Labour under an assumption

by Dr. Elizabeth Lindstad, *Chief Scientist, SINTEF Ocean AS*

In the past, many studies have demonstrated different greenhouse gas (GHG) impacts from the use of liquefied natural gas (LNG). In theory, when using emission and energy coefficients in combustion only, LNG results in about 25% lower GHG emissions than diesel (MGO) or bunker oil (HFO). However, larger well-to-tank (WTT) emissions for the LNG supply chain as well as uncombusted methane (CH_4) from the ship's engine might more than nullify any GHG gains.

A recent study performed for SEA\LNG and SGMF by the company Thinkstep reports that if the whole world fleet shifted from traditional fuels to LNG, the maritime GHG emissions could be reduced by around 15%. This was measured on a well-to-wake basis (WTW). Metrics that weigh emitted gases according to their global warming potential (GWP), to report them in terms of "CO_2 equivalents," (CO_{2e}) have become standard currency to benchmark and communicate the relative and absolute contributions to climate change. GWPs are usually calculated for 20 or 100-year time horizons, where the shortest time span gives greater weight to the short-lived climate forcers.

A key question to ask when such large reduction figures are presented is how they've got there. To understand the assumptions, hypotheses, and limitations in the Thinkstep study, I've created a simple spreadsheet model. I've found that the favourable result for LNG comes as a result of assumptions employed when Thinkstep's calculated WTT; their assumption of higher thermal efficiency for LNG than for diesel in the (engine) combustion process; and their low amounts of uncombusted methane in the exhaust gas from the ship's engines.

What difference does it make?

For the WTT calculations, Thinkstep has used the following figures: LNG 18.5 grams of CO_2 per MJ; MGO 14.4 grams of CO_2/MJ; and HFO 13.5 grams of CO_2/MJ. The LNG and the MGO figures are in line with the previously published figures both in magnitude and in relative difference. In contrast, the HFO figure is somewhat high if we consider HFO to be 'the bottom of the barrel' – the waste from the refinery process.

Since a sulphur cap was first agreed on in 2008, we have consistently been reminded that desulfurising residual fuel oils implies cost and complexity similar to conversion from residual to distillate. This means that conversion from HFO to diesel costs up to 10-15% of the energy content in the HFO. With new modern refineries set up to convert all crude into higher-priced products, HFO will hence from 2020 come from existing refineries where its share of the energy consumption is next to zero. If we acknowledge the lower energy consumption in delivering HFO and deduct the refinery part from the Thinkstep figures, we get 9.6 grams of CO_{2e}/MJ for HFO, rather than 13.5 grams of CO_{2e}/MJ.

To convert from gram of CO_2 per MJ to gram of CO_2 per kWh, we multiply by 3.6 and adjust for the thermal efficiency. The calculation for a 2-stroke engine running on MGO is 14.4 x 3.6 / 48% = 108 grams CO_{2e}/kWh and for LNG: 18.5 x 3.6 / 48% = 139 grams CO_{2e}/kWh. This gives 28% higher WTT emissions per kWh for LNG than for MGO. Here Thinkstep has apparently used a different conversion method, since they, with the same input, end up with 121 grams CO_{2e}/kWh for MGO and 132 grams CO_{2e}/kWh for LNG, which is only 9% higher WTT emissions for LNG than for MGO. For the overall calculation, the Thinkstep conversion method employed here, which I question in this note, gives LNG a favour of 3% on the total WTW emissions.

