Work Group #4: Sustainable Marine Fuels

Deliverable 3.1 Report Review Template

1. Report title	**Sailing on Solar - Could green ammonia decarbonise international shipping?**
2. Publication date	May 2019
3. Author	Ricardo Energy & Environment Ricardo is a 'global strategic engineering and environmental consultancy'
4. Client (organization and type of organization, specifying private/commercial/public; research institute/interest group etc.)	Environmental Defense Fund (EDF) Europe 'This paper was commissioned by Baroness Bryony Worthington of Environmental Defense Fund (EDF) Europe, together with Aoife O'Leary and Marie Hubatova' EDF is a nonprofit environmental organization mainly financed by contributions of its members and donations from foundations.
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)	n/a
6. Length (pages)	62
7. Link (or where to get if not available online)	https://sustainableworldports.org/wp-content/uploads/EDF-and-RICARDO_2019_Sailing-on-solar-report.pdf
8. Sector coverage	Maritime shipping
9. Main aim of the study	The study 'aims to show that it is realistic and achievable to adopt green ammonia as a maritime fuel.'

10. Methodology	The study bases its findings on 'existing scientific data, basic chemistry, engineering knowledge and practical experience'.
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 this report: • Case study: Morocco – *a specific case study for the production and use of green ammonia in Moroccan ports* • Case for green ammonia – *Why green ammonia is a good shipping fuel* • Production process – *how can green ammonia be produced?* • Vessel propulsion and on board storage – *a description of the vessel propulsion and on board storage of ammonia* • Emissions – *emissions associated with green ammonia* • Risk profile – *a description of the different risks associated with ammonia as a marine fuel* • Investments – *a discussion of the potential investments associated with green ammonia* • Low carbon electricity options – *a discussion of the energy generation process underlying green ammonia production* • Ammonia consumption – *estimations for the ammonia consumption of different types of vessels*
12. What are the main conclusions from the report?	'Green ammonia, produced using renewable electricity, is a fuel that does not emit greenhouse gases at any point in its product lifecycle and could play an important role in achieving the International Maritime Organization's decarbonisation goals.' 'Green ammonia is one of the most technically feasible in the short term': -commercially available technologies can be used for the production of green ammonia. -transportation and storage of (fossil) ammonia on ships is established -standards for the safe handling, storage and transport of ammonia in bulk by ships are already established for fossil ammonia. -existing dual-fuel engines can be upgraded to operate on ammonia -some minor adjustments are required to equip vessels to operate with ammonia as fuel. Compared to hydrogen, ammonia has the advantage that it does not require cryogenic storage and that it is relatively energy-dense as liquid.

	To eliminate NOx and PM emissions, fuel cells instead of an internal combustion engine should be used in the long-run. 'The necessary Solid Oxide Fuel Cell (SOFC) technology is not yet commercially available for marine applications, but with further development it is expected to be viable in the 2030s.' Due to their higher costs compared to conventional fossil bunker fuels, a policy mechanism will be required to incentivize the development and deployment of zero carbon fuels and to avoid penalizing early adopters.
13. What fuel/energy type(s) are discussed in the report and in what level of detail? For example: • Fuel description e.g. type, energy density, specific energy density, flash point, boiling point, fire point, flammability limits, hazards	The report focusses on ammonia. For the following fuels are also briefly discussed: • Marine gas oil • Liquefied natural gas • Methanol • Green hydrogen The following characteristics are given for each of these fuels: • Associated GHG emissions • Temperature for liquid storage • Tank volume for 1000 nautical mile range • Applicability for long/short voyages For heavy fuel oil, LNG and ammonia, the following characteristics are given as well: • Types of emissions
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 report 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 life-cycle emissions of greenhouse gasses and exhaust emissions of air pollutant emissions.
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.	Emission factors are not quantitatively determined in the report. Table 2 however presents a qualitative comparison of HFO/MGO, LNG and ammonia with respect to the following pollutants: SO_2 and metals, CO, VOCs and PAHs, NO_x, Direct particulate matter and ammonia slip.
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 considers opportunities and barriers for ships to use ammonia related to emissions, risks and technology. The report determines the maturity of ammonia on a global scale with respect to ships.
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?	Ports are not the main focus of the study. It is however mentioned that ports could profit from lower air pollutant emissions if ships were ammonia-fuelled. The case study analyses possible ammonia production at a port in Morocco which is already importing ammonia. Ports with existing ammonia related infrastructure might thus be able to be the first to profit from additional investments.
19. Does the report include capital and operating cost estimates for the ship and/or land-side?	The cost analysis is focused on the production of green ammonia.
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*	With respect to the maturity of the fuel for shipping, the following information is given: • A technology roadmap until 2050 for ammonia propulsion technologies is presented in Figure 21. The existing safety principles and systems throughout the global ammonia industry would need to be deployed.

• 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)*	
21. Are the fuels suitable for short and/or long (trans-oceanic) voyages?	The suitability of the application of different fuel types for short and long voyages is presented in Table 1.
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 determined in the report.