Increased use of LNG might not reduce maritime GHG emissions at all – June 2019

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In the past, many studies have demonstrated different Greenhouse gas (GHG) impacts from the use of LNG (Buhaug et al 2009; Bengtson et al 2011; Verbeek et al 2011; Chryssakis and Stahl 2013; Concawe and EUCAR 2013; Øberg 2013; Bengtson et al 2014; Brynolf et al 2014; Brynolf et al 2014a; Verbeek 2015; Lindstad et al 2015; Bouman et al 2017; Lindstad 2018). In theory, using emission and energy coefficients in combustion only, liquified natural gas (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 un-combusted methane (CH_4) from the ship's engine might more than nullify any GHG gains (Stenersen and Nilsen, 2010; Lindstad and Sandaas 2016; Stenersen and Thonstad, 2017).

A recent study performed for SEA\LNG and SGMF by the company Thinkstep (Thinkstep, 2019) reports that if the whole world fleet shifted from traditional fuels to LNG, the maritime greenhouse gas (GHG) emissions could be reduced by around 15%. This measured on a well to wake basis (WTW). Metrics that weight emitted gases according to their global warming potential (GWP), to report them in terms of "CO_2 equivalents", have become standard currency to benchmark and communicate the relative and absolute contributions to climate change (Shine, 2009). GWP is usually calculated for 20 or 100-year time horizon consistent with Houghton et al. (1990), where the shortest time horizon gives greater weight to the short-lived climate forcers.

A key question to ask when such large reduction figures are presented is how they got there. To understand the assumptions, hypotheses and limitations in the Thinkstep (2019) study, I created a simple spread-sheet model. I find that the favourable result for LNG comes as a result of assumptions employed when Thinkstep (2019) calculate well to tank emissions (WTT); their assumption of higher thermal efficiency for LNG than for diesel in the (engine) combustion process; and their low amounts of un-combusted methane in the exhaust gas from the ship's engines.

For the Well to tank (WTT) calculations, Thinkstep (2019) have used: LNG 18.5 Gram of CO_2 per MJ; MGO 14.4 Gram CO_2 per MJ; HFO 13.5 Gram CO_2 per MJ. The LNG and the MGO figures are in line with previously published figures both in magnitude and in relative difference (Concawe and EUCAR 2013; Verbeek 2015; Lindstad 2018). In contrast, the HFO figure is high if we consider HFO to be 'the bottom of the barrel' and the waste from the refinery process.

Since the 2020 Sulphur cap was first introduced in 2008, we have consistently been reminded that desulfurizing 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 (Shell 2016; Lindstad et al 2017). With new modern refineries set up to convert all crude into higher priced products, HFO will hence from 2020 come from existing refineries where it's 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 (2019) figures, we get 9.6 gram of CO_2 eq. per MJ for HFO, rather than 13.5 gram of CO_2 eq. per 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 two-stroke engine running on MGO is 14.4 * 3.6 / 48% = 108gram CO_2 eq. per kWh and for LNG 18.5 * 3.6/ 48% = 139gram CO_2 eq. per kWh. This gives 28% higher Well to Tank (WTT) emissions per kWh for LNG than for MGO. Here Thinkstep (2019) has apparently used a different conversion method, since they with the same input end up with 121gram CO_2 eq. per kWh for MGO and 132gram CO_2 eq. per kWh for LNG, which is only 9% higher WTT emissions for LNG than for MGO. For the overall calculation, the Thinkstep (2019) 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 (2019) has used a higher figure for LNG fuelled engines than for diesel fuelled engines. I interpret the Thinkstep figures as 46% versus 45% on four (4) – stroke engines and 49% versus 48% on two (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 utilization (Ushakov 2018). With most ships today using around 50 % of installed power to operate at speeds 2 to 4 knots or more bellow the design speed (Smith at al 2014; Fairplay 2018) there are no good reasons for using a higher thermal efficency for LNG than for diesel (Lindstad 2018; Ushakov 2018) . This assumed 1% difference in thermal efficiency by Thinkstep (2019) acconts for 2 % on the fuel and GHG emissions in favour of LNG. The explanation is that a 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.

