	4000 kg CO_2-equivalent/ tonne
EU power mix indicative level 2030	845 kg CO_2-equivalent/ tonne				
Norwegian power mix 2019	169 kg CO_2-equivalent/ tonne				
Renewable/ zero emission electricity	Close to zero				

Table 1 Approximate emissions in CO_2-equivalents (GWP 100) for wake to tank for different ammonia productions

In these calculations, the EU mix 2019 is 275 g CO_2-equivalents/kWh (/3/) – 85 g CO_2-equivalents/ kWh for the EU indicative level for 2030 (/3/) and 17 g CO_2-equivalents/kWh for the Norwegian 2019 energy mix (/4/). Further, the storage and transportation of the ammonia is not included.

In comparison, the CO2 emission factor for tank to wake for HFO as stated by IMO is 3114 kg/tonne fuel. In addition comes the well to wake, with a factor of 402 kg/ tonne fuel (/5/), adding up to a total of 3516 kg CO_2-equivalent/ tonne fuel.

The emission from the energy produced from ammonia onboard the vessel is zero – provided that no N_2O or other GHG is released, as ammonia do not contain carbon. It should be noted that this focus on blend-in of ammonia for engines, and not dual fuel (DF) engines primarily on ammonia. For these DF engines, the pilot fuel also needs to be considered.

The conclusion is that to be able to drastically reduce the GNG effect from the fuels, focus on the production method of the ammonia is essential. This includes the power mix utilized during production.

Price expectations for green ammonia

The production cost of renewable ammonia will largely depend on two parameters: The price of electricity and capital expenditure. In the white paper /2/ a calculated hypothetical ammonia production price for a plant producing ammonia from electricity. This figure is shown below (see Figure 1). This is calculated as a function of electricity prices for various capex values, and is based on an internal rate of return for the project over 20 years at 10%, with an efficiency of 52%, a 5% discount rate, and annual operational expenditures at 2.5% of the capex. The cost of onshore wind power is largely determined by the capex and capacity factor, and it has been estimated at 0.04 to 0.05 \$/kWh. The International Renewable Agency (IRENA) estimates the 2020 global weighted average cost to be reduced for on-shore wind power to 0.045 \$/kWh and for solar PV to 0.048 \$/kWh.43 The cost of PV solar is similar to on-shore wind, whereas offshore wind is higher.

Based on these estimates, the current renewable ammonia price would be in the 650 to 850 \$/t range, but electricity prices for renewable energy from wind and solar will be highly site specific. It is reasonable to expect that the renewable electricity prices will decrease over time and also that the capex for electrolysis will decrease to some extent. Hence renewable ammonia will become more competitive.

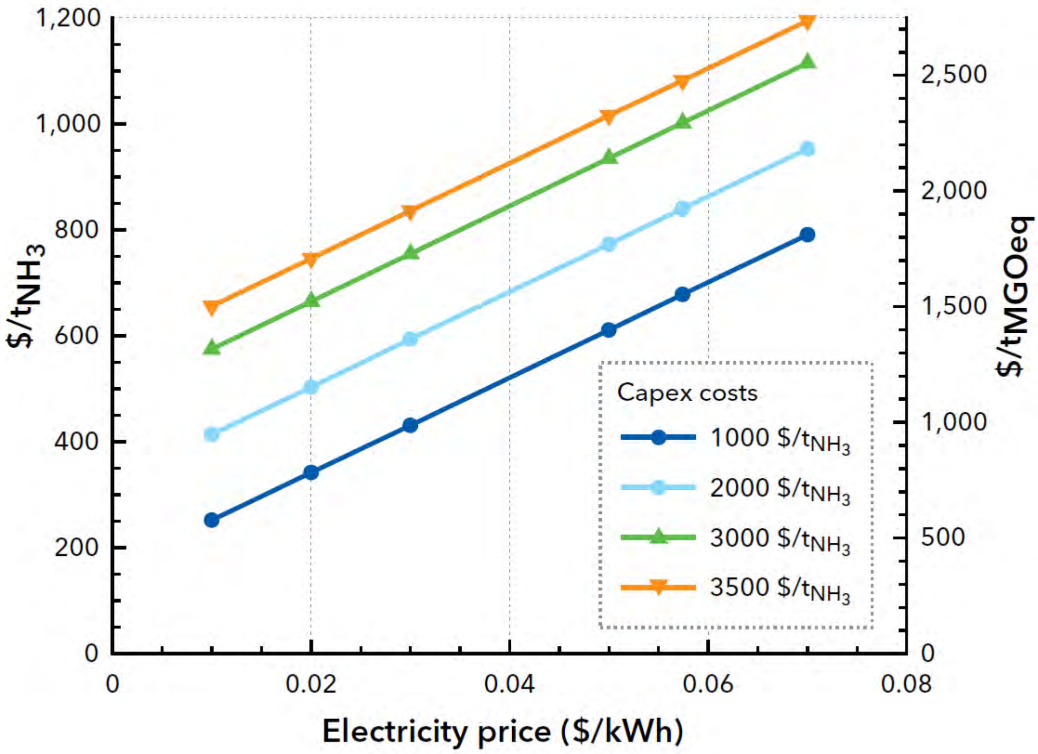


Figure 1 Estimated production cost of renewable ammonia as a function of the electricity cost at various capital expenditures (per tonne annual production capacity)

Toxicity and other challenges

One of the major disadvantages for ammonia is the toxicity. For EU the limits are 20 ppm for 8 hours exposure and 50 ppm for 15 minutes exposure. The US Occupation Safety and Health Administration (OSHA) has defined the level at which persons can be exposed without suffering irreversible health effects as 300 ppm. Exposure to very high concentrations of gaseous ammonia can result in lung damage and death, and one limit to this is 5000 ppm (0,5%).

Ammonia has a distinctly pungent, suffocating odor. The typical detection limit by humans varies considerably from 0.04 to 53 ppm with a mean of 17 ppm. Hence the detection limit may be above concentration that is considered dangerous for long term exposure, and detectors should be used where there are risks for exposure to ammonia. The distinctly odor is at the same time an advantage as well as a potential challenge. The odor will warn the population about any release, and as such it can ensure an early evacuation. At the same time, the odor of higher concentration has the potential to create panic. The public perception in case of a release might also create strong feelings and reactions against ammonia as fuel. That said – there are similar challenges with all fuels – either related to odor, potential for explosion, toxicity, or pollution.

Ammonia is categorized as very toxic to the aquatic life in safety data sheets, and also with long lasting effects. Ammonia is very soluble in water. In water there will be an equilibrium of the un-ionized ammonia – NH_3 – and the ionized ammonium ion – NH_4^+, and the proportion of the two chemical forms varies with the properties of the water, particularly pH and temperature. The toxic effect on aquatic organisms is primarily related to the concentration of the un-ionized NH_3. The sensitivity to ammonia differs largely between different species, and several studies have been conducted on ammonia toxicity. It can be mentioned that fish within the group Salmoninae – which includes salmon (Salmo salar) and trout (Salmo trutta), appear to be very sensitive to ammonia, where a concentration of 0,068-0,9 mg/l give 50% death in a test population within 96 hours (LC50) (/6/).

Ammonia is corrosive to some materials like copper, copper alloys and zinc, and care must be taken in the selection of materials. Ammonia is known to cause stress corrosion in carbon manganese and nickel steels. Furthermore, dissolved oxygen in liquid ammonia increases stress corrosion risk. Care must be taken to purge air from the ammonia systems prior to filling them with ammonia; new tanks must be thoroughly purged to eliminate air contamination. Ammonia is also reactive with CO_2 that may be contained in inert gas.

The probability of stress corrosion cracking is significantly reduced by adding a small amount of water, not less than 0.2 wt%.

References to other publications

The focus on ammonia as a potential carbon free fuel is high, and a lot of information is available in different publications. Some sources for more information are:

DNV GL White paper "Ammonia as marine fuel" – ref
https://www.dnvgl.com/Publications/ammonia-as-a-marine-fuel-191385

Økokrim Utslipp av ammoniakk, ammonium, salmiakk eller gjødsel? – 30.05.2011

Fertilizers Europe – with several technical documents on ammonia – ref
https://www.fertilizerseurope.com/publications/ under "Technical". Among others:

https://www.fertilizerseurope.com/wp-content/uploads/2019/08/Guidance_for_inspection_of_and_leak_detection_in_liquid_ammonia_pipelines_FINAL_01.pdf

https://www.fertilizerseurope.com/wp-content/uploads/2019/08/SCC2.pdf

https://www.fertilizerseurope.com/wp-content/uploads/2019/08/Booklet_1_final.pdf

https://www.fertilizerseurope.com/wp-content/uploads/2019/08/Guidance_for_transporting_ammonia_in_rail_4.pdf

Equipment for leak detection example: https://telemac.fr/wp-content/uploads/sites/3/2017/01/E-LEAK-DETECTION-FERTILIZER-PLANTS_AMMONIA_170306_01-TELEMAC.pdf

https://nh3fuel.files.wordpress.com/2013/05/riso-ammonia-transport-safety-report.pdf

Alfa Laval, Hafnia, Haldor Topsøe, Vestas, Siemens Gamesa: “Ammonfuel – an industrial view of ammonia as a marine fuel”, August 2020

Australian and New Zealand Guidelines for Fresh and Marine Water Quality: https://www.waterquality.gov.au/anz-guidelines/guideline-values/default/water-quality-toxicants/toxicants/ammonia-2000

2. Safety and Regulations

Onboard safety and regulations

Current regulations

The use of fuels is regulated by the International Maritime Organization (IMO) through the International Convention for the Safety of Life at Sea (SOLAS). The regulations for conventional fuel oils are prescriptive and based on decades of experience. Utilizing fuels with a flashpoint below 60°C (defined as Low Flashpoint Fuels) has generally been prohibited to prevent tank explosions and fires. In 2015, the SOLAS Convention was amended to allow the use of low flashpoint fuels for ships complying with the International Code of Safety for Ships Using Gases or Other Low Flashpoint Fuels (IGF Code).

Vessels flying the Norwegian flag are regulated by Regulations of 27 December 2016 No. 1883 /7/. Vessels built or retrofitted to use a low flashpoint fuel after 1st of January 2017 must comply with the IGF Code. In addition, equipment constituting or forming a part of the tank or fuel system shall be accepted by the Norwegian Maritime Authority (ref. sec. 3.).

The IGF Code provides an international standard for the safety of ships using low flashpoint fuel and requires that the safety, reliability and dependability of the systems shall be equivalent to that achieved by new and comparable conventional oil-fuelled main and auxiliary machinery. It is emphasized that operational procedures shall not replace safety barriers through the ship design. The IGF Code specifies a set of functional requirements applicable for all fuel types covered by the Code, but only contains specific design requirements to LNG.

Until such regulations are in place, approval of ships using other fuels than LNG will be based on alternative design approach, demonstrating that the design complies with the basic functional requirements of the IGF Code. This risk-based approval process is referred to as the 'alternative design' approach (part A sec. 2.3 in the IGF code), where an equivalent level of safety needs to be demonstrated as specified in SOLAS regulation II-1/55 and approved by the Administration.

The approval process for the alternative design approach is described by IMO MSC.1/Circ. 1455. It can be a time-consuming process with a high degree of uncertainty and therefore potentially higher business risk than the prescriptive experience-based rules that the maritime industry is used to working with. This must be considered as a barrier against uptake of alternative fuels in the industry.

Vessels carrying ammonia as cargo is regulated by the IGC Code (International Gas Carrier Code) that provides an international standard for the safe carriage by sea in bulk of liquefied gases. The IGC Code includes a separate chapter (ch. 16) on the use of cargo as fuel, but it does not permit the use of cargoes identified as toxic, such as ammonia. However, a proposal to remove this ban has been sent to IMO.

Ammonia is transported as cargo in large quantities in gas carriers. The requirements in the IGC Code can therefore provide useful guidance in how to design fuel storage systems for ammonia.

