Work Group #4: Sustainable Marine Fuels

Deliverable 3.1 Report Review Template

1. Report title	**Life Cycle GHG Emission Study on the Use of LNG as Marine Fuel: Final Report**
2. Publication date	10-04-2019
3. Author	thinkstep AG thinkstep is a software company with focus on software for environmental modelling purposes
4. Client (organization and type of organization, specifying private/commercial/public; research institute/interest group etc.)	SEA\LNG Ltd and Society for Gas as a Marine Fuel Limited (SGMF) SEA\LNG Ltd 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'. SGMF 'is an NGO established to promote safety and industry best practice in the use of gas as a marine fuel'.
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 study is commented on in the following paper: Lindstad E. (2019), Increased use of LNG might not reduce maritime GHG emissions at all Thinkstep replies to those comments in the following publication: thinkstep (2019), Addendum, Life Cycle GHG Emission Study on the Use of LNG as Marine Fuel
6. Length (pages)	158
7. Link (or where to get if not available online)	https://sustainableworldports.org/wp-content/uploads/thinkstep_2019_Life-cycle-GHG-emission-study-on-LNG-Final-report-report.pdf
8. Sector coverage	Maritime shipping

9. Main aim of the study	This study analyses the life cycle greenhouse gas (GHG) emissions of the use of Liquefied Natural Gas (LNG) as marine fuel compared with current and post-2020 conventional oil-based fuels. Based on this, the global warming potential of these fuels is assessed. In addition, air quality is assessed by comparing local pollutants from the operation of the vessels using these different fuels.
10. Methodology	Life cycle analysis (LCA) using LCA software and databases, literature study, data collection (e.g. test-bed data of engine manufacturers) and validation, scenario analysis, sensitivity and uncertainty analyses
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?*	This study includes the following topics (in different chapters): • Introduction – *Description of background and motivation of the study.* • Goal of the study – *Short description.* • General scope of the study – *Description of system boundaries and methodology.* • Well-to-tank analysis – *Long description of analysis scope, inventory analysis (for the LCA), GHG emissions of marine fuels, comparison of results with other studies.* • Tank-to-wake analysis – *Long description of analysis scope, inventory analysis, local pollutant emissions of marine fuels.* • Well-to-wake analysis – *Long description of analysis scope, inventory analysis, benefits for the global fleet from introducing LNG, GHG emissions (current marine fuels, post-2020 marine fuels, comparison with other studies), scenario/sensitivity/uncertainty analysis.* • Outlook on the use of bio-LNG and synthetic LNG as marine fuel – *Short description and presentation of GHG emissions.* • Interpretation – *Description of key findings, assumptions and limitations of the study, data quality assessment, reflection on model completeness and consistency.* • Conclusions and recommendations – *Short description.*
12. What are the main conclusions from the report?	• LNG provides a significant advantage in terms of improving air quality and is a viable solution to reduce GHG emissions from international shipping. • On an engine technology basis, the well-to-wake (WtW) GHG emission reduction for LNG-fuelled marine ship engines compared with HFO-fuelled engines are between 14% to 21% for 2-stroke slow speed engines, and between 7% to 15%

	for 4-stroke medium speed engines. For tank-to-wake (TtW) GHG emissions, the reduction benefits are between 18% to 28% for 2-stroke slow speed engines and between 12% to 22% for 4-stroke medium speed engines. • Local pollutants are reduced when using LNG compared with current conventional marine fuels: sulphur oxides (SO_X) to close to zero, nitrogen oxides (NO_x) by up to 95% when using Otto cycle engines, and particulate matter (PM) by up to 99%. • If the global marine transport fleet for 2015 were to completely switch to LNG then there would be a reduction of 15% marine GHG emissions based upon engine technology alone. Methane emissions from the supply chain and engine slip need to be reduced further to maximize the positive impact on both air quality and GHG emissions. • Bio-LNG and synthetic LNG can provide a significant additional benefit in terms of WtW GHG intensity (up to 90%).
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 study focuses on the comparison of LNG with HFO and MGO in terms of emissions. Included fuels and figures are: • LNG – *CO2-eq. and local pollutants emission factors, fuel consumption* • Heavy fuel oil (HFO) – *CO2-eq. and local pollutants emission factors, fuel consumption* • Marine gas oil (MGO) – *CO2-eq. and local pollutants emission factors, fuel consumption* • Bio-LNG – *CO2-eq. emission factors* • Synthetic LNG – *CO2-eq. emission factor* • Low sulphur heavy fuel oil (LSFO) – *CO2-eq. and local pollutants emission factors* • Liquefied petroleum gas (LPG) – *CO2-eq. emission factors, fuel consumption* • Methanol – *CO2-eq. emission factors, fuel consumption*
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)	GHG emissions (CO_2-equivalents, methane, N_2O), and air pollutant emissions (NO_x, SO_x, PM) are considered.
15. Does the report consider exhaust emissions only, or life-cycle, or both (or some other range of emissions)?	Life cycle emissions are considered in the study.