For thermal efficiency, Thinkstep has used a higher figure for LNG- than for diesel-fuelled engines. I interpret the Thinkstep figures as 46% vs 45% for 4-stroke engines and 49% vs 48% for 2-stroke engines. At high power, LNG might give a marginally better thermal efficiency, while at power lower than 50%, the diesel-based option gives much better fuel utilisation. With most ships today using around 50% of installed power to operate at speeds two-to-four knots or more below

Fig. 1. WTW with 2-stroke engines GWP 100

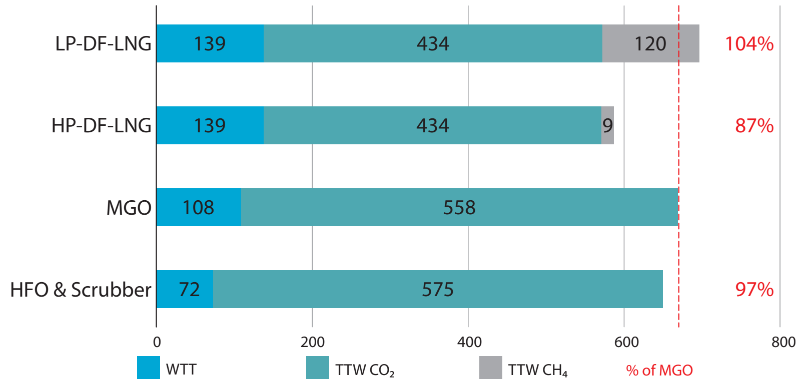


Fig. 2. Thinkstep WTW with 2-stroke engines GWP 100

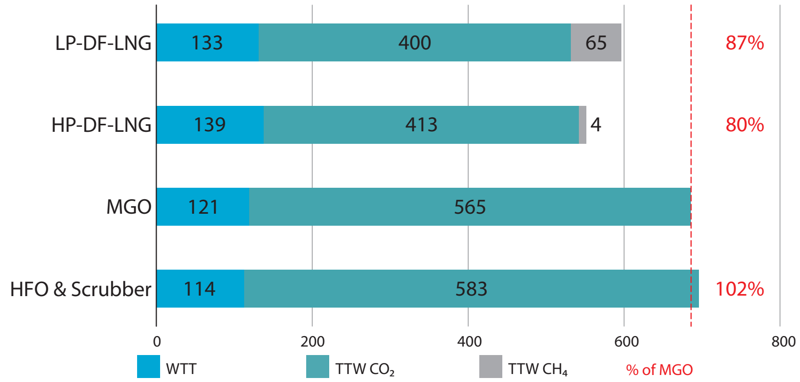


Fig. 3. WTW with 2-stroke engines GWP 20

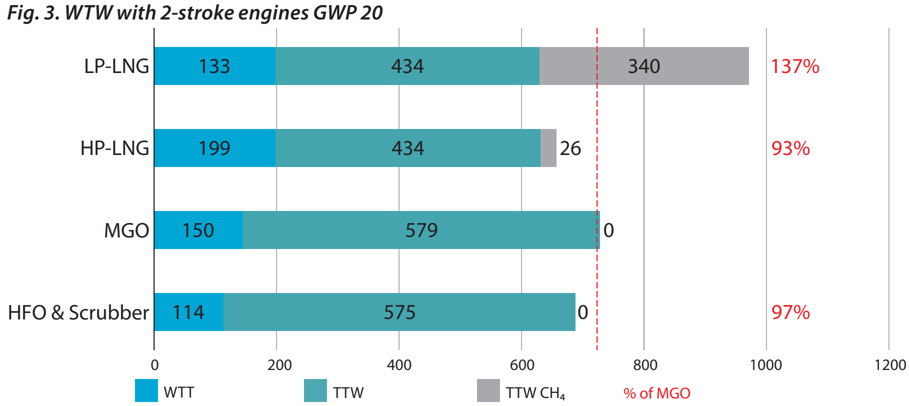
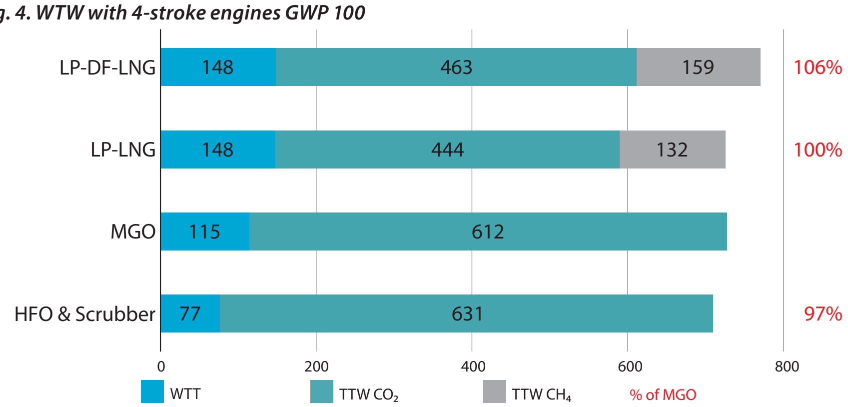