Ongoing work with updating regulations

Until specific regulations for ammonia as fuel is developed or adopted by IMO or Flag State, the alternative design approach must be applied for every newbuild or retrofit. Currently, there is no ongoing work updating these regulations from statutory bodies.

DNV has published new class rules for ammonia as fuel entering into force January 1st 2022 (Pt.6 Ch.2 Sec.14). The new class rules are based on the existing DNV class rules for LNG and LPG fuel as well as experience from IGC code and rules for using ammonia as refrigerant, and adjusted in the aspects where ammonia and methane require different designs and approaches.

When a Classification Society has developed a set of rules covering the use of a fuel where specific design requirements are not included in the IGF Code, a Flag Administration may accept the application of this rule set to ease the alternative design approach. A set of class rules may also form basis for development of international regulations in IMO.

Because risks associated with new technology are not necessarily accounted for by existing rules, it is important to focus on identifying possible new risks in the approval process for the alternative design. Both for individual sub-systems and for the vessel as a whole /9/.

The following safety barriers are the main focus for managing the risk of both LNG and ammonia in the IGF Code and the current and new class rules:

- **Segregation;** keeping the installation away from areas where it may be damaged by collision or grounding, external fires, cargo handling or other ship operations.
- **Double barriers;** arrangements that allows leakages from the fuel system to be managed safely. This will typically be to provide a secondary barrier around any leakage point. In practice, such barriers consist of specially designed spaces (e.g. tank connection spaces, fuel preparation rooms) and double piping arrangements.
- **Leakage detection**; systems that can detect leakages of gases and liquids from the fuel system. The detection methods are dependent on arrangements, but normally includes gas detection systems, low temperature measurements, changes in pressure and temperature.
- **Automatic isolation of leakages;** systems and arrangements that can isolate the leakage from the leakage source when the detection systems above find something wrong with the fuel system. In order to achieve this, a number of isolation devices are required in the system enabling automatic shut-down of the fuel supply to the damaged system.

As described earlier in the report ammonia is categorized as toxic if inhaled and very toxic for marine life. In addition to the main safety barriers listed above, the following therefore needs to be considered specifically for ammonia.

- **Emergency release;** To prevent explosions of ammonia tanks due to over pressure a safety release system must be installed. Traditionally this system is designed with pressure release valves (PRV) and a vent mast. For non-toxic gases a release to air is regarded safe if the safety distances (normally at least 10 m) from ignition sources and air intakes are followed. For toxic cargo the IGC Code requires that a vent mast is arranged at least B or minimum 25 m from the nearest air intake or other possible exposure areas for crew. It is reasonable to assume that the same minimum requirements can be applied for cargo vessels using ammonia as fuel, given that crew is trained and given the same personal protection equipment (PPE) as crew on board gas tankers carrying ammonia.

  For passenger and cruise vessels we foresee that special analyses must be performed for the emergency release system. Dispersion of the toxic gas, in connection with the location of life saving equipment, arrangement of mustering stations, evacuation time and safe return to port arrangements etc. for the calculated worst-case scenario is one aspect that must be analysed. A possible result of such analyses can be that a traditional vent mast will not be able to ensure equivalent level of safety. Therefore, new solutions such as scrubbers, releasing ammonia to sea or other means of reducing the release to air is suggested to be assessed.

An emergency release to air in port will in addition to the passengers on board, affect all citizens in proximity to the port. This will be discussed further in the chapter for safety zones for bunkering operations.

As ammonia is very toxic to aquatic life releasing ammonia to sea can have catastrophic consequences for the sea life in proximity of the release. Especially in confined waters such as ports or rivers. Lethal concentration (LC50) for aquatic life is calculated to be between 0,1 and 1 ppm. A release of 1 m^3 of ammonia in water with depth of 25 meter will therefore potentially have a lethal concentration in a radius off 100 to 250 meters around the vessel. Release of pollutants to sea is allowed in an emergency scenario according to SOLAS and MARPOL. [but might conflict with other environmental regulations in ports or rivers.] A release to water with catastrophic consequences for aquatic life will however affect public perception and should not be underestimated.

- **Flammability;** Ammonia's flammability range is from 15 to 28 per cent mixture in air. Ammonia requires minimum ignition energy of 680 mJ, which is 2 500 times more energy than methane needs to ignite and 35 000 times more energy than for hydrogen.

  Even though ammonia has a lower fire and explosion risk compared to methane and hydrogen, it is still important to ensure appropriate firefighting equipment. If water is added to a pool of liquid ammonia, the exothermic reaction will release energy and form more flammable (and toxic) vapour. Specific regulations for firefighting should be developed.

- **Pressurized or refrigerated tanks;** Ammonia can be stored as a liquid in pressurized tanks, semi-refrigerated tanks or tanks fully refrigerated at ambient pressure. When designing for either solution it is important to address their specific failure modes and risks. Such as loss of cooling, or possible pooling of liquid ammonia after a leak for the refrigerated tank.

  Bunkering stations or vessels can also have either of the three solutions. In order to ensure safe bunkering procedures, the bunkering systems should be designed to handle all the possible combinations of tanks, or strictly limited to one solution.

- **Purging of system and pipes during normal operations or maintenance;** Due to the toxicity and very potent odour of ammonia, no ammonia should be released to air or sea as a result of normal operations or maintenance. DNV rules state that release in a concentration exceeding 30 ppm is prohibited. The possibility to purge the residual ammonia in pipes and handle the gas without emissions is key to protect the crew, passengers and environment. Reliquification or scrubbing are both possible solutions.

  Even small releases of ammonia will produce a very potent odour that can cause a notable discomfort for people exposed. On board cruise or passenger vessels this can be a safety risk. Given that passengers generally do not know if this discomfort is dangerous or not, panic can occur among passengers even though concentrations are below limits regarded as safe. This must be further investigated.

  Form past experiences with ammonia on board vessels where ammonia is used as a refrigerant, it is found that most accident occurs during maintenance of the system /8/. A holistic understanding of risk is as important during non-routine operations, such as maintenance, as during regular operations. Those playing a part in the ability to perform correct and timely maintenance include crew performing regular maintenance on board; suppliers visiting vessels to perform maintenance; and people responsible for designing the technology and associated procedures for easy access and effective maintenance. /9/

On Land Safety and Regulations

Color Line in cooperation with partners from the Green Shipping Program has taken initiative to find possible solutions to bunker ammonia in an urban port. The Port of Oslo has participated in the pilot with the interest to find safe solutions for ammonia bunkering in the capital city of Oslo.

In 2018 the Action plan for a zero emission port in Oslo show that ro-pax ferries, like Color Fantasy, contribute by almost 40 percent of the ports greenhouse and local air emissions. The reason is simply that the cruise-ferries, with both passengers and roro cargo to Denmark and Germany, have daily routes all year round. One measure in the action plan is therefore to look for possible alternative fuels. Especially for ro-pax vessels in combination with shore power. All ro-pax ferries and local ferries use shore power in the Port of Oslo.

Port of Oslo have passenger traffic close to the city center of Oslo. The terminal that Color Line use today, has cargo handling, passengers, pedestrians and close neighbors in our capital city of Oslo. The Norwegian shipping company, Color Line, was possibly the first in Europe to connect to shore power. Color Hybrid has a large battery and can sail with zero emissions, and now they are investigating ammonia as a future fuel for Color Fantasy including bunkering in Oslo.

Figure 2 Color Line's terminal, Hjortnes, in Oslo – Norway. View from the city side. Photo: Oslo Havn

The pilot has included a **possibility to bunker ammonia from a tank** at port side. In the case study, the site for a bunkering tank was located as close as possible to the ship. The same area was was previously used for bunkering liquid natural gas (LNG) for local ferries.

The other solutions discussed was **bunkering from a barge at shipsid**e. The idea of using a barge gives possibly less restrictions regarding to the safety areas surrounding the ammonia tank in the port area. But most likely this solutions will be more costly.

In this pilot Yara has contributed by sharing their experience from transporting ammonia both on ships and by tank trucks. It is important to use the regulations that already do exist and not contribute to making ammonia bunkering more difficult than it actually is.

It was also very useful having a dialogue with regulators like The Norwegian Directorate for Civil Protection (DSB) and Norwegian Maritime Authority to be able to start a risk assessment and complete an QRA for the two possible bunkering solutions. Main takeaway from the QRA is found in end of this chapter.

Figure 3 Color Line's terminal, Hjortnes, in Oslo – Norway. View from the seaside. One can see that the urban city center is very close to the terminal. Photo: Knut B. Andersen/Oslo Havn

The City of Oslo and the port is committed to develop zero emission solutions for all transport modes, including ships. Electrification is part of the solutions. Local ferries in Oslo are electric, but perhaps will the more long distance commuting ferries need hydrogen in the future. Perhaps the cargo ships in the south port in will demand ammonia as a fuel in the future. It is not clear what the future brings, but as a city with high ambitions to reach zero emission we need frontrunners like Color Line, Yara and other partner in the Green Shipping Program to reach common goals.

If Oslo want to be a future zero city, future fuels are important to explore in most transport modes and not just for ships. But the maritime industry can contribute to building at regular demand in the new markets.

In the Port of Oslo, we know that if all types of ships will connect to shore power, this will only half the emissions. Sailing in and out of port is also included in the action plan. And as a port preparing for sustainable transport growth we are committed to learn more through cooperation and share knowledge with stakeholders with in and surrounding the Port of Oslo.

Figure 4 Filipstad in Oslo, will be a new city district within the next few decades. The illustration above shows that Color Line's terminal will be very close to even more urban activities in the future than today. Illustration: Nordic Office of Architecture

In Oslo, like many other European ports, the city comes closer to the port areas. The neighbors come closer and the dialogue with stakeholders becomes even more important.

This pilot shows that existing ships can retrofit and use ammonia as a fuel to reduce their carbon footprint. Ammonia is poisonous, but it in less flammable than today's fossil fuels. The smell is extreme, and passengers will detect it long before it is reaches poisons concentrations.

But how will passengers react with an ammonia leak, will it create a panic? What will port neighbours think, will it create protests, and demands for the ports to move further away from the city centre?

Nobody knows, but all we can do is contribute to build awareness and share knowledge.

In this pilot, Color Line's commitment to understanding future fuels, Yara's contributions to sharing knowledge, and an ongoing dialogue with regulators are all important, to keep the door open for ammonia as possible future marine fuel in urban port areas.

QRA of potential bunkering solutions

As part of the pilot, a QRA of potential bunkering solutions was carried out by DNV /10/. The main takeaway is presented in this chapter.

Scope for QRA

The scope for the QRA included definition of bunkering concepts and boundary conditions. The assumptions related to the concepts definition and risk modelling were defined. The established Assumption's Register was continuously updated thought the project execution.

The hazards related to the concepts' operation were systematically identified and recorded. After the HAZID, QRA scenarios subject to quantitative risk evaluation were established. Risk modelling was performed by DNV software package SAFETI v8.23.

The 3rd party individual risk results were presented by Location Specific Individual Risk Contours (LSIRCs) and assessed against DSB's RAC, /11/.

Recommendation and risk reducing measures were proposed for concepts assessed to exceed RAC.

Limitation for QRA

- QRA is limited to the 3rd party individual risk assessment.
- The 2nd party individual risk assessment is not a part of the scope (i.e. crew and passengers onboard the passenger ship), i.e. no impact risk assessment is carried out for people present on the passenger ship
- Only toxic risk is considered.
- Releases associated with storage tank failures either on the bunker ship or truck are not part of this QRA.
- Releases associated with storage tank and equipment on the passenger ship are not part of this QRA.
- The actual geometry of the area of bunker operations was not considered by this QRA.
- No evaluation for impact on marine life has been included in this QRA.
- The generic frequencies for transfer equipment are based on recorded frequency of accidents for LNG, LPG transfers by ship, and ammonia transfers by road truck. The actual design of transfer equipment to be utilized for future operations was not considered for failure frequency estimates due to the early concept phase.
- The dispersion simulations of toxic gas are performed by Safeti and do not account for actual layout of the port. The gas dispersion and air dilution are considered being impacted by large obstacles in the area and influence toxic gas effect zone.
- The analysis is limited to system definition as presented in Section 4 and analysis assumptions documented in Appendix A, Assumptions' Register.

