The research project [*MaritimeNH3*] is part of to the industry-led Green Platform project AFBN: [*Ammonia Fuel Bunkering Network*]. In *MaritimeNH3,* SINTEF develops and disseminates new knowledge to facilitate the implementation of ammonia (NH_3) as a zero-carbon ship fuel.

Consortium meeting in Trondheim

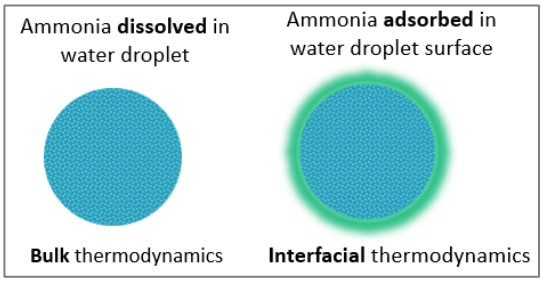
By the end of 2023, a seminar was arranged to exchange knowledge between researchers and industry representatives. Read more: Ammonia Fuel Bunkering Network project making rapid progress - #SINTEFblog

Scientific publications and presentations

WP1: Safety aspects - modelling of ammonia release

The WP1 research team has submitted two scientific papers - one already published in *Fluid Phase Equilibria*, and one being under review in *Journal of Loss Prevention in the Process Industries.* Both papers underscore the importance of refining models to handle ammonia's complex interactions.

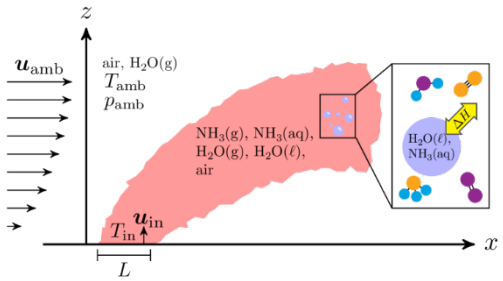
With ammonias tendency to absorb water (hygroscopicity) and its toxicity, a thorough understanding of ammonias interaction with water is important. This requires accurate thermodynamic models , which is the topic of the paper: Bulk and interfacial thermodynamics of ammonia, water and their mixtures



Some highlights:

- Experimental data on bulk properties for NH_3-H_2O mixtures are available for model validations.
- A refined version of the commonly used Peng-Robinson model enabled accurate predictions of bulk properties like density, saturation pressure and heat capacity.
- For interfacial properties, like surface tension, more work is required both on the experimental and modelling side, since measurements are only available at room temperature, and models are not able to qualitatively describe the features of adsorption.

The other paper, Influence of NH_3-H_20 fog formation on NH_3 dispersion from a liquid spill, aims to increase the understanding on how ammonia disperses under various ambient conditions, being crucial for safety considerations. For this purpose, an advanced CFD dispersion model was developed, also including NH_3 interaction with humid air.

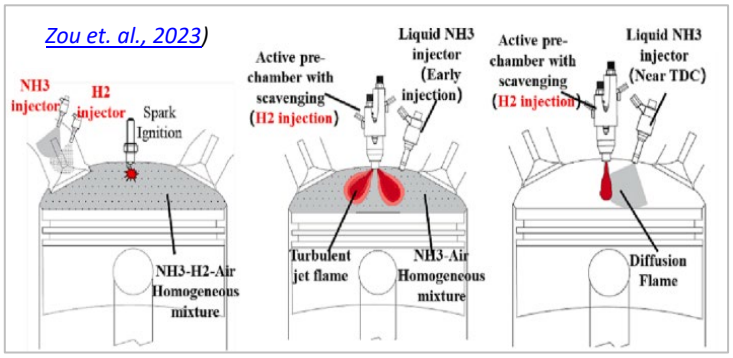


Some highlights:

- The model successfully considers the formation of NH_3-H_2O fog, and its effect on buoyancy.
- Results includes fog visibility and the influence on safety distance for various conditions.
- More fog is formed at higher humidity, and can reduce the NH_3 spreading by up to 35 %.
- Only at high humidity, the visible fog extends as far as the lower dangerous concentration.
- Models not including fog formation can potentially fail in predicting safety distances.
- The absence of fog does *not* equate to safe concentration

WP2: End-use technology – combustion engines

The development of ammonia-fuelled combustion engines is challenging due to ammonia's poor combustion properties. By cracking a small part of the ammonia fuel into hydrogen, the hydrogen can be used as a carbon-free combustion promoter. Previous research in *MaritimeNH3* has focused on simulating the combustion process when mixing H_2 with NH_3 before ignition (left picture below).



