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

Up-coming project events

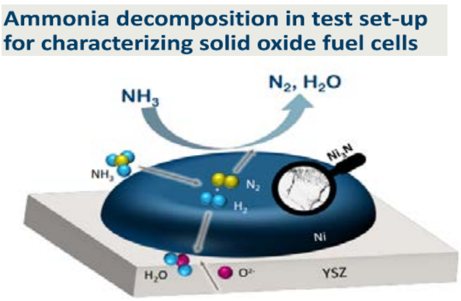
After summer we will arrange three webinars, all on Wednesdays between 10 pm and 11 pm.

- Aug. 16th: Use of ammonia in combustion engines and fuel cells.
- Aug. 30th: Modelling of ammonia spills to improve safety around bunkering installations.
- Sept. 13th: A model for an ammonia value chain for maritime transport in Norway.

More information will be available at Events - SINTEF

MaritimeNH3 presented at three international conferences in 2022.

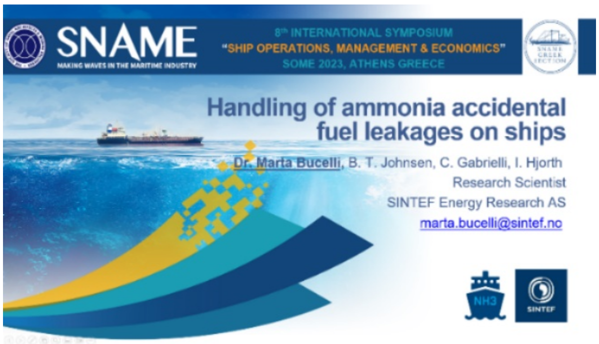
Belma Talic presented a poster at the 15th EFCF 2022 - an international fuel cell and electrolyser event. Belma shared experiences and results from experimental testing of NH_3-fuelled solide oxide fuel cells. The importance of material selection in the test facility was highlighted, as this must be considered when evaluating the fuel cell performance. The influence of temperature and gas flow was also discussed.



Andrea Gruber attended the 39th International Symposium of Combustion. Andrea chaired a session on low-emission combustion technologies. He also presented a paper made in cooperation with Sandia Laboratories, US. The work includes advanced numerical simulations of flame characteristic during combustion of ammonia-hydrogen fuel mixtures. Especially, the formation of undesired nitrogen oxides compounds was evaluated. The paper will be included in Proceedings of the Combustion Institute.

39th INTERNATIONAL SYMPOSIUM ON COMBUSTION

Marta Bucelli presented a paper at the 8th International Symposium on "Ship Operations, Management & Economics", arranged by SNAME (Society of Naval Architects and Marine Engineers).

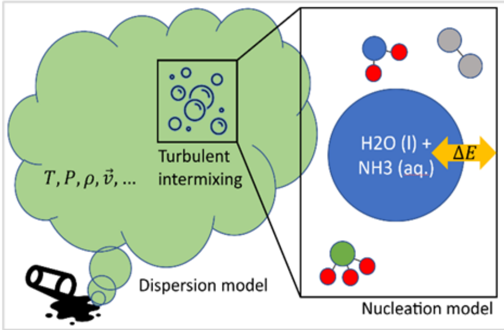


The study focused on handling of accidental releases from refrigerated NH_3 storage tanks, and from the NH_3 fuel system in enclosed spaces. A potential technology for handling NH_3 leaks on ships are compact scrubbers. The study aimed at identifying design characteristics for such scrubbers, which can improve the NH_3 dissolution or neutralization efficiency.

Our research in the different work packages

WP1- Safety aspects - modelling of ammonia release

Preventing hazards related to an ammonia release requires a sound understanding of how it behaves upon a leakage. Therefore, in WP1, we aim at developing a CFD model that is able to simulate this behavior. By that we can contribute to increase safety in vicinity of NH_3 bunkering installations in Nordic climates.



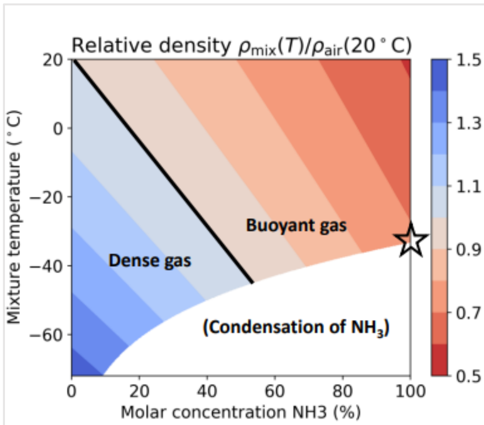
Already well-known is that, since the boiling point of NH_3 is -33°C, a spill of liquid NH_3 will be evaporated into a gas cloud. But more knowledge is needed, especially on what happens when cold NH_3 gas meets humid air.

A liquid NH_3 release analysis was made as input to the modelling tasks**.** It includes a review of release accidents, and of previous studies related to experiments and modelling of NH_3 releases. We also made a screening of release scenarios that are relevant for the planned bunker installations in the industry-led project (Ammonia Fuel Bunkering Network).

