Work Group #4: Sustainable Marine Fuels

1. Report title	**Comparison of Alternative Marine Fuels**
2. Publication date	2019-07-05
3. Author	DNV GL
4. Client (organization and type of organization, specifying private/commercial/public; research institute/interest group etc.)	SEA\LNG Ltd SEA\LNG is a ‘multi-sector industry coalition whose members work together to demonstrate the benefits of LNG as a marine fuel throughout the entire value chain’.
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)	-
6. Length (pages)	65
7. Link (or where to get if not available online)	https://sustainableworldports.org/wp-content/uploads/DNV-GL_2019_Comparison-of-alternative-marine-fuels-report.pdf
8. Sector coverage	Maritime shipping
9. Main aim of the study	Assessment of the commercial and operational viability of alternative marine fuels in comparison to LNG
10. Methodology	Review of academic and industry literature; DNV GL’s own expertise as classification society
11. Topic(s) and indication of the level of detail For example:	The study assesses the commercial and operational viability of alternative marine fuels. The approach assesses how well six alternative fuels perform compared to LNG fuel applying 11 criteria. Conventional liquid fuels are not

• 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?*	covered in this study, however 2020 compliant fuel options (HFO+scrubber or low sulphur fuels) are included in the conclusion for comparative purposes. Fuel/energy types: - LNG - Hydrogen - Ammonia - Methanol - LPG - Advanced biodiesel - Fully electric Converter types: -Fuel Cell -Internal combustion engine The 11 criteria are divided into four main categories: applicability, economics, environment, and scalability: 1.Applicability - Energy density - Technological maturity - Flammability and toxicity - Regulations and guidelines (including existence of bunkering/fuel loading guidelines and regulations) 2.Economics - Energy costs - Capital costs 3.Environment

	- GHG emissions - well-to-wake - Air pollutant emissions - SOx, NOx and PM 4.Scalability - Main current usages - Availability - Global production capacity and locations The color scheme in Figure 1.5 in the report presents an overview of the outcome of the multi-criteria assessment.
12. What are the main conclusions from the report?	The report assesses how well six alternative fuels, applied in 16 different fuel technology pathways, perform compared to LNG fuel on a set of 11 key parameters. Time to commercial availability of promising alternative fuels will depend largely on level of R&D efforts, and even more importantly on the level and speed of which environmental regulations are implemented and incentive schemes are developed. As shown in this report, several of the promising alternative marine fuels are far more expensive than current solutions, and adoption rate will be minor/at piloting stage until regulations or incentive schemes makes them more competitive. Figure 7.1 in the report represent the performance on the key parameters for LNG and the different alternative fuels. The figure does not conclude on the overall performance of the fuels. When evaluating alternative fuels, the specifics for the case being evaluated have to be taken into consideration, such as ship specifications, local conditions, access to energy carriers and so on. More detailed conclusions about each individual alternative fuel can be found in the conclusion of the report.
13. What fuel/energy type(s) are discussed in the report and in what level of detail? For example:	The following fuel/energy types are discussed in the report: - LNG - Hydrogen

• Fuel description e.g. type, energy density, specific energy density, flash point, boiling point, fire point, flammability limits, hazards	- Ammonia - Methanol - LPG - Advanced biodiesel - Fully electric
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 GHG emissions (CO_2) and air pollutant emissions (SOx, NOx and PM).
15. Does the report consider exhaust emissions only, or life-cycle, or both (or some other range of emissions)?	The report considers well-to-wake GHG emissions which include emissions from production, transport and storage of each fuel, as well as combustion/conversion to mechanical energy on board the vessels. The resulting comparative measure of well-to-wake emissions is the mass of CO_2 equivalent emissions per unit of shaft output energy. Figure 1.4 provides the well-to-wake emissions for fuel/technology pathways (in g CO_2e/kWh shaft output), taking into account energy content of fuel and system efficiency.
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 ranges are provided per fuel/converter option for CO_2 equivalent, NOx, SOx and PM emissions: Figure 6.7 provides the well-to-wake emission ranges for fuel/technology pathways (in g CO2e/kWh shaft output), taking into account energy content of fuel and system efficiency. Figure 6.8 provides the tank-to-propeller NOx emission ranges for different fuel/converter options (in g/kWh). Figure 6.9 provides the tank-to-propeller SOx emissions for different fuel/converter options (in g/kWh). Figure 6.10 provides the tank-to-propeller PM emissions for different fuel/converter options (in g/kWh).
17. Does the report discuss barriers and opportunities for <u>ships</u> to use the fuel(s)/energy? Does the report identify the	The barriers and opportunities are described per fuel type. Barriers and opportunities are related to emission reduction, production capacity, costs, bunkering infrastructure, applicability on ships, safety, technical feasibility.

maturity level of the fuel on a regional or global scale with respect to use by vessels?	
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?	Storage tank costs and stage of development/availability of bunkering infrastructure are assessed per fuel type. Regarding fully/hybrid electric ships, stage of development/availability of on-shore connection is assessed.
19. Does the report include capital and operating cost estimates for the ship and/or land-side?	The report focusses on converter and storage tank costs.
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* • 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)*	Technology readiness level: the report provides the maturity level per fuel/converter combination. Safety standards, regulations, concerns and challenges are discussed per fuel type. An on board safety readiness level and an external safety readiness level of the system are not provided per fuel type.
21. Are the fuels suitable for short and/or long (trans-oceanic) voyages?	Suitability for short and/or long voyages not only depends on fuel/energy type, but also on the conversion technology, the storage capacity and options on board ships. All these aspects are discussed in the report per fuel/energy type.

22. Does the report identify/discuss potential issues around community acceptance for this fuel, or potential social/community impacts associated with the system?	-