Zou et. al., 2023)

With a joint effort in *MaritimeNH3* and HYDROGENi, recent research activities have focused on numerical investigations of two alternative combustion configurations, where a hydrogen-fired prechamber is used to ignite the main ammonia charge. Results are presented in a paper submitted to SAE Int. Journal of Engines, and were presented by Nils Erland Haugen at the 19th Int. Conference on Combustion, Tokyo.

Some highlights:

- Two injection strategies for the ammonia main charge are considered (mid and right picture)
- For conventional port-injection, with pre-mixed NH_3-air in the combustion chamber:
  - The H_2-fired prechamber is a sufficient ignition source at "high-enough" fuel-to-air ratios.
  - The combustion characteristics, including emissions, largely depends on fuel-to-air ratio.
- For direct-injection (non-pre-mixed NH_3-air), with liquid NH_3 sprayed into combustion chamber:
  - Robust ignition and significantly reduced emissions of NO_x and N_2O at certain condition
  - Careful optimization of ignition timing relative to spray injection is crucially important.

WP2: End-use technology – solide oxide fuel cells

Solid oxide fuel cells (SOFC) can be fuelled directly by NH_3 (i.e. no need for converting NH_3 to H_2 before the fuel cell). However, there are possible concerns related to nitridation and corrosion of system components, due to the high operation temperature (<600°C) and humidified gasses. While knowledge exists on dry NH_3-H_2-N_2 gas mixtures, there is a lack of data on wet NH_3-containing gas mixtures, being important for safe operation of SOFCs. To address this, a dedicated test set-up has been constructed, as a joint effort from *MaritimeNH3* and the EU project SINGLE. In the poster session of the *H_2science* conference, details of this set-up and preliminary results were presented by Belma Talic: Evaluation of high-temperature corrosion in wet ammonia containing atmospheres.

WP3: Modelling a Norwegian NH_3 value chain for maritime transport

In WP3 the focus is on developing a modeling framework for techno-economic and environmental assessment of a maritime NH3 value chain, from production to end-use. Traditionally, NH_3 production is modelled as a coupled process including H2 production through steam reforming. In *MaritimeNH3* an innovative, more flexible, model has been developed, where the actual ammonia production is separated from the hydrogen production. The new model enables to study the impact of efficiencies, costs and lifetime for all technologies involved, like different options for H2 production.

At the *H_2science* conference, Elettra Vantaggiato gave a presentation on the new model: The impact of the hydrogen source on process conditions in ammonia production. Here, a specific focus was put on changes in operating conditions for the NH_3 production, depending on the hydrogen source.

Spin-off project and SINTEF's ammonia research activites

SafeAm – Increased safety of ammonia handling for maritime operations

This new competence-building project, led by Marta Buccelli at SINTEF Energi, is a spin-off from *MaritimeNH3* and the Low Emission research centre.

Some of the research activities include:

- Experiments and modelling of ammonia spills on and into water
- In-sea and in-air ammonia dispersion case studies
- Safety and environmental risk analysis, input to standards and guidelines.

SINTEF Research Area Ammonia

Following the increase in NH_3-related research activities across SINTEF, "Ammonia" is now a one of SINTEF's specified research areas. Here you can learn more about NH_3 projects covering the entire value chain, from production to use as fuel onboard ship, in offshore installations, and as refrigerant, as well as related safety and environmental aspects.

SINTEF researchers in meetings with international ammonia players

Singapore Maritime and Port Authority (MPA) initiated a meeting with for a technical discussion on the production, storage, transmission, and bunkering of green NH_3, for them to learn more on how they can accelerate the transition to future fuels in Singapore. Steinar Kostøl gave an overview of AZANE's bunkering projects, and Adriana Reyes Lua summarised SINTEFs research activities along the NH_3 value chain.