Un-combusted Methane: HFO and diesel fuels are used in traditional diesel engine, while LNG is used in two types of alternative dual fuel engines, high pressure (HP) and low-pressure systems (LP), plus in pure gas engines (LP-LNG) (Lindstad 2018; Ushakov 2018). Dual fuel (DF) means that the engine can run on traditional fuel such as HFO or MGO in addition to LNG. Only the high pressure 2-stroke engine (HP-DF-LNG) has low emissions of un-combusted methane. For all other LNG engine options, the amount of un-combusted methane is significant and hence a challenge. Methane gives an GHG impact 28 – 34 times higher per gram emitted than CO_2 in a one hundred-year perspective (IPCC, 2013). In a shorter-term perspective such as 20 years, the warming impact of methane is 85 time larger per gram than CO_2 (IPCC, 2013).

Thinkstep has chosen to use the testbed data from the NOx testing cycle for their estimate of un-combusted 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 NOx 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 (Smith at al 2014; Fairplay 2018).

More worrying: at these high loads the un-combusted methane for LNG is lowest. In addition, testbed values tend to be lower than when measurements are performed based on the same testing cycle at vessels at the sea. This is well document in the SINTEF Study: *GHG and*

*NOx emissions from gas fuelled Engines- Mapping, verification, reduction technologies (*Stenersen and Thonstad, 2017*)*, which is publicly available through the Norwegian NO-fund homepage.

Comparing the results from the SINTEF report Stenersen and Thonstad, 2017 with Thinkstep (2019) for 4 stroke engines we get:
Low Pressure (LP-LNG) = 4.4 gram per kWh (Thinkstep = 2.0 gram per kWh)
Low pressure dual fuel (LP-DF-LNG) = 5.3 gram per kWh (Thinkstep = 3.9 gram per kWH)

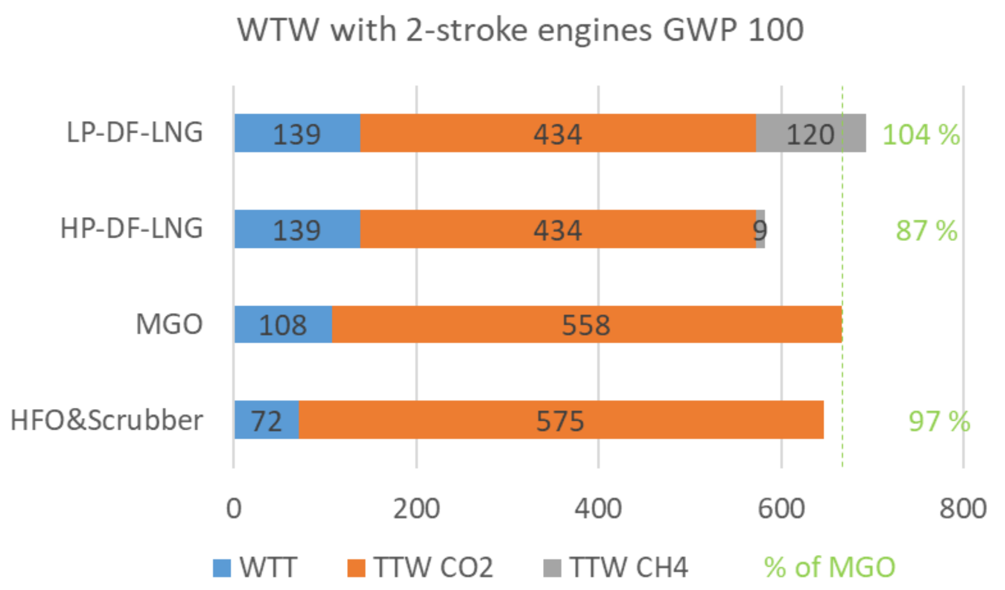
For 2- stroke the SINTEF report does not have measurements, but it we assume same tendencies:
High pressure (HP-DF-LNG) = 0.3 gram per kWh (Thinkstep = 0.14 gram per kWh)
Low pressure dual fuel (LP-DF-LNG) = 4.0 gram per kWh (Thinkstep = 2.18 gram per kWh)

