AN INVESTIGATION INTO THE VIABILITY OF AMMONIA AS AN ALTERNATE SHIP FUEL

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1. Introduction and Background

- IMO in 2018 pledged to reduce emissions of greenhouse gases (GHGs) by 50% by 2050 compared to 2018 levels (IMO, 2020).
- In 2018 shipping activity produced 1076 tonnes of CO_2, accounting for 2.89% of global emissions of CO_2 (IMO, 2020).
- In the short term, IMO plans to improve the Energy Efficiency Design Index (EEDI) of new ships, before shifting to lower carbon and zero carbon fuels (IMO, 2020).
- To determine how ships could shift to lower carbon fuels, this project investigated various alternate fuels. Ammonia was determined the candidate to focus on for implementation on a case study vessel, the *Clipper Pennant*, an Irish sea ro-ro ferry.
- The storage considerations, power generation methods and environmental impact from the propulsion system were all determined and assessed against the current system, to evaluate the viability of ammonia and the challenges associated with its implementation.

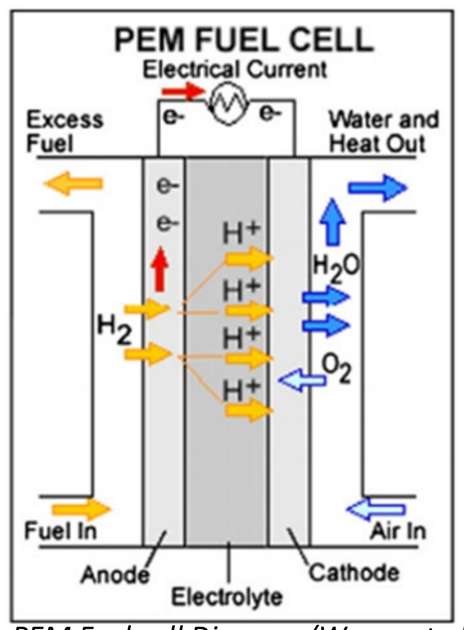
The Clipper Pennant (Johannsson, 2013)

2. Methodology

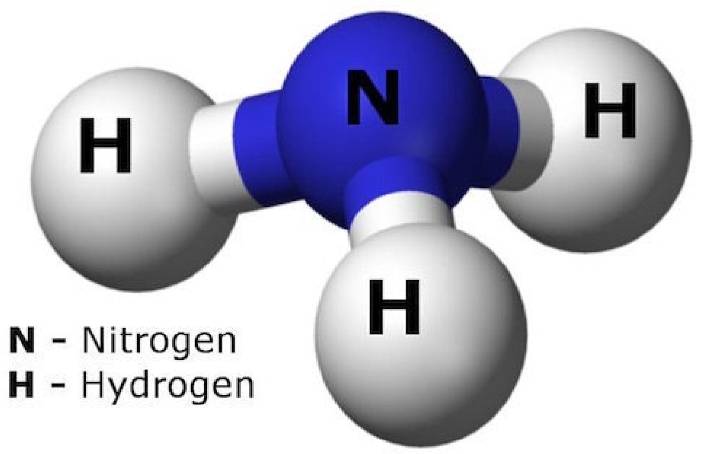
- Various studies were used to determine Ammonia, LNG, LPG, Hydrogen and Uranium as candidate fuels, before assessing them based on their sustainability, ease of storage, energy density and environmental impact
- Ammonia was found to be most favourable due to its sustainability, low environmental impact and relative ease of storage.
- Once ammonia was decided more detailed investigations into the potential storage methods were determined by looking at current LNG storage on ships and ammonia on land, before researching the environmental impact of switching and the different potential power generation methods.
- After all the information was gathered, the proposed systems were evaluated and compared to the current system, to determine whether such a system is viable.