The concepts design is at its early stage and should be regarded as coarse.

The results of this assessment are only valid within the validity of the assumptions

Methodology

Analysis approach

With the reference to project scope description, the following approach was adapted and followed as depicted in figure below. The detailed presentation each of the analysis's steps and associated uncertainties are presented in subsequent sections below.

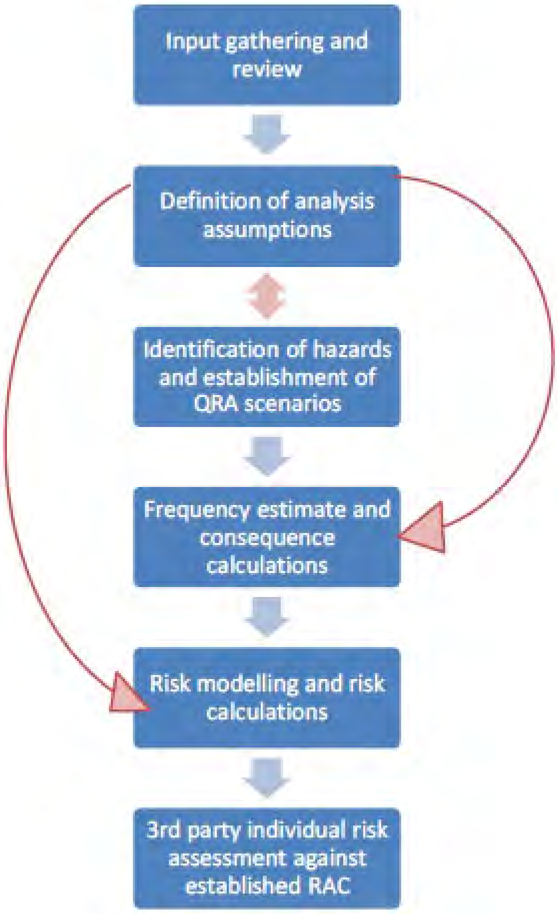


Figure 5 Approach defined for application to QRA

Quantitative risk analysis

The risk analysis methodology adopted in this QRA is as presented in Figure 6.

The risk is calculated by using the DNV standard risk analysis package SAFETI version 8.23. The Safeti software has been the industry standard method for carrying out quantitative risk analysis of onshore process, chemical and petrochemical facilities for more than 30 years. The modelling and simulation of consequences is performed by integrated consequence package – PHAST version 8.23. Event frequency calculations are conducted by DNV Software Leak v.3.3.

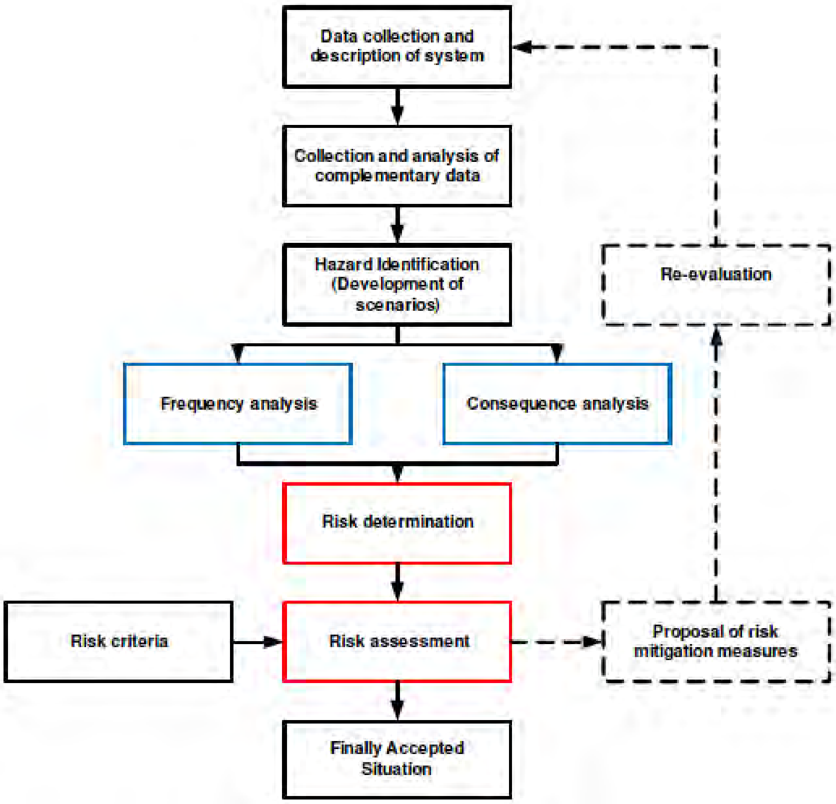


Figure 6 QRA Methodology

Risk estimate and assessment

Risk modelling and risk calculations are performed by DNV Software package SAFETI v 8.23.

The software incorporates consequence analysis capabilities of PHAST, including UDM. SAFETI analyses complex consequences from accident scenarios and quantifies the risks associated with the release of hazardous chemicals. Once the consequences have been calculated by the integrated PHAST consequence modelling package, they are combined with the input weather and wind directional probabilities, corresponding failure case frequencies and with the event tree probabilities to calculate the risks. Each failure case is analyzed to determine its impact. The probability of death, due to a toxic release, at a point is calculated via the "probit equation" or defined probit function.

The individual risk results in this QRA are presented by location specific individual risk (LSIR) contours or iso-contours. To obtain these, the point risk calculations are repeated at a large number of grid points within the area of interest.

These iso-contours represent a probability that an average unprotected person, permanently present at a certain geographical location, is killed in a period of one year due to an accident resulting from a hazardous activity. It is assumed for individual risk that the population is out of doors and does not shelter or escape.

Concepts

Two (2) main concepts were defined for the QRA:

Concept 1: Bunkering from a pressurized storage tank onshore to a passenger ship and

Concept 2: Bunkering from a bunker ship to a passenger ship

In concept 1, the storage tank is 1000 m^3 in size and filled either by pressurized ammonia from 2 trucks every day (concept 1A) or refrigerated ammonia by bunker ship every 4th day (concept 1B). The location of the defined QRA scenarios on quay is seen on Figure 7.

S1A-ammonia transfer from the truck; **S1B**- ammonia transfer from the ship; **S2A/B** – receiving manifold;

S3-Storage tank; **S4**-Process pipe; **S5**-Loading Arm

Figure 7 Location of QRA scenarios Concept 1 A/B on quay.

In concept 2, the ammonia is delivered to the vessel by a bunker vessel (or barge) every 4th day by a flexible hose.

3rd party individual risk results

The risk results based on frequency and consequence analysis combined with the input weather and wind directional probabilities for 3rd party individual risk are presented in a form of LSIR contours or isocontours. The risk level is calculated as an average over 24 hours per day for a representative 12-month period. The iso-contours are depicted at 1 m representative height above ground level.

The risk results for Concepts 1 A and B are assessed to exceed defined RAC presented in

Figure 8 LSIR contours – Concept 1A

Figure 9 LSIR contour – Concept 1B

For Concept 2, risk results are illustrated in Figure 10, the risk is assessed acceptable against defined RAC.

Figure 10 LSIR contours – Concept 2

CONCLUSION FROM QRA

The general conclusion from the QRA is that the 3rd party individual risk is assessed as not acceptable for Concept 1 A/B, while it is assessed as acceptable for Concept 2 following the DSB's risk acceptance criteria. The main reason for this is that the ammonia is stored as pressurized in concept 1, whereas in concept 2 it is refrigerated. For the pressurized ammonia scenarios in Concept 1 A/B, more severe consequences are predicted compared to Concept 2.

Discussion

The presented risk results are sensitive to the following system properties applied in the modeling:

Storage tank scenario on the quay:

***Ammonia stored at pressurized condition in the storage tank on quay*:** The high pressure causes a long dispersion length. In case of release of pressurized ammonia, it will become diphasic after atmospheric expansion, forming fine aerosol mist flashing when pressure is reduced to ambient followed by vaporization and further dilution with air. When temperature is reduced to ambient, ammonia will expand 700 times from storage density as a liquid to vapor at its boiling point of - 33,4°C. Ammonia is hygroscopic (readily absorbs moisture), i.e. in the presence of moisture (such as high relative humidity), the liquefied anhydrous ammonia gas forms vapors that are heavier than air and travels along the ground on long distances.

Pressurized storage tank being 100% full at all times: This implies ammonia being released in liquid state only. In case the inlet connection to the tank is at the tank level below level of stored liquid, the failed connection on the inlet line is considered to release gas followed by two-phase until pressure in the tank is equalized. That will reduce extent of consequences assessed for Segment 3B – top contributor to the risk assessed for Concept 1.

External tank connections failure: The risk in concept 1A/B is driven by continuous liquid release associated with failed external connections to the pressurized storage tank. Since this is in conceptual stage, no information or details have been provided about the storage tank, and conservative assumptions have therefore been applied for the different leakage scenarios.

Rainout inside the bund: Ammonia leaks from storage tank will be collected in the bund. The leak can potentially hit outside the bund followed by longer rainout distance. The storage tank outlet bottom line is assumed being obstructed by the bund followed by rainout inside the bund. The tank's ammonia inlet line is assumed to be obstructed by equipment/structure in the vicinity of the release with the rainout inside the bund. The storage tank is considered being protected by the wall to limit external access to the tank. Otherwise, much worse consequences are predicted followed by larger risk contours. Longer rainout distances (up to 50 m) will contribute to higher vaporizations level and to more ammonia stay in the cloud, followed by less rainout rate to the pool.

Bunkering:

Number of bunkering operations: The full storage tank has been modelled to represent a possibility of ammonia bunkering to more than one passenger ship. This implies higher frequency of bunkering operations and higher contribution of ammonia bunkering scenarios, such as Segment 1, 2, 4, and 5 (Concept 1). That will as well imply more frequent transfer of ammonia to the storage tank. The risk picture presented in this report will no longer be valid if more receiving vessels involved.

Pump isolation time: In this assessment, the bunkering pump is assumed to be isolated 90 sec after the leak start regardless of ESD function. In case of longer time required to stop the pump, that will greatly affect amount of ammonia being released during bunkering operations and extent of consequences. That applies both to Concepts 1 A/B and 2.

These assumptions greatly impact risk results and are open for discussion.

Recommendations

This chapter summarizes proposed recommendations for application to Concepts 1 and 2.

Concept 1A and 1B

The project team identified several proposals for conceptual changes and design measures that may reduce the size of the risk contours, either by reducing the likelihood or consequences of ammonia release. Further studies of these measures will be needed to determine whether the risk contours can be sufficiently reduced to be within the acceptance criteria established by DSB.

The proposed measures for follow-up studies for Concept 1A and 1B are:

- Use refrigerated atmospheric storage tank onshore instead of pressurized tank (i.e. refrigerate bunkering concept). The accidental loss of containment associated with refrigerated ammonia (stored at atmospheric conditions) is assessed to produce smaller toxic gas clouds compared to the release of pressurized ammonia. It is therefore considered to reduce the extent of risk contours. For this particular case with the passenger vessel, it seems not to be a likely option, however it may be considered for the application to other concepts. It should be noted that hazards and associated consequences related to pressurized ammonia will still be relevant if processing equipment to pressurize the ammonia is taken onboard the receiving ship. Nevertheless, the exposure time to the toxic release from the equipment onboard of the receiving vessel will be reduced to time spent by the vessel in the port.