Combining all of this outlined above and keeping all other values as described in the Thinkstep (2019) report, it is feasible to compare the results. The figures bellow shows the CO_2 equivalent emission in grams per kwh. First my own calculation (Lindstad 2019) and then the Thinkstep (2019) calculations both with a 100-year time horizon (GWP 100), followed by own calculations with a 20-year time horizon (GWP 20). In the figures the blue colour is used for WTT, for TTW we spilt with a red colour for CO_2 and grey for un-combusted methane. At the right end the percentage shows the WTW emissions relative to the MGO option.

The results from my own calculations (Lindstad 2019) indicate that the only LNG option which contributes to reducing GHG emissions, is the 2–stroke high pressure dual fuel option (HP-DF-LNG). For all other LNG options, the GHG emissions increases or are equal to using MGO or HFO. This in comparison to the results from Thinkstep (2019), which indicates a reduction potential for all LNG options. If we take a short-term view (GWP 20), motivated by the need to rapidly reduce GHG emissions, the results for LNG is even worse (apart from the 2-stroke HP-DF option), because the un-combusted methane really boost global warming the first 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 (Archer et al., 2009), 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 (HP-DF-LNG) risks lock-in the sector into a high-carbon infrastructure not commensurate with required commitments in the long term (Gilbert, 2014).

This letter is based on my own analysis and the best intentions of contributing to sound analysis and decision making. In case anything has been misinterpreted or misunderstood please challenge my analysis.


