Work Group #4: Sustainable Marine Fuels

Deliverable 3.1 Report Review Template

1. Report title	**Safe and effective application of ammonia as a marine fuel**
2. Publication date	2019-05-2019
3. Author	Niels de Vries
4. Client (organization and type of organization, specifying private/commercial/public; research institute/interest group etc.)	n/a
5. Context of study (e.g. project in the context of which report is published or titles of other reports if part of a series)	The report constitutes a thesis for the degree of M.Sc. in Marine Technology in the specialisation of Marine Engineering at the TU Delft. The thesis has been written at and supervised by C-Job & Partners B.V., a Naval architecture-engineering firm. The master student is currently working for C-Job.
6. Length (pages)	100
7. Link (or where to get if not available online)	https://sustainableworldports.org/wp-content/uploads/TU-DELFT_2019_thesis_Safe-and-effective-application-of-ammonia-report.pdf
8. Sector coverage	Maritime shipping
9. Main aim of the study	Main aim of the study is to investigate how ammonia can be applied safely and effectively as a marine fuel.

10. Methodology	The thesis is based on a literature review and preliminary design calculations.
11. Topic(s) and indication of the level of detail For example: • System Description - *A description of the full marine energy system.* • System Components - *A description of all the components.* • Infrastructure requirements for new fuels • Applicability - *which of the new fuels are expected to replace existing fuels?*	The following topics are covered in detail: • Comparison of renewable fuels – *a quick comparison of different renewable fuel characteristics* • Onshore technical feasibility of ammonia power generation options – *description of the different ammonia power generation options that are feasible onshore* • Marine technical feasibility of ammonia power generation options - *description of the different ammonia power generation options for marine applications* • Marine performance of ammonia power generation options – *a detailed discussion of the suitability of the power generation options for maritime shipping* • Safety – *detailed discussion of safety aspects of ammonia and hydrogen as well as a risk assessment of ammonia as marine fuel*
12. What are the main conclusions from the report?	The report concludes that ammonia is, compared to other renewable fuels, a balanced fuel for maritime shipping in terms of volumetric energy density and renewable synthetic productions cost. Using ammonia also reduces harmful emissions significantly compared to conventional options, with NOx emissions being similar. The following ammonia conversion technologies are considered feasible for marine applications: internal combustion engine (ICE) (using ammonia hydrogen mixture), all three fuel cell types considered (PEMFC, AFC, SOFC); the ICE is assessed to be the best current option; fuel cells could become a main power generation option in the future. In a basic cost scenario, fuel expenses for ammonia are expected to be 3.2 times higher than for 0.5% HFO, based on an equal range. The flammability risks of ammonia are relatively low compared to the toxicity risks; storing and handling of ammonia requires adequate means to limit likelihood and effect of exposure to humans and the environment, leading to additional costs. More research is required further investigating the application of fuel cells in shipping, investigating ammonia leakage and addressing onboard storage of ammonia as a fuel.
13. What fuel/energy type(s) are discussed in the report and in what level of detail?	The report discusses ammonia in detail. The following specifications are given: • fuel costs

For example: • Fuel description e.g. type, energy density, specific energy density, flash point, boiling point, fire point, flammability limits, hazards	• flammability • toxicity • lower heating value For ammonia, CNG, LNG, Diesel and ULSFO the following specifics are stated: • a list of hazards per fuel (Table 7-1) For MGO, liquid methane, ethanol, methanol, liquid hydrogen, compressed hydrogen and liquid ammonia the following specifics are stated in Table 2-2: • energy density (LHV; MJ/kg) • volumetric energy density (GJ/m^3) • renewable synthetic production costs (MJ/MJ; relative costs approximated by the energy demand of the production of the fuels) • storage pressure • storage temperature For biofuels based on rape seed, sugar beet and sugar cane, the following specifics are stated in Table 2-1: • yield [W/m^2] • required otherwise unproductive land to provide the whole maritime shipping sector with energy
14. What environmental aspects does the report consider? E.g. Air quality emissions, climate change emissions (GHG + BC), other (for example terrestrial or underwater noise, water quality, emergency releases, fugitive emissions, odour, water resources, mining)	The study considers both greenhouse gas and air pollutant emissions.
15. Does the report consider exhaust emissions only, or life-cycle, or both (or some other range of emissions)?	The report considers exhaust emissions only.

16. If determined in the report, what are the emission rates/factors by pollutant? NOx, SOx, PM10, PM2.5, ultra fine PM, VOC, NH3, GHGs, Black carbon, and any others e.g. that may be unique to the fuel/energy.	For internal combustion engines which use ammonia as a fuel, the emission rates of NO_x are stated in terms of g/kWh. For the reference case of HFO the emissions of CO_2, SO_x, PM and NO_x are stated in Table 6-2.
17. Does the report discuss barriers and opportunities for <u>ships</u> to use the fuel(s)/energy? Does the report identify the maturity level of the fuel on a regional or global scale with respect to use by vessels?	The report discusses technical and safety barriers and opportunities for ships to use ammonia as a maritime shipping fuel. The study also identifies the maturity level of LNG as well as ammonia and hydrogen on a global scale (Figure 6-8 and Figure 6-9).
18. Does the report discuss barriers and opportunities for <u>ports</u> to provide the fuel(s)/energy? Does the report identify the maturity level of the fuel on a regional or global scale with respect to provision by ports?	Not discussed in the report.
19. Does the report include capital and operating cost estimates for the ship and/or land-side?	The thesis gives operational and capital expenditure estimates for ships with ammonia as fuel in various tables in chapter 5. The thesis compares total operational and capital costs for ships with ammonia as fuel and ships with conventional fuel (see Table 6-3, Table 6-4 and Table 6-6). Costs for landside infrastructure are not considered in this study.
20. When are the fuel(s)/energy expected to be at a demonstration stage vs. commercialization? For example: • Technology Readiness Level of the system - *Estimated maturity of the system technology*	The study gives a visualization of the timeline for the implementation of renewable bunker fuels in general (Figure 6-8) and for the implementation of ammonia as renewable bunker fuel in specific (Figure 6-9).

• On Board Safety Readiness Level of the system - *Estimated maturity of the risk mitigations on board (on a scale of 1-9)* • External Safety Readiness Level of the system - *Estimated maturity of the risk mitigations for bunker operations (on a scale of 1-9)*	Regarding the latter, a step-wise approach is proposed: starting with a combination an ICE and an ammonia/marine diesel mix, then moving on to a combination of spark ignited engines and an ammonia/hydrogen mix and finally applying the combination of SOFCs and ammonia. The graphs are however schematic, without giving specific years.
21. Are the fuels suitable for short and/or long (trans-oceanic) voyages?	This is not explicitly discussed in the report.
22. Does the report identify/discuss potential issues around community acceptance for this fuel, or potential social/community impacts associated with the system?	This is not explicitly discussed in the report.