- Enhanced safety integrity of shore storage tank and external tank connections. The risk in concept 1A/B is driven by continuous liquid release associated with failed external connections to the pressurized storage tank. Since this is in conceptual stage, no information or details have been provided about the storage tank, and conservative assumptions have therefore been applied for the different leakage scenarios. Design measures such as welded connections, reducing number of external connections, design of tank connections (material, stress analysis) etc. may reduce the leakage probability and hence reduce the risk contours.
- Double shell/secondary enclosure for piping which should be able to contain any leakages from the primary containment. This will ensure all leakages are contained in a secondary enclosure. The released ammonia can be stored (if feasible/safe) or be released by Pressure Relief Valves (PRVs) in a dedicated safe location. This may reduce the risk contour sizes.
- Detailed CFD simulation of accidental releases from the storage tank, representing actual geometry of the location of operations. It is possible to combine risk contours produced by CFD tool with risk results produced by SAFETI for remaining risk scenarios. Further, potential hazards associated with ammonia release incidents on the receiving ship (while is in the port) should be considered being included to the total risk picture.

Other measures only relevant for Concept 1A/B (shore-based operations):

- Designated truck parking and waiting positions in designated areas.
- Performing tank-filling operation during night-time, where traffic level is considered to be limited and limited presence of public in the area.
- Apply best practice regarding corrosion protection of pipelines, incl. supports clams.
- Integrity testing of lines prior to transfer to detect potential leaks (mandatory for maritime applications).
- Designing the piping with sufficient design pressure to account for expansion pressure to avoid the need for Thermal Relief Valves (TRVs). Should TRVs be needed, consider routing lines back to the tank (if I can be done safely).
- Further assess the risk of trapped liquid to decide if this can be accepted.
- Strategies for lowering the concentration of ammonia vapor in air, e.g. by water screens or water curtains set up in the path of a travelling plume. The water screens should be placed between the release point and the threatened area (e.g. terminal).

Concept 2

For Concept 2 the risk is found acceptable. However, DSB states that generally risk should be reduced to a level which can reasonably be achieved (ALARP). Thus, the following risk reducing measures should be implemented unless it can be demonstrated that the cost involved in implementing the measure is grossly disproportionate to the benefit gained:

- Apply best practice on filling procedures from other ammonia loading operations in populated areas (non-industrial sites).
- Procedure Hazard and Operability (HAZOP) study of bunkering checklists.
- Risk mitigation measures for passengers onboard: Areas to be closed, ventilation strategy (normal ventilation, emergency ventilation, stop of ventilation, over/under-pressure strategy etc.), emergency plans and procedures, location of air intakes relative to potential release points, etc.
- Mechanical shielding of leakage points (for crew).
- Placement and type of gas detectors for best possible leakage detection (e.g. by conducting smoke test, dispersion simulations etc.)
- Water curtain system to control and mitigate toxic vapors.
- Designing a solution that prevents any overfilling to be released to the vent mast (e.g. overfilling tank and drain arrangement).
- The results from Safeti are possibly underestimating the extent of the risk contours in the directions in front and aft of the ship since the structure of the ship will lead more gas in those directions than are applied in the Safeti modelling. Therefore, to get a more accurate

representation of the risk contours, it is recommended to perform CFD simulations of the gas dispersion where the effect of the geometry is accounted for.

To ensure safe bunkering operation, the following standards and guidelines should be considered in the further concept development. Most of these concern LNG, but many of the safety measures will still be relevant for ammonia:

- DNV - Ammonia as a marine fuel safety handbook
- DNV Recommended Practice G105 - Development and operation of liquefied natural gas bunkering facilities
- EMSA - Guidance on LNG Bunkering to Port Authorities and Administrations.
- ISO 20519 - Specification for bunkering of liquefied natural gas fuelled vessels
- ISO 28460:2010 - Installation and equipment for liquefied natural gas - Ship-to-shore interface and port operations
- IACS – LNG Bunkering Guidelines No. 142.
- IAPH – LNG Bunker Checklists
- SGMF – Gas as a marine fuel (safety guidelines).
- DSB - Guidance on use of dangerous substances (Temaveiledere).

It must be emphasised that this risk assessment results only apply to the 3rd party individual risk. The 2nd party individual risk, i.e. risk to people located on either passenger ship or bunker vessel/truck is not assessed by this QRA.

Finally, this evaluation should be regarded as coarse and presented conclusions rest on the assumptions made for concept definition and risk modelling as well as on failure data applied.

3. Power Technologies

FuelCells

Background

This chapter describes fuel cell technology in general, fuel cell types that may be applicable for use with ammonia as fuel and the current developments within this field of application.

Fuel cell technology

A fuel cell is an electrochemical cell that converts the chemical energy of hydrogen and oxygen into electricity through a pair of redox reactions. Fuel cells are different from most batteries in requiring a continuous source of fuel and oxygen to sustain the chemical reaction.

In a fuel cell, hydrogen gas in the form of H_2 is introduced to a catalyst such as platinum where the hydrogen molecule is split into single hydrogen ions while losing two electrons thus becoming oxidized. The hydrogen ions can only move through the electrolyte, while the electrons are routed through wiring from the anode to the cathode where the hydrogen ions are re-acquainted with the electrons and oxygen. Atomic oxygen is reduced, combined with the hydrogens ions and forms water. The electrochemical reactions taking place are:

At the anode: $H_2 \rightarrow 2\,H^+ + 2e^-$

At the cathode: $O_2 + 4e^- + 4H^+ \rightarrow 2H_2O$

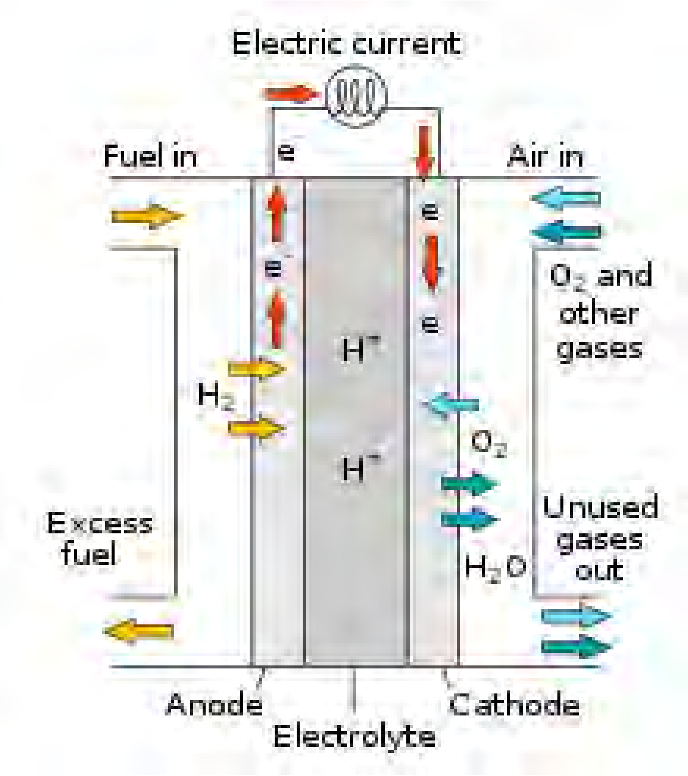


Figure 11 FC basics – source: Wikipedia

The concept of a fuel cell was demonstrated in the early 19th century by Humphry Davy (chemist, held the position of President of the Royal Society 1820-1827), and the first practical fuel cell was demonstrated by William Grove, also chemist, in 1839. This was approximately 40 years before the first diesel engine was developed by Rudolf Diesel.

For several reasons the fuel cell underwent little development for the next 100 years, and it was sir Francis Bacon who in 1959 demonstrated the first 5 kW practical system. The fuel cell was deemed practical by NASA for supplying the needed energy to prolonged space flight and was made integral to the Apollo Lunar Landing program during the late 1960s and early 1970's. The fuel cell system carried onboard provided 1.5 kW of power with the benefit of making drinking water as its exhaust. Fuel cells remain a vital part of manned space flight today.

A fuel cell exhibits its highest efficiency at part load, typically around 50-60% load. A typical fuel cell system consists of the fuel cell stack, with a number of individual fuel cells stacked together to form a unit producing DC voltage and current. Fuel cell systems require several other subsystems and components—the so-called balance of plant (BoP)—which constitute the supporting infrastructure that enables a fuel cell to operate. The types of BoP equipment required depend heavily on the fuel cell type, the fuel source, and the application. In addition, specific operating conditions and requirements of individual cell and stack designs determine the characteristics of the BoP. Most fuel cell systems include BoP equipment that perform fuel processing or reforming, thermal management, water management, and electric power conditioning. The BoP represents a significant fraction of the weight, volume, and cost of most fuel cell systems. The BoP also plays a significant role in the reliability and durability of most fuel cell systems. BoP equipment is sometimes developed and manufactured by manufacturers other than fuel cell manufacturers.

When stating the efficiency of fuel cells, figures are often given for the fuel cell stack without the BoP, although the BoP is a parasitic load and vital for the functioning of the system. It should thus be considered part of the efficiency equation.

Types of fuel cells

There are several types of fuel cells, differentiated both by the material used for the electrolyte and the charge carrier. The types are:

- Polymer electrolyte membrane (PEMFC)
- Phosphoric acid (PAFC)
- Alkaline (AFC)
- Molten carbonate (MCFC)
- Solid oxide (SOFC)

The typical characteristics of these types of fuel cells are given in the table below.

	PEMFC	PAFC	AFC	MCFC	SOFC
Electrolyte	Polymer membrame	Liquid H_3PO_4	Liquid KOH	Molten carbonate	Ceramic
Charge carrier	H^+	H^+	OH^-	CO_3^{2-}	O^{2-}
Operating temperature	80-90 °C	200 °C	60-220 °C	650 °C	600-1000 °C
Catalyst	Platinum	Platinum	Platinum	Nickel	Perovskites
Cell components	Carbon based	Carbon based	Carbon based	Stainless steel	Ceramic based
Fuels	H_2	H_2	H_2	H_2, CH_4	H_2, CH_4, CO, NH_3
Efficiency	35-55%	35-50%	45-65%	40-50%	45-60%

Table 2 Overview of fuel cell technologies

The PEMFC is the technology used for automotive applications and has also been suggested for use as the primary type for maritime applications. This type of fuel cell needs a feedstock of pure hydrogen and it is sensitive to pollution – especially carbon monoxide and Sulfur. The PEMFC requires high purity of the hydrogen supply, often more than 99.99%. Platinum is used as catalyst due to the low operating temperature, to split the hydrogen into atomic hydrogen before oxidation at the anode. The PEMFC has the highest power density of all fuel cell types, with values between 500-2500 mW/cm^2. The cell type has fast start-up response times and has high tolerance of load cycling and on/off cycling. Therefore, the technology is preferred for use in automotive applications.

The Solid oxide fuel cell (SOFC) was first dveleoped by Nernst in 1899 when he introduced zirconia (ZrO_2) as an oxygen ion conductor. The SOFC is a fully solid-state device and converts the chemical energy of its fuel by the oxide ion–conducting ceramic material of its electrolyte to electrical power. In the SOFC the negatively charged ion (O^{-2}) is transferred from the cathode through the electrolyte to the anode and produces water at the anode side. SOFC can use a range of different fuels including hydrogen and carbon monoxide. The high-operating temperature of the SOFC eliminates the need for the precious metal electrocatalysts, but it does introduce a range of other material related problems.

At temperatures above 600 °C the choice of materials is limited by its ability to handle stress, vibrations, thermal expansion resulting in sealing problems, leakage management and high ignition probability due to very high temperatures, corrosivity and general reactivity at elevated temperatures etc.

In 1993, Rolls Royce Fuel Cell Systems, located in Canton, Ohio, and the United Kingdom, began to focus on developing fundamental aspects of SOFC technology. It developed a unique stack, which it called the integrated planar solid oxide fuel cell (IP-SOFC). A typical IP-SOFC consists of a flattened ceramic tube with segmented-in-series electrochemical cells deposited on its outer surfaces. This design concept represented a cross between tubular and planar fuel cell designs. The IP-SOFC was intended for use in medium-scale 1 MW stationary power applications.