When it comes to **modelling activities**, we have mainly worked on the following two topics, both serving as input to the final CFD model.

Estimations of liquid pool spreading and evaporation. This includes estimates of spill radius and time until complete evaporation of liquid NH_3 on concrete, both for a continuous and instantaneous spill. We have developed analytical models for upper estimates, and implemented a spill model built on the open-source software Clawpack, with a Python interface. Using Clawpack will allow us to simulate more arbitrary spill sources and geometries, thus enabling us to analyse specific cases in detail.

Estimations of thermodynamic properties of mixtures of cold ammonia and humid air, to increase the understanding of how NH_3 gas disperse in the air. The evaporated NH_3 from a spilled liquid pool is initially 30% lighter than air, meaning that it is buoyant (moves upwards). Any mixture with more than 55% NH_3 in *dry* air is also buoyant, no matter the temperature.



However, when a gas is mixed with humid air, a number of physical effects can influence the dispersion dynamics. This is especially relevant for NH_3, being very hygroscopic. Therefore, it might be dissolved in water droplets, and potentially create an NH_3-water fog. Understanding these fogs hinges on improved models for formation and growth of NH_3-water droplet.

In 2023 we will present such a model!

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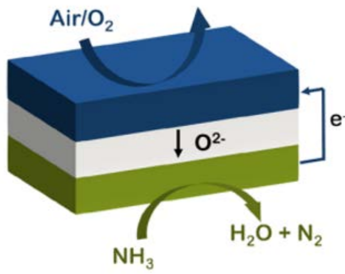
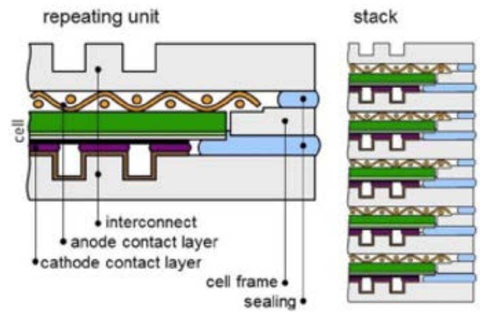
WP1 – End-use technology: Fuel Cells & Combustion Engines



<u>Fuel cells</u>: The two most promising fuel cell types for maritime use are the proton exchange membrane (PEM) fuel cell and the **solid oxide fuel cell (SOFC)**. We focus on SOFCs mainly because these could use NH_3 as fuel directly. For the PEM fuel cell, the NH_3 must first be converted (cracked) into hydrogen. The high operating temperature in SOFCs enables cracking of NH_3 to hydrogen (H_2) and nitrogen(N_2) inside the fuel cell.

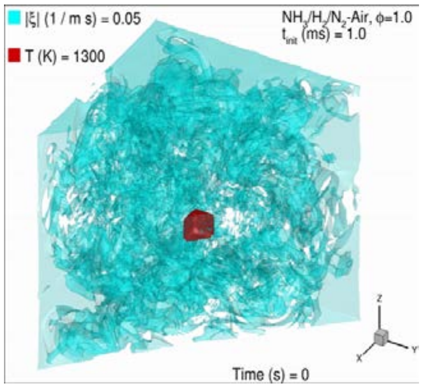
A potential concern with direct use of NH_3 is increased **degradation** of the fuel cell. More specifically, a degradation of the interconnect material and electrode due to nitridation (and corrosion).



In 2022, we prepared for **activities in our new NH_3 lab** at SINTEF Industri. A test matrix was designed for evaluating the stability of the interconnect material, and potential mitigation strategies such as coatings. Tests will be performed with varying temperature, humidity, gas compositions, and various coatings. Following the initial test with 100 hours duration, the most promising coatings will be tested for 1000 hours. We will soon present the first test results!

<u>Combustion engines</u>: There are various combustion engine technologies that potentially could be applied for ammonia. However, NH_3 combustion is challenging since it is hard to ignite (high auto-ignition temperature) and burns slowly (low flame speed). Most concepts under development are dual-fuel engines and require a pilot fuel for ignition. We focus instead on spark-ignited engines with pre-mixed flames, meaning that fuel and air are mixed before combustion. One way to improve the combustion properties is to add a substance that is easier to burn, such as hydrogen. This can be done by **partial cracking of ammonia to a NH_3 / N_2 /H_2–blend. But more knowledge is needed on the behavior of such a mixture, to design efficient and low-emission engines.**

One of the most important parameters in engine designing is the turbulent **burning velocity**. Therefore, we use advanced simulations, so called **Direct Numerical Simulations** (DNS), to evaluate the combustion of NH_3 /N_2/H_2 -air mixtures, in terms of burning rate, flames characteristics, and formation of undesired emissions. We have also compared the DNS results with predictions from a, relatively, simpler open-source CFD software.



Since it proved satisfactory, the next step is to deploy it to **simulate more realistic configurations**. For example, more complex geometries and higher pressure will be evaluated, with input from an engine manufacturer.