WTW with 2-stroke engines GWP 100
LP-DF-LNG
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HFO&Scrubber
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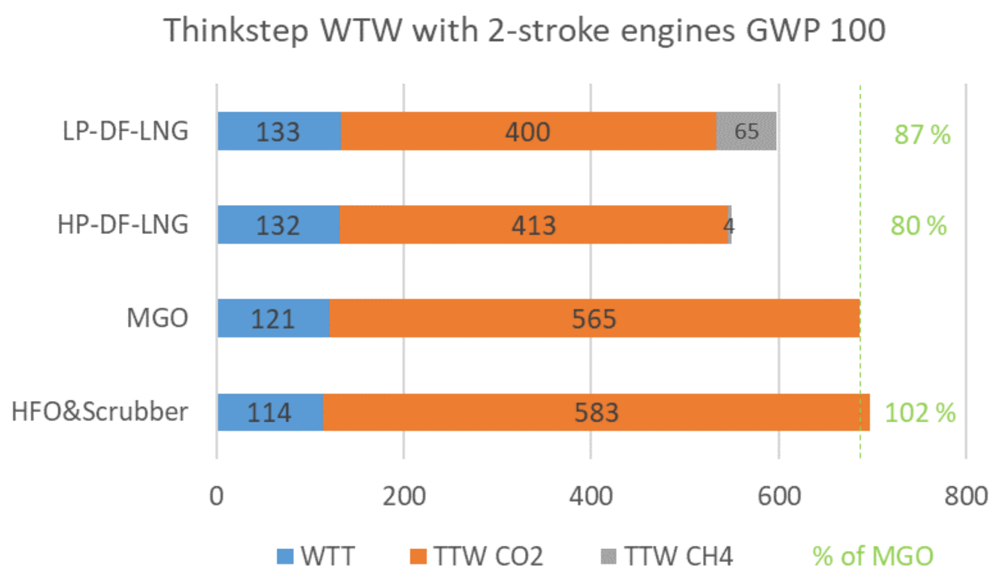
Thinkstep WTW with 2-stroke engines GWP 100
LP-DF-LNG
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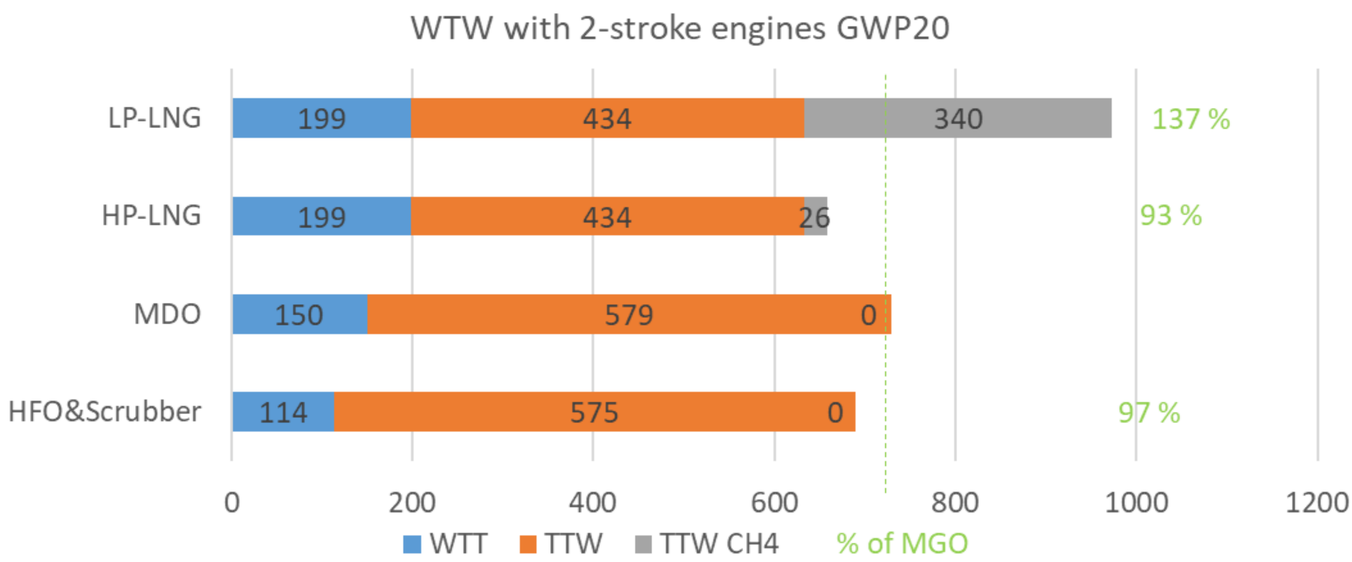
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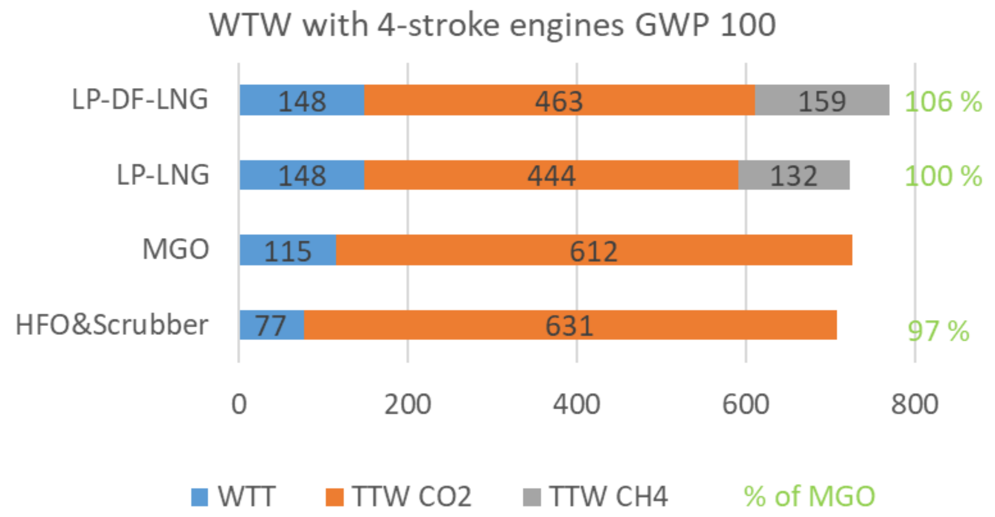