In 2000, RR developed a 1 kW planar SOFC stack for laboratory testing. The positive result made RR highly optimistic about the near-term commercial prospects. RR was convinced that the optimum product for market entry would be a pressurized system at MW scale.146 RR participated in a large number of UK and EU Framework R&D projects to scale up its stack. By 2007, RR had successfully developed a 15 kW stack.

RR also had been developing an SOFC gas turbine hybrid system fueled by natural gas for power-generation applications on the order of a megawatt. RR's hybrid 1 MW power plant to be developed under the SECA program would reportedly consist of an 800 kW SOFC and a 200 kW RR Gas Turbine. Rolls Royce has since terminated its activities on SOFCs and is now focusing on PEMFC development through its subsidiary MTU.

Use of ammonia as fuel

PEMFC

These fuel cells need a high degree of fuel purity, as mentioned in a previous section. The PEMFC operates on hydrogen as fuel, thus an application using ammonia, NH_3, needs to shed the nitrogen component prior to the feedstock entering the fuel cell stack. To achieve this such a system must use a process unit call a cracker. An ammonia cracking unit is a thermal device capable of splitting the NH_3 molecule into N_2 and H_2 dispersing the N_2 gas and introducing H_2 gas to the stack. There is a need for a purification unit ensuring the H_2 flow holds the required quality in order to avoid contamination of the fuel cell stack.

Ammonia crackers are found in landbased refineries and other process plants. In order to make such systems applicable for use onboard ships they must be re-designed with focus on size and weight. In addition, the ammonia cracking process is designed for constant or slow variations in load. Process output is thus not proportional to the power requirements of the fuel cell stack. The system needs a buffer tank solution similar to the HFO day tank used on ships today. This will add the complexity of a hydrogen compressor and tank system.

There are currently no such ammonia fuel systems on the market today.

SOFC

Ammonia fuelled SOFCs for transportation have been proposed, such as that of Al-Hamed and Dincer who proposed an ammonia-fed SOFC integrated with a gas turbine and ammonia-organic Rankine cycle to recover and utilise waste heat as a tri-generation system for cleaner railway applications. The hybrid system was studied using a thermodynamic model to evaluate its energy and power outputs. It was found that the energy efficiency of the integrated system was 59%, with no CO2 emissions and sufficient energy demand to satisfy a passenger locomotive.

Along with public transport, power generation from ammonia fuelled SOFCs has been proposed to power fuel cell vehicles (FCV). Perna et al. studied a combined heat, hydrogen and power (CHHP) system, where an ammonia fuelled SOFC was used to produce 100 kg per day of hydrogen to refuel between 20 and 30 FCVs. It should be noted that the oxide materials for making SOFCs are fragile, making them challenging to directly power electric vehicles. SOFCs based on metal current collectors are more robust. Further research is required to determine whether these materials are strong enough to be used in transportation applications.

A hybrid type of technology may be used to power electric vehicles whereby ammonia SOFCs can work alongside a battery component to be used as a range extender of an electric vehicle. The electricity from a direct ammonia SOFC may be used to charge the battery during the duration of recharge and electricity from the battery may be used to power the electric vehicle. Further to this, ammonia SOFCs can be used as auxiliary power units (APUs) to supply electricity for lorries, buses, trains and ships.

Proposed SOFC projects

The MultiSchiBZ project run by a consortium led by ThüssenKrupp is aiming at developing and demonstrating a solid oxide fuel cell (SOFC) suitable for maritime use by 2020-2022.

The SOFC4Maritime led by Alfa Laval aims to accelerate the development of solid oxide fuel cell (SOFC) technology, which can use green fuels to generate electricity. The project will look at different future green fuels – such as ammonia, hydrogen or bio-methane – for power production onboard marine vessels.

ShipFC is a project aiming at providing a 2 MW SOFC for powering an offshore supply vessel. Consortium partners are Eidesvik, Equinor, Prototech, Wärtsilä and Maritime CleanTech. The project aims to isntall a working system onboard the Viking Energy by late 2023.

Challenges, R&D needs

Current use of SOFC are for stationary power applications, although several efforts have been made to investigate use in mobile and other non-stationary applications. SOFCs operate at very high temperatures which leads to challenges in selecting suitable materials that achieve both high actual operating efficiencies and high lifetime. The US DOE reported to Congress in 2019 that no existing SOFC technologies had been demonstrated at or beyond their stated goal of achieving 40.000 hours lifetime at degradation rates of less than 0.2% per 1000 hours, a target said to be vital for industrial competitiveness of the technology.

The challenges related to materials also manifest themselves through sensitivity towards mechanical stress. Very few materials exist that can be subjected to temperatures above 600 °C while handling high mechanical stress. In mobile applications a fuel cell will be subject to accelerations, impacts and vibrations.

Major challenges for SOFCs that need to be addressed through research, development and innovation are:

- Materials for high temperature operation with low degradation rate and the ability to handle mechanical stress

- Trade-off between system efficiency and operating lifetime, materials can be found that increase lifetime while sacrificing maximum efficiencies

- System performance and control strategies. Thermal management and load following, combined with system architecture to ensure high operational efficiency throughout the operational profile of vessel.

- Manufacturing cost.

- Fuel flexibility. A SOFC can operate on different fuels, but there is a need to verify performance with different fuels and also in fuel switching to see how this affects lifetime, degradation of catalysts

-Exhaust gas handling. During load variations a fuel cell will need to bypass some of the fuel flow to avoid flooding the fuel cell. E.g. ammonia slip must be handled, also NO_x and possible N_2O must be handled to avoid negative impacts from exhaust gas emissions.

- Validation of small and large scale systems

Internal Combustion Engines (ICE)

Ammonia powered internal combustion engines

In 1933 Norsk Hydro converted a small truck. The truck carried an ammonia reformer that extracted hydrogen and then burned it in the trucks ICE.

First utilization of liquid anhydrous ammonia as fuel for motor busses took place in Belgium in 1943.

South Korean researchers succesfully road tested a dual fuel passenger car in 2016 running on 70% Ammonia and 30% Gasoline.

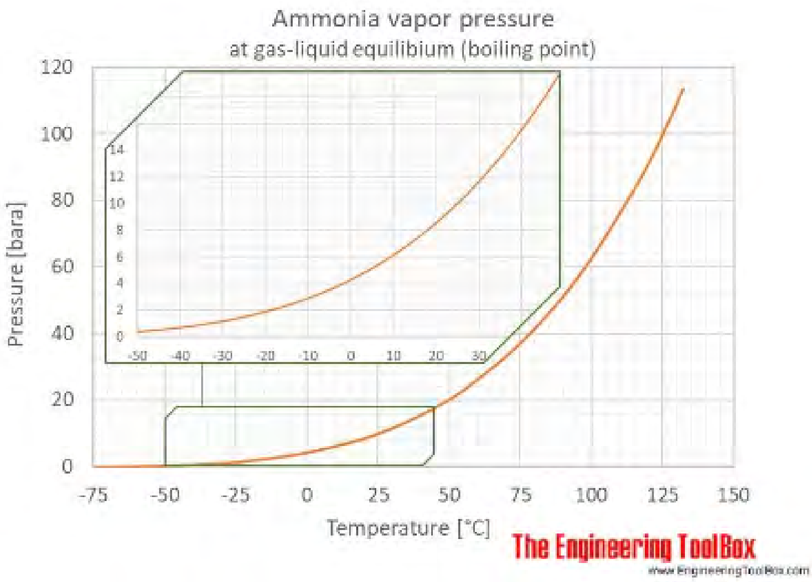
Australia's CSIRO tested a Toyota Mirai fuel cell vehicle on ammonia in 2018

Using ammonia as fuel for ICEs is not an entirely new concept. Kobayashi et al. (2019) explain that the first-time ammonia was used as fuel was during world war II. During the war, ammonia was used to power omnibuses. Ammonia was mixed with coal, which was used more commonly as fuel. Lhuillier et al. (2019) states that the first real wave of interest using ammonia as fuel was in the 1960s. A study carried out by Pearsall and Garabedian in the '60s concluded that ammonia could be used as a fuel in a compression ignited engine if a very high compression ratio is used. Gray, Dimitroff, Meckel, & Quillian reported similar results a year earlier. Kobayashi et al. (2019) explain that ammonia has not been utilized as a fuel since war times in combustion systems; it has been used to study NOx formation and reduction chemistry in combustion systems, particularly in the 1970s. The second wave of interest in using ammonia as an energy source rose in the 1990s due to the ongoing discussion about global warming.

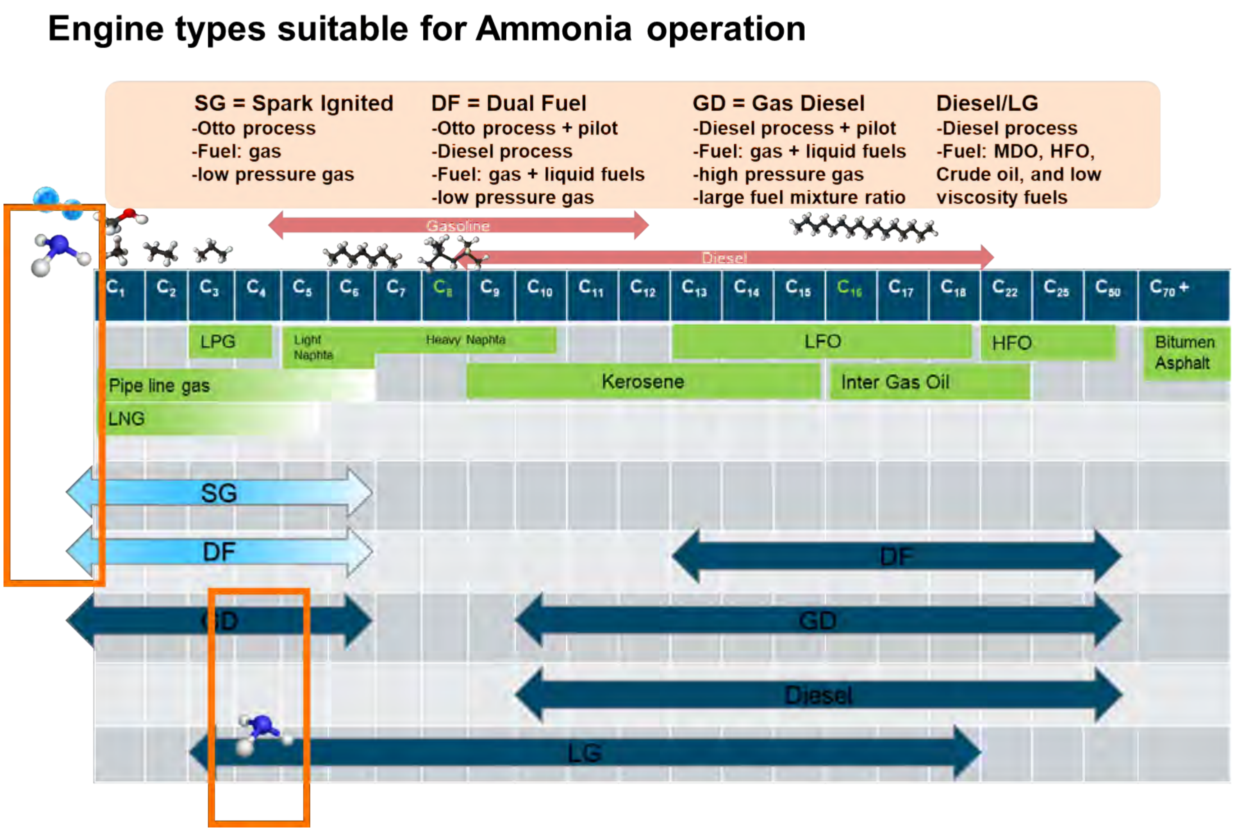
The internal combustion engine is an efficient and robust energy converter for almost any fuels. The choice of the best engine type to select for a certain application is depending on many parameters such as CAPEX, OPEX, fuel availability, space required, emission regulations, fuel flexibility, loading performance, etc.