3. Ammonia Propulsion Systems

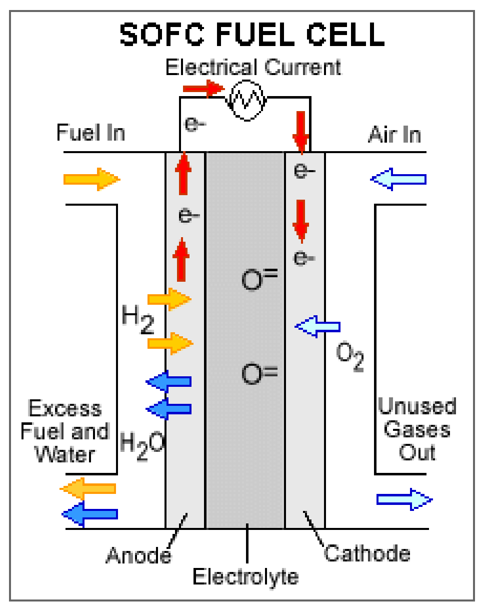
- The first propulsion system to consider was an ammonia main engine, as this is most similar to what ships operate with currently
- Main engines were found to be unfavourable due to their poor efficiencies, which makes ammonia difficult to implement as the poor energy density of ammonia relative to carbon-based fuels is one of the main barriers to it's use
- Fuel cells were then considered due to their considerably higher efficiencies, with polymer electrolyte membrane and solid oxide fuel cells both being considered
- It was found that solid oxide fuel cells were most appropriate for this application due to their higher efficiencies and greater reliability due to the fact very pure hydrogen is required for polymer electrolyte fuel cells. The requirement for pure hydrogen also further reduced efficiencies and increased the machinery requirements of the system.
- Main challenges to overcome for solid oxide fuel cells are their rate of degradation, slow response to load changes and long start up times
- These challenges were evaluated and found that they could be somewhat mitigated by the material selection of the cell to avoid thermal stresses and allow for faster start ups and responses to load times. It was found degradation rates could be reduced to acceptable limits by choosing appropriate materials and carefully controlling fuel supply to consumption ratio.
- Current solid oxide fuel cells were found to be a suitable method of providing power to the ship, with advances in cell technology making them an interesting candidate for the future of decarbonisation.



PEM Fuel cell Diagram (Wang, et al., 2011)



3D ammonia molecule(Ashish, 2021) (Mills, 2012)



Solid Oxide Fuel Cell Diagram (Darling, 2021)

4. Storage

Ammonia storage was determined primarily by looking at LNG ships which already have established means of storing fuels which are gaseous at room temperature and pressure. Things to consider were:

- Space requirements – ammonia has such a poor energy density compared to current fuels that properly utilising space of the fuel storage was essential
- Class regulations – these were considered by looking a the DNV regulations for gas tankers (DNV-GL, 2017) and IMO regulations on carrying liquified gases in bulk (IMO, 2014) and making adjustments to suit ammonia specifically where necessary
- Safety implications – methods again were adopted from the storage of LNG, with various risks being evaluated and how they could best be mitigated. It was found that in general most safety risks with transporting LNG are not as likely to be a problem with ammonia due to its higher boiling point.

Membrane tanks were found to be the best option for fuel storage on the pennant, as their design does not impact the cargo carrying capacity of the vessel.

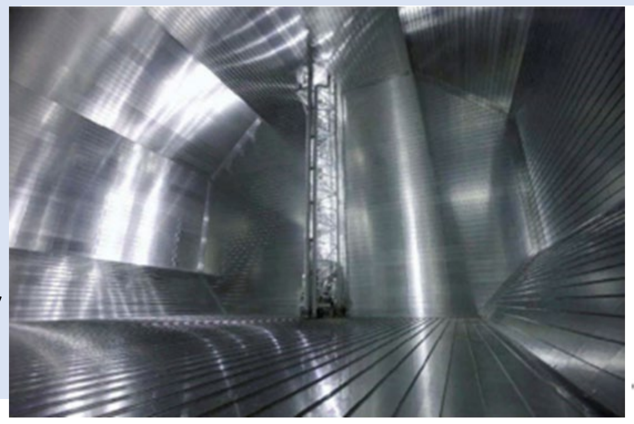


Figure 5 Inside of a membrane tank of a ship (Bruce & Eyres, 2012)

