Comparing the lifecycle emissions of marine fuels.

Conor Walsh[1], Paul Gilbert[1], Uchenna Kesieme[2], Kayvan Pazouki[2], Alan Murphy[2].

[1]Tyndall Centre for Climate Change Research,

School of Mechanical, Aerospace and Civil Engineering

University of Manchester

M13 9PL

[2]School of Marine Science and Technology,

Newcastle University,

Armstrong Building,

Queen Victoria Road,

Newcastle upon Tyne,

NE1 7RU

1.0 Introduction and aims

In light of increasing greenhouse gas emissions, greater emphasis is being placed on the need to mitigate emissions in the short term (Stocker, Qin et al. 2013). Within the shipping sector a number of distinct operational and technological options have been identified to potentially assist in reaching decarbonisation targets. A notable example is the potential to switch from established marine fuels to more novel or emergent alternatives such as bio-derived fuels (Smith, Jalkanen et al. 2014). In terms of the emissions released during ship operation, many of these fuels present (on first evaluation) attractive alternatives as they represent a much lower direct emission burden. However in order to inform a realistic comparison with established marine fuels, it is necessary to compare emissions across the entire fuel cycle, including the production and transportation of alternative fuels (Chryssakis 2014). With that in mind, the objective of this study is to derive full lifecycle emission estimates for a number of distinct fuels. Whilst this is informative in itself, the capacity to incorporate such data into high-level sectoral scenario generation tools affords the opportunity to add value and move beyond the often 'snapshot' service of lifecycle assessment.

2.0 Methodology

This study applies standard attributional lifecycle assessment (ALCA) methods to quantify the emissions embodied by fuel throughout its entire lifecycle (Brander, Tipper et al. 2008). Within ALCA the emissions are attributed to the production of individual intermediate products, which act as the main outputs for each distinct given lifecycle stage. Taking a modular or unitary perspective, each output, with its embodied emissions, becomes an input for the next lifecycle stage (e.g. the emissions associated with extraction of 1 kg of rapeseed oil, itself an input into the production of rapeseed derived bio-diesel). This process is continued until the final lifecycle stage is reached. On occasions, where a given lifecycle stage results in the production of more than one product the overall emissions of that lifecycle stage are allocated amongst each co-product. Within this study, emissions are allocated based on the mass and energy content of the co-products. Data used in this study is taken from a range of sources including published reports and data repositories (Jaramillo, Griffin et al. 2005; Draucker, Bhander et al. 2010; Bengtsson, Andersson et al. 2011; Bengtsson, Fridell et al. 2012; Cetinkaya, Dincer et al. 2012; Ecoinvent 2013; ELCD 2014; Skone, Littlefield et al. 2014; Moirangthem 2016)

3.0 Scope and functional unit

The study boundaries reflects a well to propeller (WTP) perspective, as it encompasses each individual stage along the supply chain; including feedstock extraction, processing, storage, and transport (termed ‘well to tank’) – referring to upstream emissions; as well as the emissions released during the operation of a ship (termed ‘tank to propeller’) - referring to operational emissions (Chryssakis 2014). The fuels covered are summarised in Table 1, reflecting established and emergent marine fuels. The results are expressed in terms of two functional units; i) emissions per unit of fuel combusted and ii) emissions per unit of power delivered off the shaft. The latter is estimated by using estimates of specific fuel consumption (SFC), which reflects the type of fuel that is likely to be consumed within different engines types. Whilst the study quantifies a number of different emission species, reflecting both greenhouse gases (GHGs) and local pollutants, this paper focuses on GHG emissions.

Fuel	Feed Stock	Process Route	Engine Type
Heavy Fuel Oil	Crude Oil	Refining Catalytic hydrocracking etc.	Slow speed diesel engine
Marine Diesel Oil	Crude Oil		Fast to medium speed diesel
Liquid Natural Gas	Raw Natural Gas	Desulphurisation liquefaction	Spark ignition gas engine
Liquid Hydrogen (fossil, w/o CCS).	Liquid Natural Gas	Steam reforming	Fuel cell
Liquid Hydrogen (renewable)	Water	Electrolysis	Fuel cell
Methanol	Liquid Natural Gas	Steam reforming, synthesis and distillation	2/4 stroke engine.
Rape Biodiesel	Straight Rapeseed Oil (SVO)	Drying and oil extraction, transesterification.	Slow to medium speed diesel
Soya Biodiesel	Straight Soya Oil (SVO)		Slow to medium speed diesel
Bio-LNG	Agricultural Waste	Anaerobic digestion	Spark ignition gas engine

Table 1: Summary of fuel and engine type.