Andrea Gruber, SINTEF Energi, was invited to the **IHI/Yokohama factory** and their Combustion Technology Advisor. IHI Power system has completed their land-based test of a four-stroke NH_3 engine, which showed stable operation up to 80% NH_3 fuel, and is soon to be demonstrated on a tugboat.

Important milestone for the AFBN Project!

- Yara Clean Ammonia and Azane granted safety permit to build world's first low emission ammonia bunkering terminal
- Florø: Grønt lys for ammoniakkanlegg | Tu.no

Coming soon: *MaritimeNH3* at The Maritime Hydrogen Conference

A break-out session is dedicated to key insights from *MaritmeNH3*!

3. **Building competence on ammonia as a safe and cost-efficient maritime fuel.**
Risk mitigation and technological advancements in the ammonia value chain - key findings and insights from the research project MaritimeNH3. Facilitated by Sintef.

The Maritime Hydrogen Conference
Florø, Norway — 15 - 16.10.24

See you there!

The Maritime Hydrogen Conference

A bunch of "Ammonia News and Reports", January – June 2024

The interest in ammonia as maritime fuel is growing!

- Stor interesse for ammoniakk-seminaret - RENERGY
- Voldsom interesse for ammoniakkskip
- Equinor vil ha forsyningsskip med ammoniakk som drivstoff: – Interessen er stor

Ammonia fuelled ships

- Verdens første containerskip på ammoniakk, NCL/Yara
- DNV awards AiP for NH_3-Powered Container ship design
- 146 millioner i Enova-støtte til ammoniakk-drift for skip
- 1,2 Enova-milliarder til grønne skip
- Amon Gas to build ammonia-powered MGCs

Ammonia bunkering / transfer:

- Trafigura completes first ship-to-ship transfer of ammonia
- The Fortescue Green Pioneer sails in Singapore harbour on ammonia fuel
- NYK Set to Achieve World's First Truck-to-Ship Fuel Ammonia Bunkering

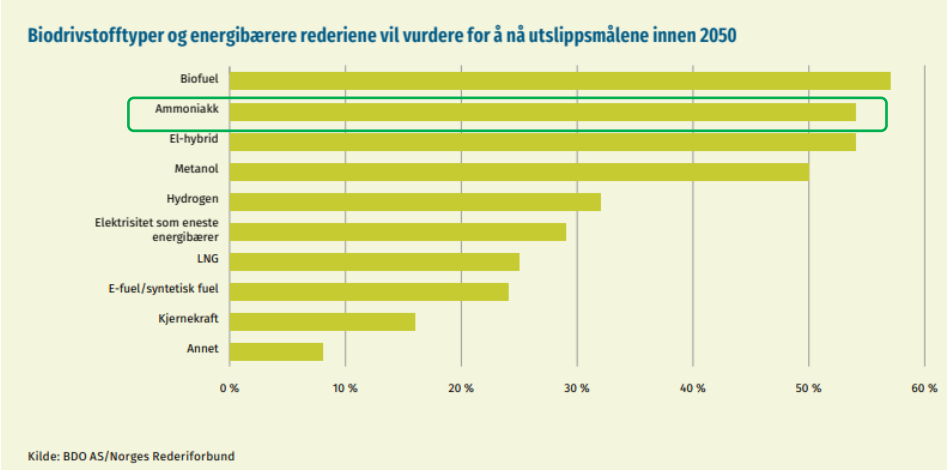
Ammonia on-board technology

- Wärtsilä introduces Ammonia Fuel Supply System to ease shipping's transition to ammonia fuel
- Corvus Energy - Funding For Integration Of Ammonia Cracker Technology With Their PME.
- Amogy - Skal kjøre verdens første taubåt på ammoniakk ned Hudson River

REPORTS on ammonia as maritime fuel

- 1st Life Cycle GHG Emission Study on the Use of Ammonia as Marine Fuel (sphera.com)
- Safety of ammonia on board.pdf (lighthouse.se)
- Managing the Transition to Zero-Carbon Marine Fuels – Clean Air Task Force
- Fuel for thought: Ammonia report | LR
- Availability of green and blue ammonia in 2030 to 2050 (dnv.com)

And, finally, from the 2024 Konjunkturrapport Norwegian Shipowners Association:



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