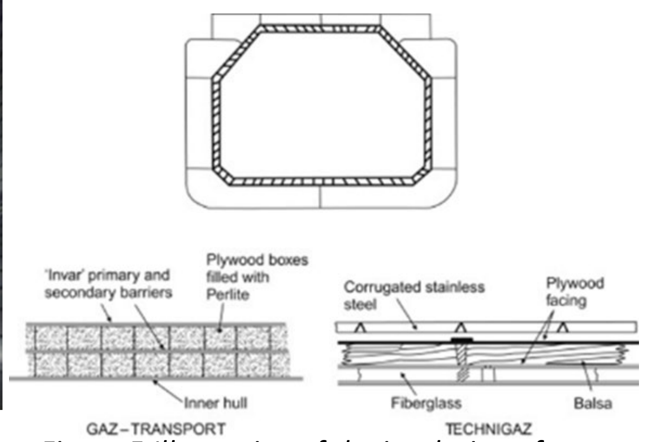


Figure 5 Illustration of the insulation of a membrane tank (Mokhatab, et al., 2013)

5. Environmental Impact of Ammonia

Environmental impact of operating with ammonia was determined and compared to the current system. The environmental impact was only considered from the ship itself and not from the impact of supplying it to the vessel, though it is possible to produce ammonia carbon-free and it is renewable (Ye, et al., 2017). It was determined that:

- The biggest concern for ammonia based systems is production of NO_x
- NO_x was found to be an unacceptable substitute for CO_2 if produced in large enough quantities
- NO_x could be accounted for by aftertreatment systems
- Ultimately most systems considered were unlikely to produce considerably more NO_x than the current system, with the eventual candidate likely to produce significantly less

5. System Evaluation

For the evaluation, the proposed systems were initially discussed, with solid oxide fuel cells having significant advantages over the other systems such as higher efficiencies and reliability that made it the most suitable method for generating power in this instance. The current system was used as a benchmark for the success of the project, finding that:

1. Ammonia can power the ship for 4.43 days operating continuously at max load
2. A total of 14.18 ferry crossings can occur at this load given the *Pennant's* typical operating route
3. No emissions are likely to occur from this operation, with the only potential pollutant being NO_x which can be accounted for if necessary with an aftertreatment system.

5. Project Evaluation

The success of the project can be determined by looking at the aims and objectives outlined in the proposal made at the commencement of the project and comparing them to the eventual outcomes, shown in the table below.

Objective	Achieved?	Reasoning
To investigate the ways in which ammonia can be used as a fuel to find a method suitable for a ship propulsion system	Yes	Multiple methods of operating the ship with ammonia were assessed, finding that some methods can be used which do not result in an unacceptable decrease in ship performance
Find the amount of ammonia needed to power the ship to determine the amount of storage needed	Yes	Amount of ammonia required to replicate current ship performance was determined. Methods for storing ammonia in the same place as current fuels also found
Identify possible design constraints of such as system and the ways in which it may be difficult to implement and operate such as system	Yes	Design constraints and barriers to implementation were identified. Possible solutions in the future and market trends also described to show the severity of these barriers long-term.
Find the requirements for storing ammonia in a way that allows the system to operate optimally whilst complying with class requirements	Yes	It was found that by utilising membrane tanks little fuel storage space is lost. Current class regulations were also determined, with considerations made to exceptions that may have to be made for ammonia.
Determine the viability of this system with regards to the feasibility and life-cycle input and evaluate if a ship could realistically utilise such a system	To a certain degree	Feasibility critically evaluated, finding that though there are some notable disadvantages the system could work in some applications, particularly if technology continues to improve. Life-cycle input determined only so far as pollution from ship operations, with pollution from manufacturing merely touched upon.

6. References

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