Ammonia can be stored and used both in liquid form as well as in gaseous form and can thus be used in several engine concepts.

The exhaust from the ICE is expected to be NOx rich, and aftertreatment will be needed. Further, the potential of N2O as well as NH3-slip in the exhaust need to be carefully handled.



Different engines basic technologies and their suitability for various fuels is shown in the picture below.



Engines can be divided into different categories depending on the design. These are:

- 2-stroke and 4-stroke

- Diesel and Otto combustion
- High speed, medium speed and low speed
- Single fuel and multiple fuel
- High-pressure and low-pressure fuel injection
- Lean burn and stoichiometric combustion

The development for ammonia as fuel is ongoing on both 2-stroke and 4-stroke engine platform. Three different engine concepts for the 4-stroke engines are presented here and similar concepts can also be developed for the 2-stroke engines and they are also shortly mentioned in the text.

4- stroke, medium speed, dual fuel, lean burn gas engine.

This engine type is used both as main engine and as auxiliary engine. The engine type is available from most of the major engine makers and the engine output is ranging from ~500 kW to ~20 MW.

The dual fuel engine is a multiple fuel engine that can operate on both gaseous fuels as on liquid fuel. The fuel systems are divided so that the engine can easily switch between different fuel modes when requested or required. There are also possibilities to operate the engine on both gas and liquid fuel simultaneously i.e. fuel sharing.

The engine operates in gas mode according to the otto combustion principle and in liquid fuel mode according to the diesel combustion principle. In gas mode the ignition is handled by a micro pilot diesel injection.

The dual fuel lean burn gas engine is by nature compliant with the IMO Tier III NOx regulations, thanks to the lean burn otto engine concept that provides fast combustion, which provides a high efficiency, together with a rather low combustion temperature, which provides both low NOx emissions as well as low thermal loading on the engine components.

The medium speed dual fuel engine provides fast loading characteristics that make is suitable for most of the marine applications. As the engine is also equipped with a liquid fuel system the fuel modes can be switched without delay, which makes the engine concept both robust and safe.

The low-pressure gas system is providing a safe and easy to install fuel system for the vessel. The low-pressure gas system also requires minimal external power to operate.

The medium speed dual fuel engine can operate both as a constant speed engine and as a variable speed engine depending on the application. The engine efficiency can be kept high on a wide range of the operating field.

In this type of engine ammonia can be used in two different ways:

1. As blended together with natural gas (or LNG) in gaseous form before the engine gas inlet. This operation will then be similar as a DF engine operating in gas mode.
2. As separate admission of ammonia via the gas system and operated together with the liquid fuel (fuel sharing)

This concept can be compared to the WinGD gas engine for the 2-stroke engines

4- stroke, medium speed, spark ignited, lean burn gas engine.

This engine type is used both as main engine and as auxiliary engine. The engine type is available from several engine makers and the engine output is ranging from ~500 kW to ~10 MW.

The spark ignited gas engine is a single fuel engine, that is developed to operate on gaseous fuels. As the engine is a single fuel installation, the fuel system simple and easy to design.

The engine operates according to the otto combustion principle. The ignition is handled by a spark plug that can either be in a prechamber or as an open chamber directly in the combustion chamber.

The spark ignited lean burn gas engine is by nature compliant with the IMO Tier III NOx regulations, thanks to the lean burn otto engine concept that provides fast combustion, which provides a high efficiency, together with a rather low combustion temperature, which provides both low NOx emissions as well as low thermal loading on the engine components.

The medium speed gas engine provides fast loading characteristics that make is suitable for most of the marine applications.

The low-pressure gas system is providing a safe and easy to install fuel system for the vessel. The low-pressure gas system also requires minimal external power to operate.

The medium speed gas engine can operate both as a constant speed engine and as a variable speed engine depending on the application. The engine efficiency can be kept high on a wide range of the operating field.

In this type of engine ammonia can be used as blended together with natural gas (or LNG) in gaseous form before the engine gas inlet.

4- stroke, medium speed, high pressure gas diesel engine.

This engine type is used both as main engine and as auxiliary engine.

The high-pressure gas diesel engine is a multiple fuel engine that can operate on both gaseous fuels as on liquid fuels. The fuel systems are divided so that the engine can easily switch between different fuel modes when requested or required. There are also possibilities to operate the engine on both gas and liquid fuel simultaneously i.e. fuel sharing.

The engine is always operating according to the diesel combustion principle independent of the fuel. In gas mode a small pilot fuel is injected simultaneously with the gas to achieve a robust start of combustion.

The high-pressure gas diesel engine is operating as a diesel engine, which gives the similar combustion properties regardless of the fuel. The engine is compliant with the IMO Tier II NOx regulations.

The medium speed high-pressure gas diesel engine provides fast loading characteristics that make is suitable for most of the marine applications. The engine is also rather insensitive of the fuel quality, thanks to the diesel combustion.

The high-pressure gas system is providing a direct and robust cylinder wise fuel injection which is providing a complete combustion with a minimum of unburned hydrocarbons.

The medium speed gas engine can operate both as a constant speed engine and as a variable speed engine depending on the application. The engine efficiency can be kept high on a wide range of the operating field.

In this type of engine ammonia can be used in three different ways:

1. As blended together with natural gas (or LNG) in gaseous form before the engine gas inlet. This operation will then be similar as a GD engine operating in gas mode.

2. As separate admission of ammonia via the secondary fuel system and operated together with a pilot liquid fuel. This is similar to the methanol usage in Stena Germanica
3. As separate admission of ammonia via the secondary fuel system and operated together with the liquid fuel (fuel sharing)

This concept can be compared to the MAN ME-GI gas engine for the 2-stroke engines

The different engine concepts are showing that the adaptation of ammonia for the engines in the marine sector will in most cases start with the blending of ammonia together with another fuel. This will also allow the vessel to operate as before on the other fuel so that the build up of ammonia infrastructure, availability and usage can adapt to the increasing demand.

In the two tables below the main features of the engines for the different concepts are listed. The first table shows engine concepts with LNG as the main fuel and table 2 shows the engine concepts with MDO or HFO as the main fuel.

Feature	Impact
Output	SG/DF: The output can be kept at the same level as with LNG. GD: The Ammonia system is separate and can be dimensioned as required without any impact on the MDO/HFO system All: The maximum ratio of Ammonia is restricted by combustibility and thermal load
Efficiency	Expected to be lower as the combustion speed is lower with Ammonia compared to diesel or LNG at the same output.
Pros and Cons	SG/DF: + Ammonia can easily be pressurized to the needed pressure level - Ammonia slip to be dealt with GD: + Small quantities of Ammonia slip
Possibility for retrofit	SG/DF: Minor modifications on the engine. The gas system need to have mixing possibilities GD: A diesel engine could be converted with a new fuel injection system and with necessary controls
Emissions	NOx: SG/DF: IMO Tier III GD: Expected to be on the same level as with MDO, need SCR. CO2: Depending on the mix ratio SOx: SG/DF: No emission. GD: Depending on the mix ratio N2O: Not known
Multi-fuel capability	SG: Natual gas/Ammonia DF: Natural gas, MDO/HFO, Ammonia The engine can also run on full output with MDO/HFO GD: MDO/HFO can be mixed with Ammonia before the engine. The engine can also run on full output with MDO/HFO.

Table 3 The impact on performance and feasibility by mixing ammonia with natural gas (SG, DF or GD engine types) or separately injected into the cylinder simultaneously with MDO/HFO (DF or GD engine types)

Feature	Impact
Output	The fuels system to be dimensioned for the maximum ratio of Ammonia. The maximum ratio of Ammonia is restricted by combustibility and thermal load
Efficiency	Expected to be lower as the combustion speed is lower with Ammonia compared to diesel at the same output.
Pros and Cons	+ Ammonia doesn't need to be evaporated as it can be pumped to high pressure from liquid + Small quantities of Ammonia slip - The engine need to be optimized for one quality range of fuel
Possibility for retrofit	A diesel engine could be retrofitted with a new fuel injection system and with necessary controls
Emissions	NOx: Expected to be on the same level as with MDO, need SCR. CO2: Depending on the mix ratio SOx: Depending on the mix ratio N2O: Not known
Multi-fuel capability	MDO/HFO can be mixed with Ammonia before the engine The engine can also run on full output with MDO/HFO.

Table 4 The impact on performance and feasibility by mixing ammonia with MDO/HFO (LG engine type)

Ammonia as the main energy carrier for future

One suggestion for future use of ammonia as the main energy carrier can be by catalytic cracking to form a mixture of hydrogen, nitrogen and ammonia. A suggested fuel system for 100% ammonia as fuel is shown in Figure 12 using a catalytic cracking to form fuel suitable for a diesel engine. The combustion properties of the mixture can be adjusted by the concentrations of H2 and NH3. The mixture concentrations are dependent on the type the catalyst and temperature. Since ammonia has a low reaction rate in combustion and hydrogen has a high reaction reaction rate, the feed fuel will be a mixture of NH3 and H2 for use in diesel engines.

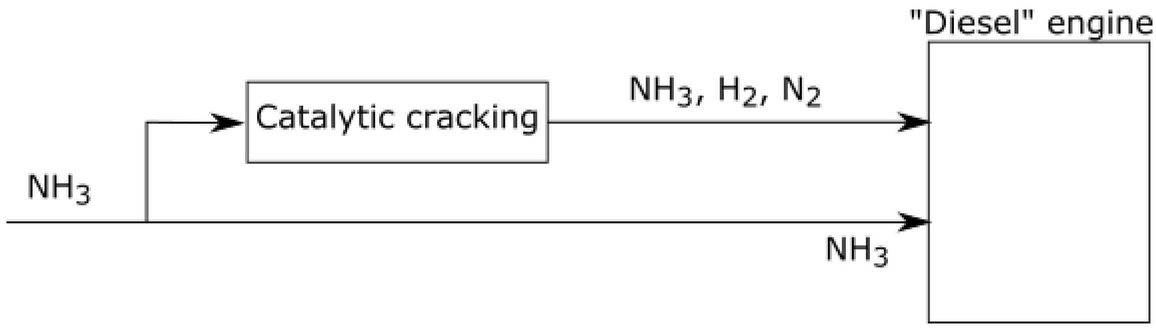


Figure 12: Simple schematic of fuel system for 100 % ammonia.

The combustion properties of the H2/N2/NH3 mixture in air can be controlled by the concentrations of each component. The H2/N2 ratio is fixed by the amount of ammonia that is converted in the cracking process, but additional ammonia can be fed directly to the engine. This pure ammonia stream can also be injected as liquid. An example of how the laminar burning velocity and ignition delay times in pre-mixed gas is dependent of NH3/H2 fractions is shown in Figure 13. These properties are also compared to methane and propane for reference. An possible solution for using close to 100% ammonia as fuel can be to use this mixture the same way as for LNG in a diesel engine where the mixture is ignited by a small diesel spray or spark.

For use in a diesel engine the critical combustion properties need to be determined at states relevant for an ICE. There is an additional need for research on for instance energy efficiency of the system to determine if this is a possible way of introducing ammonia as a main energy carrier.