4.0 Baseline (2010) Results

Figure 1 below summarise results the GHG results per kg of fuel. Results are expressed in carbon dioxide equivalents based on global warming potentials (GWP) published in (IPCC 2015). Please note that the direct CO_2 emissions associated with bio-derived fuels are excluded as they are assumed to be carbon neutral (however, direct methane emissions are retained).

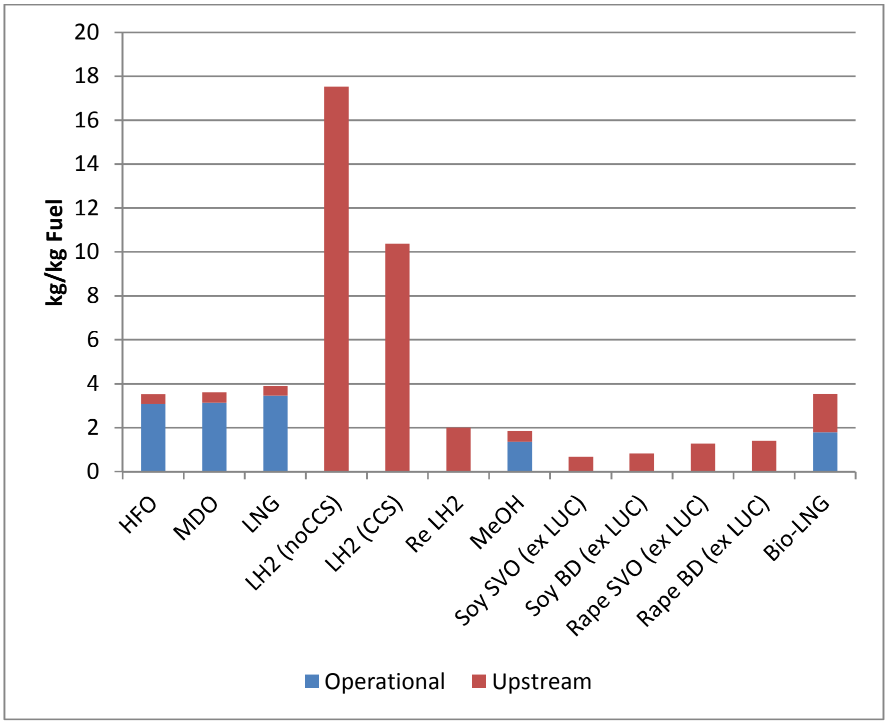

Figure 1: Well To Propeller GHG Emissions (exc operational biogenic CO_2 and emissions due to land-use change).

The results demonstrate the importance of adopting a lifecycle perspective for fuels that nominally are treated as low carbon. For example, whilst being carbon free from an operational perspective, the production of fossil derived liquid hydrogen entails consumption of considerable quantities of both natural gas and electricity. Similarly, reviewing both well to tank and well to propeller emissions in tandem allows for a more complete comparison between fossil and bio-derived equivalents. Figure 1 identifies, for example, how upstream emissions for bio-fuels appear to exceed those for more established marine fuels.

However, comparing fuels purely in terms of mass does not appreciate the different engine configurations. Figure 2 expresses the results in terms of shaft output; a low SFC estimate for a fuel cell decreases the relative impact of liquid Hydrogen in comparison with existing marine fuels, but in the case of Methanol, a large SFC (itself highly uncertain) results in a higher GWP estimate than existing fossil fuels.

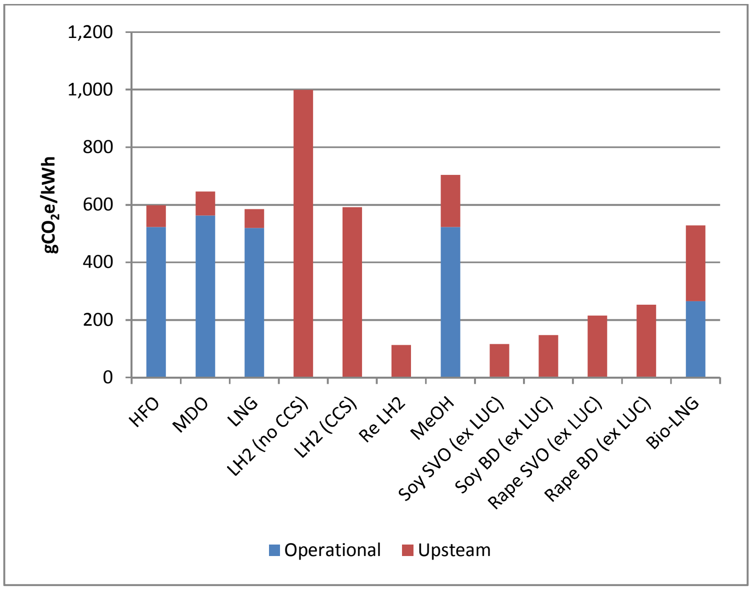

Figure 2: WTP GHG emissions per kWh based on engine type.