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 (g/kWh engine output):

		CO2-eq.			Local air pollutants		
Fuel	**Engine**	**Well-to-tank**	**Tank-to-wake**	**Well-to-wake**	**SOx**	**NOx**	**PM**
HFO	2-stroke slow speed diesel	114	583	697	9.15	3.40	n.a.
	4-stroke medium speed diesel	118	623	741	9.87	2.55	1.231
MGO	2-stroke slow speed diesel	121	565	686	0.34	3.40	n.a.
	4-stroke medium speed diesel	124	600	724	0.37	2.55	0.173
	4-stroke high speed diesel	145	713	859	0.44	2.01	n.a.
	Gas turbine	152	802	954	0.49	1.59	0.124
	Gas turbine CCGT	107	566	673	0.35	1.17	0.088
LNG	2-stroke slow speed diesel dual fuel	132	417	549	0.01	3.40	n.a.
	4-stroke medium speed Otto dual fuel	144	549	692	0.01	1.96	0.016
	2-stroke slow speed Otto dual fuel	133	465	598	0.003	0.88	n.a.
	4-stroke medium speed Otto single fuel	141	488	629	0.00	1.20	0.008
	4-stroke high speed Otto single fuel	178	634	812	0.00	1.51	n.a.
	Gas turbine	196	602	798	0	1.11	0.055
	Gas turbine CCGT	132	405	537	0.00	0.77	0.038
LSFO	2-stroke slow speed	*not provided*	*not provided*	*not provided*	1.79	3.40	n.a.
	4-stroke medium speed	*not provided*	*not provided*	*not provided*	1.92	2.55	1.231
LPG	2-stroke slow speed diesel	61	473	535	*not provided*	*not provided*	*not provided*

Methanol	2-stroke slow speed diesel	224	524	748	*not provided*	*not provided*	*not provided*
	4-stroke medium speed diesel	241	561	802	*not provided*	*not provided*	*not provided*

CO_2-eq. emission factor (g CO_2-eq/MJ (LHV)):

Fuel	Well-to-tank
LNG	18.5
Oil-based fuels	13.2-14.4
LPG	8.3
Methanol	31.3

CO2-eq. emission factors (g CO_2-eq/kWh engine output):

		100% syn. LNG	100% bioLNG	80% LNG, 20% syn. LNG	80% LNG, 20% bioLNG	80% LNG, 10% bioLNG, 10% syn. LNG	100% LNG
2-stroke slow speed Otto dual fuel	Well-to-tank	10	141	108	134	121	133
	Tank-to-wake	72	72	387	387	387	465
2-stroke slow speed diesel dual fuel	Well-to-tank	12	140	108	134	121	132
	Tank-to-wake	29	29	340	340	340	417
4-stroke medium speed Otto single fuel	Well-to-tank	9	150	115	143	129	141
	Tank-to-wake	65	65	403	403	403	488
4-stroke medium Otto dual fuel	Well-to-tank	11	152	117	145	131	144
	Tank-to-wake	129	129	465	465	465	549

4-stroke high speed Otto single fuel	Well-to-tank	12	189	145	180	163	178
	Tank-to-wake	103	103	528	528	528	634

17. Does the report discuss barriers and opportunities for ships 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 GHG and local pollutant emissions of different marine fuels are considered to be barriers/opportunities for ships, in light of emission regulations. Furthermore, some opportunities for further reducing GHG emissions of ships are described.
18. Does the report discuss barriers and opportunities for ports 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?	Opportunities to improve energy efficiencies of supply chains are mentioned as part of the recommendations. No other barriers and opportunities are discussed.
19. Does the report include capital and operating cost estimates for the ship and/or land-side?	No.
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)*	This is not discussed.

21. Are the fuels suitable for short and/or long (trans-oceanic) voyages?	The fuels are suitable for both short and/or long voyages. This is not explicitly mentioned, but the fact that different engine types are needed for different types of ships (ocean-going vessels vs. smaller ships such as support vessels and tug boats) is. This implies that the considered fuels could be used for both short and long voyages.
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 discussed.