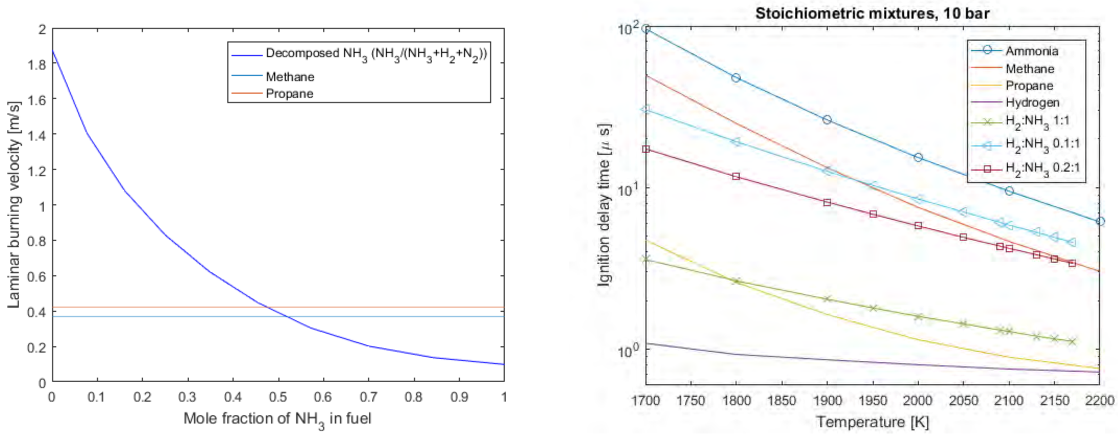


Figure 13: Left: Laminar burning velocity of NH3-H2-air, methane-air and propane-air at 1 bara and 298 K. Right: Ignition delay times as a function of temperature at 10 bara for mixtures of NH3 and H2 in air compared to methane and propane.

4. Case study

Is it possible to convert an existing passenger vessel to use ammonia as fuel? Color Fantasy was chosen for this case study. The study included bunkering arrangement, tanks, fuel treatment systems, location of equipment, installation requirements from the authorities (flag state and Class). Color Line has together with Fosen Design & Solutions made a proposal how to install the main components onboard. We have had good and important contributions from Wärtsilä Gas Solutions, Yara and Purenviro with knowledge and solutions. There are still a lot of issues that must be solved, but we think it will be possible to design and install safe solutions to utilize ammonia as a fuel on passenger vessels.

Info about existing vessel

Vessel details

M/S Color Fantasy

Call signal LMSD
IMO no. 9278234
MMSI Selective call no.257 182 000
Registration: NOR
Built year: 2004
Classification society: DNV GL

Principal dimensions:

Length over all: 223.72 m
Max width incl. fender beam (Bmaxf): 35.43 m
Total height from keel to top of mast (H(max)):59.22m
Max Draught: 7.0 m
Gross registrated tonnage (GRT): 75027 RT
Net registrated tonnage (NRT): 48197 RT

Capacities		
Passengers	2700	persons
Crew	300	persons
Persons onboard	3000	persons
Lane Meters (truck)	1270	meters
Cars (4.5 m units)	750	units

M/V «Color Fantasy» has been chosen as a case-vessel for this study.

- Vessel available in Oslo every 2nd day.
- Chief Engineer (Roar Tverberg) attends this study.
- Ship is fairly equal in machinery concepts and annual energy revenue and as for 3 other vessels in our fleet. Results may be copied there and beyond.
- May bunker in Oslo, Norway and/or Kiel, Germany.

Color Line MARINE

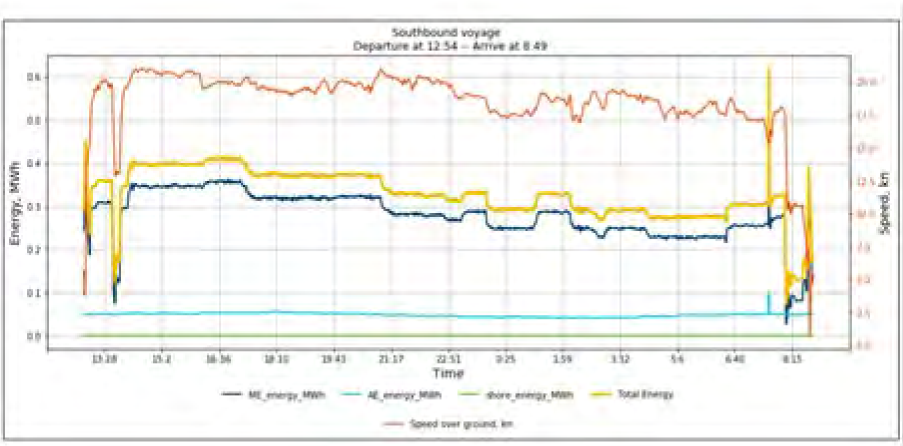
COLOR FANTASY: PROPULSION PLANT

Conventional diesel-mechanic:

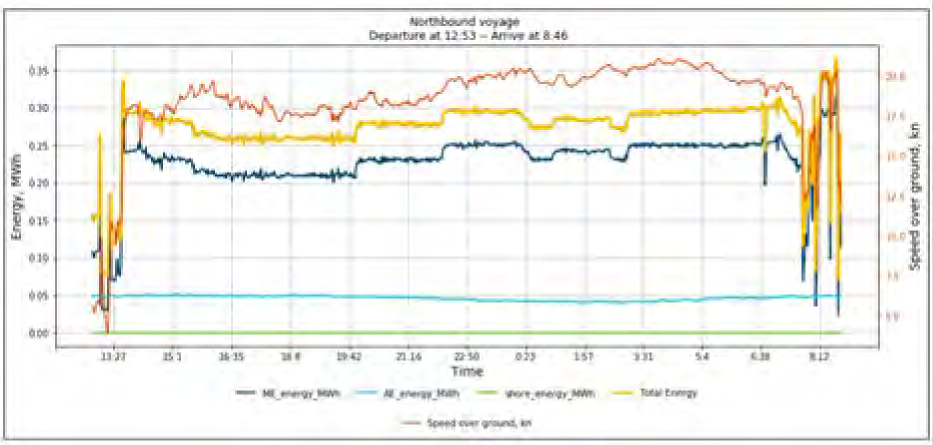
- 4 Medium speed main engines Wärtsilä 8L46B ⇒ 31 200 kW
- 4 Medium speed auxiliary engines Wärtsilä 6L26A2 ⇒ 8 160 kW
- 2 Shaft generators ⇒ 9 600 kW

Operating profile

Oslo-Kiel (Southbound)



Kiel-Oslo (Northbound)



In this case study we assume Color Fantasy will take bunker (ammonia) every second port call to Oslo, every 4th day. The vessel will have the required volume for one additional roundtrip as spare. With a blending of 70% of the energy for HFO and 30% for ammonia the calculated reduction of CO_2 emissions is 25%.

AMMONIA CONSUMPTION/CO2 EMISSIONS

Color Line MARINE

Current fuel consumption/CO2 emissions compared with 70/30 mix with ammonia

	Operating profile	HFO	MGO AE consumption	CO2		HFO consumption (70%)		NH3 consumption (30%)		MGO AE consumption	CO2	
				HFO	MGO						HFO	MGO
		(t)	(t)	t	t	(t)	(nm^3)	(t)	(m^3)	(t)	t	t
ONE ROUND TRIP	Oslo											
	Port stay											
	Maneuvering out	0,25	0,05	0,79	0,16	0,18	0,40	0,17	0,29	0,05	0,55	0,16
	Slow speed	0,43	0,08	1,33	0,26	0,30	0,66	0,28	0,49	0,08	0,93	0,26
	Transit speed	74,16	14,38	230,97	46,11	51,91	115,36	48,77	86,01	14,38	161,68	46,11
	Slow speed	0,85	0,17	2,65	0,53	0,60	1,32	0,56	0,99	0,17	1,86	0,53
	Maneuvering in	0,25	0,05	0,79	0,16	0,18	0,40	0,17	0,29	0,05	0,55	0,16
	Port stay in Kiel											
	Maneuvering out	0,22	0,04	0,69	0,14	0,15	0,34	0,15	0,26	0,04	0,48	0,14
	Slow speed	1,15	0,22	3,58	0,71	0,80	1,79	0,76	1,33	0,22	2,50	0,71
	Transit speed	74,16	14,38	230,97	46,11	51,91	115,36	48,77	86,01	14,38	161,68	46,11
	Slow speed	0,43	0,08	1,33	0,26	0,30	0,66	0,28	0,49	0,08	0,93	0,26
	Maneuvering in Oslo	0,22	0,04	0,69	0,14	0,15	0,34	0,15	0,26	0,04	0,48	0,14
		152	**30**	**474**	**95**	**106**	**237**	**100**	**176**	**30**	**332**	**95**

Ammonia for 2 round trips + 1 ⇒ Total 530 m^3

- 25% CO2 emissions

FOSEN DESIGN & SOLUTIONS
MAKES THE FUTURE AT SEA

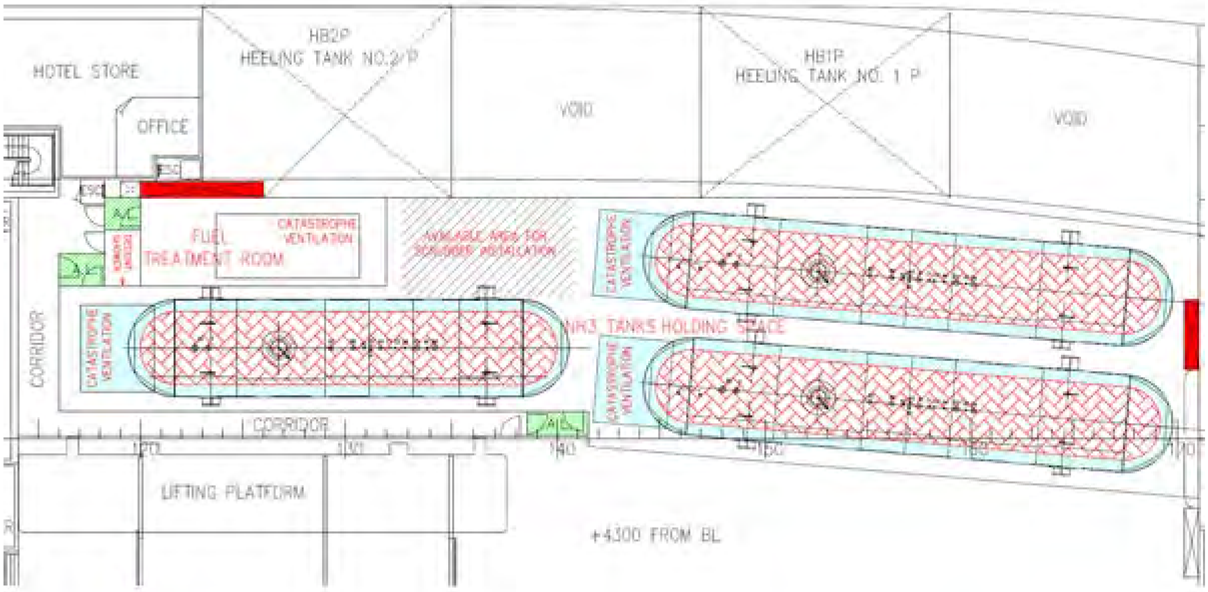
Possible system solutions / configurations onboard

The design includes 3 tanks of type C, 2 x 240 m3 and 1 x 120 m3, total volume is 600 m3. Ventilation in and out of the tank holding space is marked with red color. Air locks are marked green. Escape ways have been identified. Fuel treatment room and space for scrubber installation are marked.