5.0 Discussion

The results summarised in the paper reflect baseline values consistent with 2010 levels of technology penetration and assumptions on the energy efficiency of marine engines. However, the results as presented represent “snap shots” of a particular fuel cycle. In order to add value to these results, a number of fuel cycle or system boundary assumptions are altered to reflect potentially important sensitivities and thereby be more informative within a wider scenario context. For example, including the impact of land use change is seen to significantly increase the carbon dioxide emissions associated with the production of Soya based bio-diesel (from 0.7 kg CO_2/kg fuel to >4 kg CO_2/kg). This is based on the assumption that soya is cultivated on newly conditioned land in South America including the effects of deforestation. In contrast, for Liquid H_2 assuming that i) renewable electricity is used to liquefy hydrogen, ii) that CCS can exceed a 90% capture rate and that gaseous natural gas is the feedstock is sufficient to reduce the embodied carbon by >75%. It should be noted that both these modifications reflect different scales of fuel cycle intervention. The choice of cultivation expansion reflects a decision that is made along the fuel cycle (admittedly by a potentially different party to the fuel processing agent). In contrast, the provision of a decarbonised grid reflects a system-level change which is likely beyond of the gift of a specific industrial supply chain or process manager.

6.0 Conclusion

The results illustrate the challenges inherent in decarbonising the shipping sector. Fuels such as Hydrogen, for example, require system changes in order to approach the levels of emission reduction that might, in the first instance be anticipated for a “carbon free” fuel. Similarly bio-fuels can, depending on the cultivation method, embody significant upstream emissions. However, that should not be taken as a reason for discounting the potential value of fuel switching, as there remain fuels which are likely to offer emission reductions in the near term. Therefore, perhaps the most rational position is the management of expectations with regards what can reasonably be expected by fuel switching in the near-term and adopt a healthy scepticism towards viewing fuel switching as a panacea for sectoral decarbonisation.

7.0 Bibliography

Bengtsson, S., K. Andersson, et al. (2011). "A comparative life cycle assessment of marine fuels liquefied natural gas and three other fossil fuels." Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment **225**(2): 97-110.

Bengtsson, S., E. Fridell, et al. (2012). "Environmental assessment of two pathways towards the use of biofuels in shipping." Energy Policy **44**: 451-463.

Brander, M., R. Tipper, et al. (2008). Technical Paper: Consequential and attributional approaches to LCA: a Guide to policy makers with specific reference to greenhouse gas LCA of biofuels, Econometrica Press.

Cetinkaya, E., I. Dincer, et al. (2012). "Life cycle assessment of various hydrogen production methods." International journal of hydrogen energy **37**(3): 2071-2080.

Chryssakis, C. B., O; Anton Tvete, H; Brandsæter, A; (2014). Alternative fuels for shipping, DNV.

Draucker, L., R. Bhander, et al. (2010). "Life Cycle Analysis: Natural Gas Combined Cycle (NGCC) Power Plant." National Energy Technology Laboratory, Pittsburgh, PA, US.

Ecoinvent (2013). Lifecycle Inventory Data. P. Consultants.

ELCD (2014). Lifeycle inventory data for UK grid electricity.

IPCC (2015). Climate change 2014: mitigation of climate change, Cambridge University Press.

Jaramillo, P., W. M. Griffin, et al. (2005). Comparative Life Cycle Carbon Emissions of LNG Versus Coal and Gas for Electricity Generation, Civil and Environmental Engineering, Carnegie Mellon University, Pittsburgh, PA.

Moirangthem, K. (2016). Alternative Fuels for Marine and Inland Waterways, European Commission.

Skone, T., J. Littlefield, et al. (2014). "Life cycle analysis of natural gas extraction and power generation." Office of Fossil Energy, National Energy Technology Laboratory, US Department of Energy.

Smith, T., J. Jalkanen, et al. (2014). "Third imo ghg study 2014." International Maritime Organization (IMO), London, http://www. iadc. org/wp-content/uploads/2014/02/MEPC-67-6-INF3-2014-Final-Report-complete. pdf.

Stocker, T. F., D. Qin, et al. (2013). "Climate change 2013: the physical science basis. Intergovernmental panel on climate change, working group I Contribution to the IPCC fifth assessment report (AR5)." New York.