WP2 contacts:

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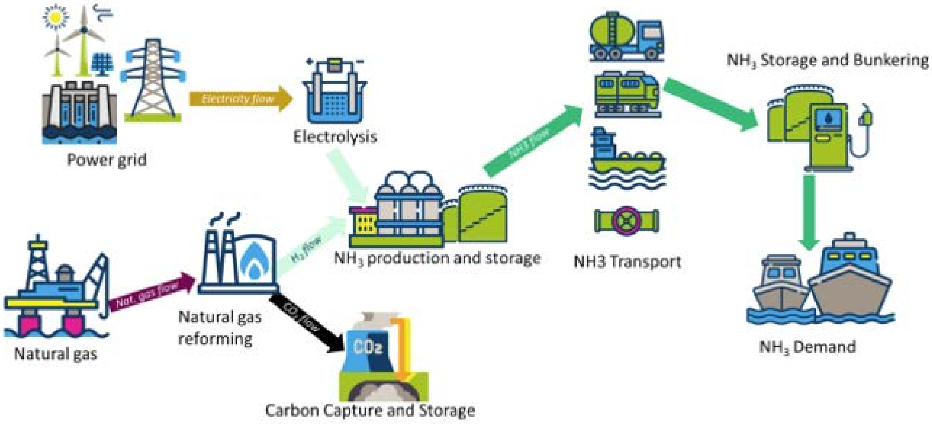
WP3: Techno-economic analysis and GHG assessment

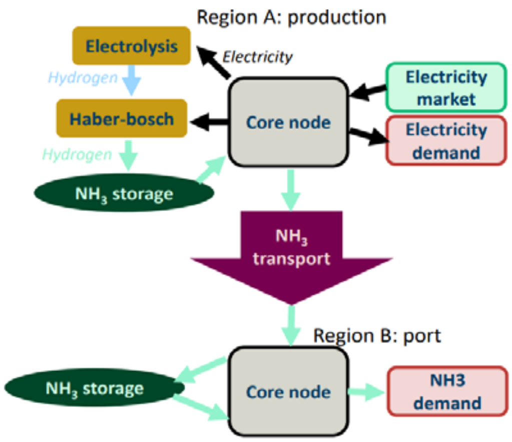
Here we will develop a model that represents the whole **value chain of a Norwegian ammonia-based energy system for maritime transport**. Then we will use the model to evaluate the most cost-efficient value chain versus the one with lowest emissions. We will also compare the ammonia value chain with hydrogen value chains in a period from today to 2050.

The first step is to define and describe an **input data set** for the modelling purposes. This includes boundary conditions, technical and economical parameters as well as assumptions, uncertainties and sources. We have defined a preliminary data set, which will be updated in 2023, both with input from industry discussion and with results from other project activities.



Most existing estimates of future fuel cost does not consider the potential for technology improvements, for example in the production process. Therefore, we have put a special modelling focus on the NH_3 production process. By using **APSEN-HYSYS,** which includes costing of process equipment, we will provide updates on ammonia production costs. This will then be used when optimising the NH_3 value chain for maritime transport.

We have also started to define the scope of the optimisation framework to be used to **optimise the NH_3 value chain**. It will be based on the CleanExport project, were we work on value chains with multi-energy carriers. Since the focus there is on hydrogen, electric power, natural gas and CO_2 ,the framework must be adopted for the purpose of *MaritimeNH3*. It also has to be complemented with NH_3-specific models for production, transport, bunkering, storage, etc.



Later in 2023 we will present results from a first **case study**, representing a national simplified NH_3-based energy system for maritime transport. Lessons learned will be used in a more detailed case study in 2024, and in a complete techno-economic and greenhouse gas assessment of this future national NH_3-based energy system.

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Highlights from Ammonia Fuel Bunkering Network (AFBN)

The intensive work on developing the design concept of a floating bunkering terminal, including extensive safety studies, resulted in an AIP (Approval in Principle) from DNV in August 2022.

In early 2022, Yara Clean Ammonia pre-ordered 15 bunker barges from Azane, and teamed up with NorSea Group to operate the units at their logistics bases.

15 locations have been mapped out for the bunkering network. Detailed feasibility studies were made for 5 of them, in collaboration with local stakeholders. It was concluded on the first location – Saga Fjord Base, Florø.

A HAZID workshop for the bunker terminal, at location Florø, was held in September and the application for Consent at DSB (Norwegian Directorate for Civil Protection) has been prepared and submitted.

As part of the Maritime hydrogen conference in Florø (September 2022), we arranged a "all hands meeting". Here, we invited the public (politicians and other 3rd parties that were interested) for presentations by AFBN team and Q&A. In March 2023, a two-day HAZOP workshop for the floating terminal was carried out with all AFBN project partners present.

Ammonia-ready ships are being ordered!

According to Clarkson's, 61% of the newbuilding tonnage ordered in 2022 will be alternatively fuelled, (35% by ship number). More than 10% of the new-builds ordered will be "NH_3-ready" (90 orders). In total there are 130 "NH_3-ready" vessels on order. Below you can see some of them!

More information

Read more about ammonia, and SINTEF's ammonia-related projects in our blog: Ammonia: From cleaning product to maritime fuel - #SINTEFblog

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