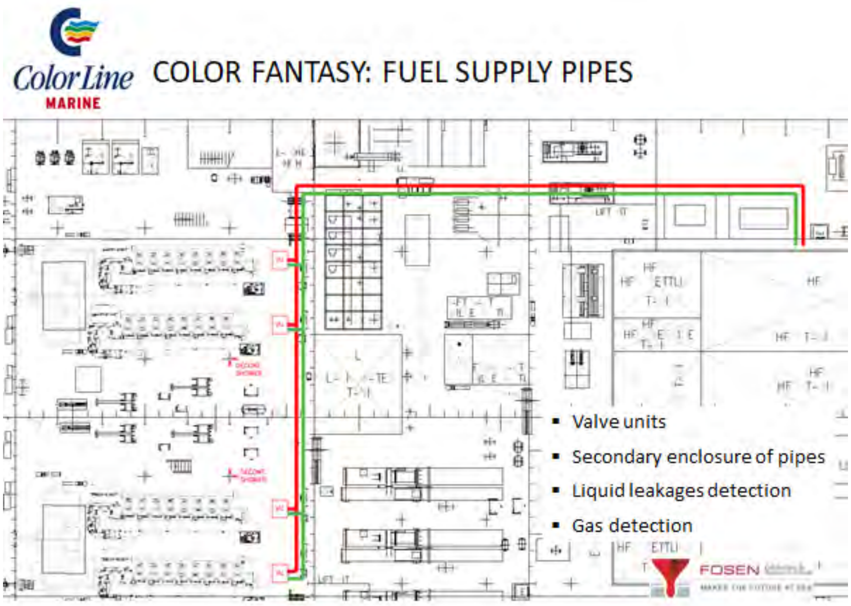
Release of ammonia to the atmosphere is not an option for this type of vessel.

Operational releases of ammonia from purging of pipes etc. will be handled in a closed loop scrubber system.

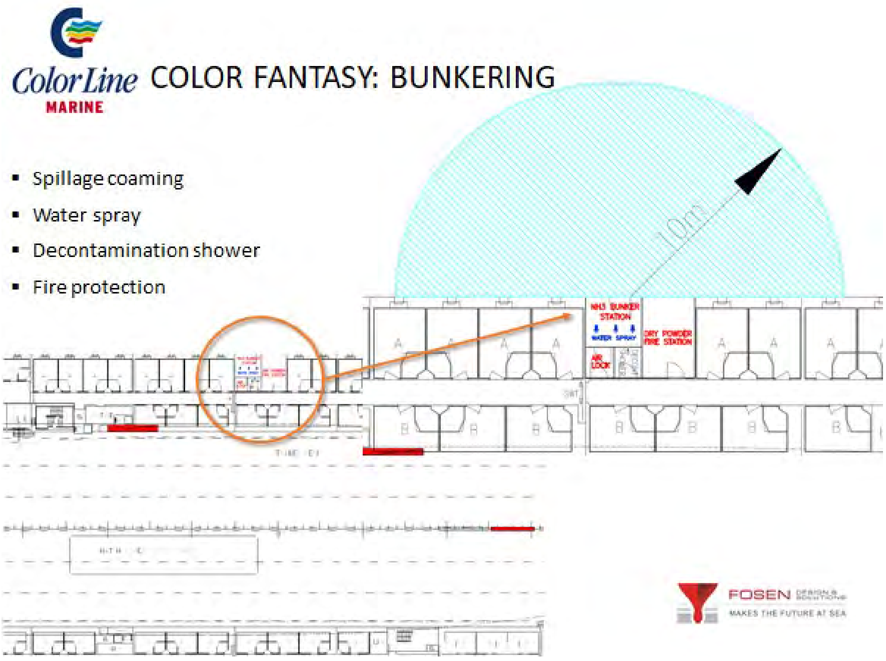
In an emergency situation like failure of one PV breaker or fire leading to increased tank pressure the released ammonia will be treated in a scrubber before it is released to the sea.



Routing of NH3 fuel pipes from tanks to engines



Bunkering station for ammonia to be arranged



Estimate OPEX (fuel, safety, maintenance)

New equipment to handle ammonia will need to be installed. In addition to the rebuilt or new engines this includes components like scrubbers, ventilation systems, pumps, pipes, tanks and bunkering systems. Operating expenses will increase to maintain these systems.

Estimated additional running costs = Current running cost for Main Engine(s) + 15%

The price of the ammonia is not included in this estimate.

Estimate CAPEX for the most attractive alternatives

The prices for installation of tanks and equipment, and converting the main engines have been estimated based on input from suppliers and shipyards.

Engineering, piping, nitrogen generator, NH3 tanks, scrubbers, yard materials and yard installation costs are estimated to NOK 144 million.

Converting the Main Engines 4 x W46 are estimated to NOK 60 million.

5. Financial aspects

Governmental support programs

For a ship owner that shall reduce the carbon footprint of their operations, using ammonia as fuel is one of the promising solutions, especially for ships with need for high for power and/or relative long range. In a transition period where the price and availability for ammonia as fuel most likely will be varying based on the operational areas of a ship, it is likely that a lot of existing ships will be converted in order to be able to use ammonia as fuel. This will be a decision based on a combination of local regulations, operational predictability, and requirements from the customers.

In the long run when the price and availability of green ammonia is more stable, it is expected that ships are designed and built to operate on ammonia from the day of delivery.

Before the combustion engines or fuel cells operating on ammonia is considered a mature technology, it will be possible to apply for financial support from some of the Norwegian governmental institutions. Normally, it is possible to receive up to 40 to 50 % of the extra investment needed compared to building a conventional ship. This will apply for both conversions and new ships. We expect that the support programs in the future will reflect the introduction of the different alternative fuels on a more specialized support program, but currently, the following programs are available that is addressing ship owners:

1. Enova
   a. Electrification of sea transportation
      This program is based on a battery-based hybrid installation and the upgrade of the supporting systems such as switchboards and ventilation. A ship owner can install a battery package and then also include other emissions reduction technologies and obtain the same share of financial support. This could be investments in storage tanks for ammonia, fuel cells for ammonia or extra cost for consumption engines operation on ammonia.

   b. Piloting of new energy and climate technology

      This program is aimed to reduce the technology risk before the economic risk is triggered. This program can support development and verification of new technology and solutions and is targeting zero-emission solutions that involves several partners in a project. (Examples are Topeka, Yara Birkeland and the new hydrogen powered ferry from Norled)

   c. Full scale testing of innovative energy and climate technology

      Risk mitigation support for first movers that is aimed to increase the competence in Norwegian companies. Support can be granted to companies that would like to implement innovative solutions that is considered to be way ahead of the common practice in the industry

2. Green platform
   Green platform can give companies and research institutions economic support to research and innovation driven green transition. This support program will enable Norwegian companies to align and utilize support programs from EU such as Horisont Europe Green Deal. The purpose is to support projects from early research phase through development and testing to commercialization and is aimed to support the export of green technology form Norwegian companies. This is strengthening some of the established support programs such as Pilot-E.

3. Pilot-E

This program is cooperation between NRC, Innovation Norway and Enova and is described as a fast track trough the governmental support programs from idea to the marked. The program targets a group of companies that join forces to develop new ideas and take this to a commercial level.

As for all support programs, they are mainly targeting to close the gap for investment in new and environmentally friendly technologies. In addition, the state support regulations only allow maximum support of 50 % of the additional cost. The remaining 50 % extra investment will then need to be covered by the ship owner that need to be paid back through increased rates and possibly other incentives from the customers.

In addition to the additional investment cost, the cost of alternative fuels is expected to be significantly higher for a long time and the future prices and availability relates to a lot of uncertainty that needs to be addressed. This is expected to be on the political agenda as a crucial barrier that need to be solved soon.

Financial risks and consequences

The current and future risks for ship owners are related to stricter regulations coming from IMO, individual national states, increased focus from the cargo owners, changes in global supply and demand situation.

The banks and investors are aware of these risks and are mitigating their risk exposure by increasing their requirement for reporting of the carbon footprint for all their investments. One example is the Poseidon principles where the 22 banks have joined forces and established a common a global framework for assessing and disclosing the climate alignment of financial institutions' shipping portfolios. They establish a common, global baseline to quantitatively assess and disclose whether financial institutions' lending portfolios are in line with adopted climate goals.

As a part of the increasing climate risks, the financial institutions are also constantly screening their portfolio and categorize their investments in different shades of green. The climate risk will therefore play an increasingly important role when assessing new projects as well as renewing expired bonds. Assets that are associated with high climate risk will need to pay a risk premium on the interest rate or risk to lose the financing.

The big question that arises is whether a ship owner should convert existing assets to comply with the future regulations and requirements or if they should order new vessels? This evaluation will look different in the different ship segments and the ambition for this pilot was to explore how the banks are evaluating the passenger ferry/cruise sector operating on fixed routes and using Color Line as pilot owner. Compared to other ship segments, this would be a good case for testing a methodology for creating a pathway for a shipowner mitigating the climate risk. This is because the current fleet is fixed as well as the current and future area of operation.

Unfortunately, the challenges with the current COVID situation, have limited the possibility to go into details with respect to an evaluation of the financing options for the existing fleet. All effort from the pilot owner has been focused on the re-structuring and survival through the pandemic.

It still is a need to understand how to assess the investment options for conversion of a fleet to extend the lifetime of the vessels compared to build new vessels and as a continuation, this pilot proposes to lift this topic into a separate pilot. The new pilot is proposed to explore and develop a generic framework for evaluation of existing assets in a climate risk perspective and end up with specific guidelines that can be used both by shipping companies and financial institutions.

New pilot proposal

Pilot owner:
DNB or another shipping bank

Pilot participants:
- Ship owners representing different segments (e.g. Stove Shipping, Thome, Color Line, DFDS...)
- Yards, equipment suppliers

Background -why this pilot?
As a part of the increasing climate risks, the financial institutions are also constantly screening their portfolio and categorize their investments in shades of green. The climate risk will play an increasingly important role when assessing new projects as well as renewing expired bonds. Assets that are associated with high climate risk will need to pay a risk premium on the interest rate or risk to lose the financing.

The big question that arises is whether a ship owner should convert existing assets to comply with the future regulations and requirements or order new vessels?

Aim of the pilot study:
Explore a and develop a generic framework for evaluation of existing assets in a climate risk perspective and to end up with specific guidelines that can be used both by shipping companies and financial institutions

Main activities of the study:
- Map existing framework, publicly available for evaluation of climate risk in the shipping industry
- Map and define the ship segments to be covered in the study and identify a set of scenarios to be evaluated
- Selection of case ships in the selected segments with a representative age profile
- Estimation of conversion costs and newbuild costs, based om the defined scenarios
- Develop a generic tool that can be used by ship owners and financial institutions that can provides decision support for ship owners in short, medium and long time perspective

Deliverables: A PowerPoint presentation and a climate risk calculation and decision tool (Excel based) for shipowners and financial institutions

REFERENCES

/1/ https://www.regjeringen.no/en/dokumenter/the-governments-action-plan-for-green-shipping/id2660877/

/2/ DNV GL White paper "Ammonia as marine fuel" – ref https://www.dnvgl.com/Publications/ammonia-as-a-marine-fuel-191385

/3/ European Environment Agency – EEA – ref https://www.eea.europa.eu/data-and-maps/daviz/co2-emission-intensity-6#tab-googlechartid_googlechartid_googlechartid_googlechartid_chart_11111

/4/ Norges vassdrags- og energidirektorat - https://www.nve.no/nytt-fra-nve/nyheter-energi/stromforbruk-i-norge-har-lavt-klimagassutslipp/

/5/ Lindstad, E. Increased Use of LNG Might Not Reduce Maritime GHG Emissions at All, Transport & Environment (T&E)

/6/ Økokrim Utslipp av ammoniakk, ammonium, salmiakk eller gjødsel? – 30.05.2011

/7/ https://www.sdir.no/contentassets/627b963904e54f89994b41c01fe6a410/27-december-2016-no.-1883-ships-using-fuel-with-a-flashpoint-of-less-than-60-degrees-c.pdf?t=1614178618848

/8/ NMA accident reports

/9/ DNV GL – White paper - CLOSING THE SAFETY GAP IN AN ERA OF TRANSFORMATION

/10/ DNV - report - AMMONIA BUNKERING OF PASSENGER VESSEL CONCEPT QUANTITATIVE RISK ASSESSMENT ref Report No.: 2021-0205.

/11/ DSB Sikkerheten rundt anlegg som håndterer brannfarlige, reaksjonsfarlige, trykksatte og eksplosjonsfarlige stoffer, kritierier for akseptabel risiko, DSB utgave 2012, Kapittel 2, Akseptkriterier