Fig. 4. WTW with 4-stroke engines GWP 100



the design speed, there are no good reasons for using a higher thermal efficiency for LNG than for diesel. This assumed 1% difference in thermal efficiency by Thinkstep accounts for 2% on fuel and GHG emission savings in favour of LNG. The explanation is that thermal efficiency of 48% means that 48% of the energy in the fuel is converted to mechanical energy for propulsion and 52% is heat loss through the exhaust gas and cooling water.

Uncombusted methane

HFO and diesel fuels are used in traditional diesel engines, while LNG is used in two types of alternative dual-fuel (DF) engines, high- (HP-LNG) and low-pressure systems (LP-LNG), plus in pure gas engines. Only the high-pressure 2-stroke engine (HP-DF-LNG) has low emissions of uncombusted methane. For all other LNG engine options, the amount of uncombusted methane is significant and hence, a challenge. Methane gives a GHG impact 28-to-34 times higher per gram emitted than CO_2 in a one-hundred-year perspective. In a shorter-term perspective, such as 20 years, the warming impact of methane is 85 times larger per gram than CO_2.

Thinkstep has chosen to use the test-bed data from the NO_x testing cycle for their estimate of uncombusted methane (they have used the average of the manufacture's figures for each of the engine types). The weakness of this approach is (if the purpose is to find representative figures) that the NO_x test cycle assumes that the engine operates at 75-100% power, 70% of the total time, which is not representative for how the world fleet is operated today. More worrying – at these high loads, the uncombusted methane for LNG is lowest. In addition, test-bed values tend to be lower than when measurements are performed based on the same testing cycle at vessels at sea. This has been well documented in the SINTEF Study: *GHG and NO_x emissions from gas fuelled engines – mapping, verification, reduction technologies* (publicly available through the homepage of the Norwegian NO_x Fund).

All the difference in the world

Comparing the results from the SINTEF report with Thinkstep for 4-stroke engines we get: LP-LNG = 4.4 grams/kWh (Thinkstep = 2.0 grams/kWh); LP-DF-LNG = 5.3 grams/kWh (3.9 grams/kWh); for 2-stroke engines the SINTEF report does not have measurements, but if we assume the same tendencies, we have then HP-DF-LNG = 0.3 grams/kWh (0.14 grams/kWh) and LP-DF-LNG = 4.0 grams/kWh (2.18 grams/kWh).

Combining all of this and keeping

all other values as described in the Thinkstep report, it is feasible to compare the results. The figures below show the CO_{2e} emission in grams per kWh. First my own calculation and then the Thinkstep one, both within a 100-year time horizon (GWP 100), followed by my calculations across a 20-year time span (GWP 20). In the figures, the blue colour is used for WTT, for TTW we spilt with a green colour for CO_2, and grey for uncombusted methane. At the right end, the percentage shows the WTW emissions relative to the MGO option.

The results from my own calculations indicate that the only LNG option which contributes to reducing GHG emissions is the 2-stroke high-pressure dual-fuel option. For all other LNG options, the GHG emissions increase or are equal to using MGO or HFO (this is in comparison to the results from Thinkstep, which indicates a reduction potential for all LNG options). If we take the GWP 20, motivated by the need to rapidly reduce GHG emissions, the results for LNG are even worse (apart from the 2-stroke HP-DF option), because the uncombusted methane really boosts global warming the first few years after it has been emitted. In addition, as a carbon-based fuel of fossil origin, combustion of LNG still results in continued CO_2 emissions.