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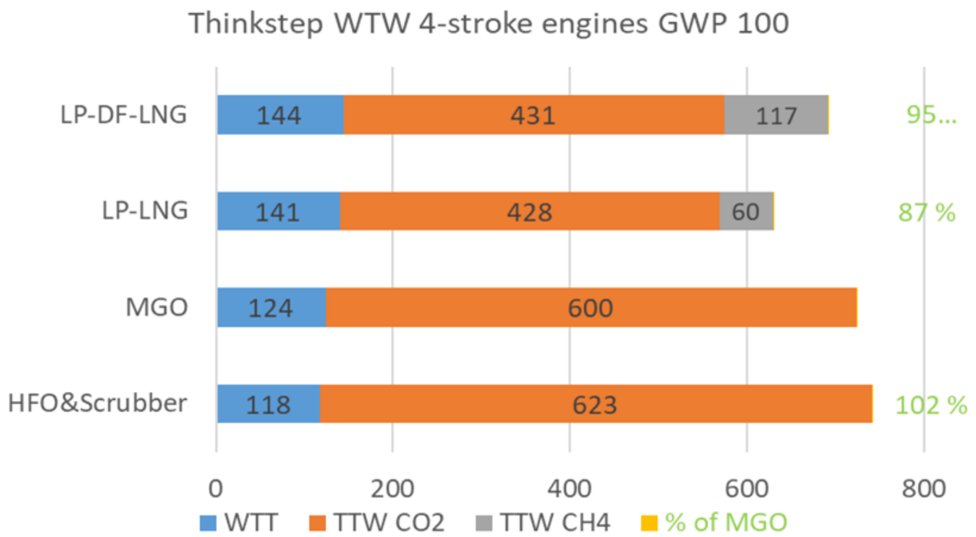
Thinkstep WTW 4-stroke engines GWP 100
LP-DF-LNG
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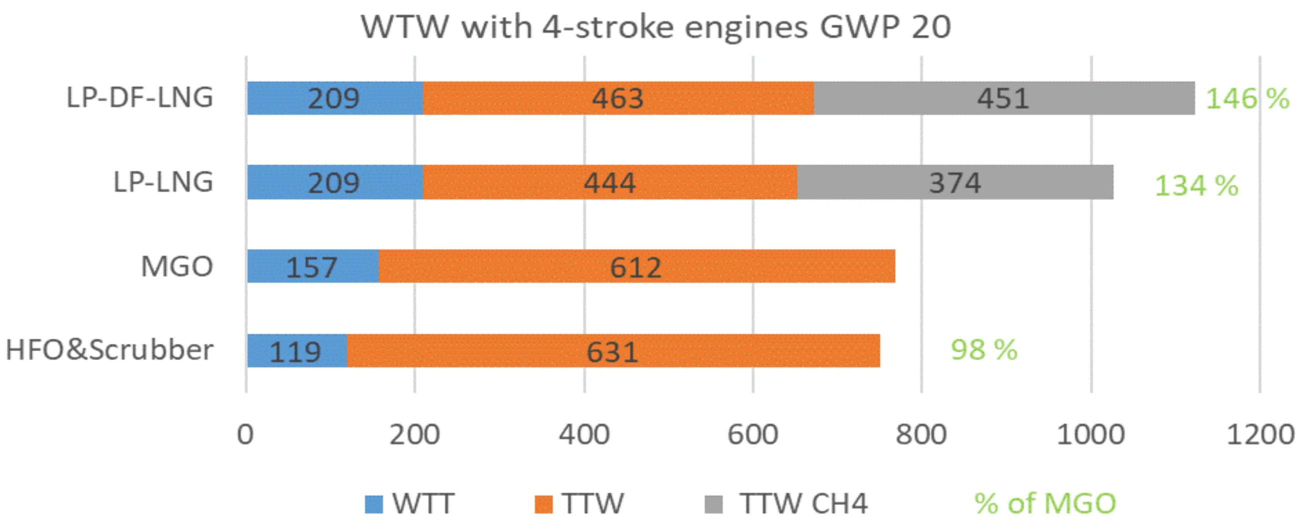
WTW with 4-stroke engines GWP 20
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% of MGO

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