Considering that the residence time of CO_2 in the atmosphere is thousands of years and that there is a clear carbon budget associated with the goals set forward in the Paris Agreement, even with the high-pressure dual-fuel option, risks lock-in the sector into a high-carbon infrastructure not commensurate with required commitments in the long-term.

Fig. 5. Thinkstep WTW with 4-stroke engines GWP 100

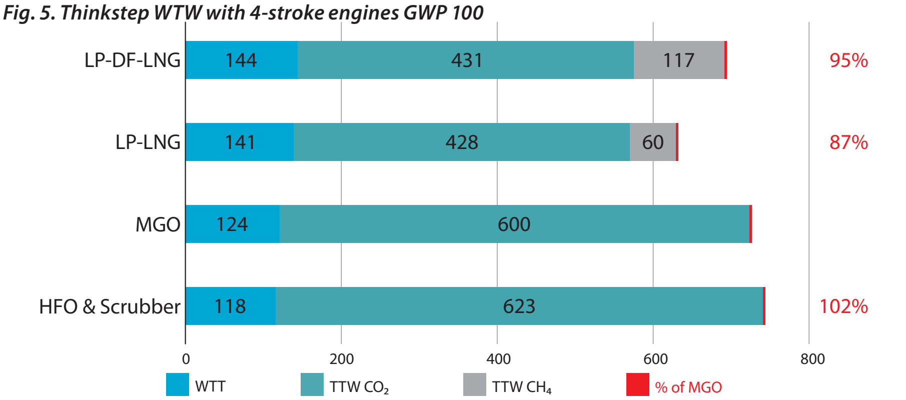
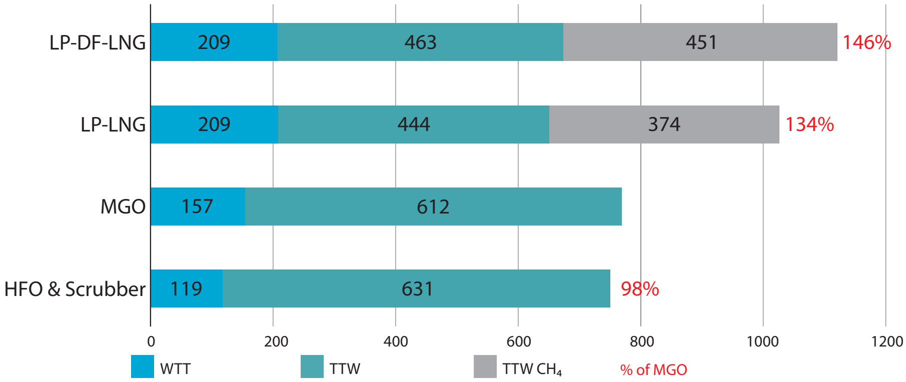
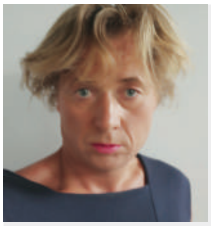


Fig. 6. WTW with 4-stroke engines GWP 20





Dr Elizabeth Lindstad is a Norwegian University of Science and Technology PhD Naval Architect and holds an MSc in Civil Engineering which she obtained at the Norwegian Institute of Technology. Dr Lindstad has vast experience in developing, initiating, and managing research and development projects, with a particular focus on sustainable shipping solutions, new innovative vessel designs, and supply chains. A member of the European Sustainable Shipping Forum, she has co-authored a number of EU and IMO policy studies. This article is based on her own analysis and the best intentions of contributing to sound analysis and decision-making. In case anything has been misinterpreted or misunderstood, Dr Lindstad is open to address any objections.