INTERNATIONAL MARITIME ORGANIZATION

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Agenda item 3

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FURTHER DEVELOPMENT OF THE LIFE CYCLE GHG ASSESSMENT (LCA) FRAMEWORK

Fugitive and Unburned Methane Emissions from Ships (FUMES): Characterizing methane emissions from LNG-fueled ships using drones, helicopters, and on-board measurements

Submitted by WWF, Pacific Environment and CSC

SUMMARY

Executive summary:	This document summarizes the key findings of the Fugitive and Unburned Methane Emissions from Ships (FUMES) project, a collaboration between the International Council on Clean Transportation (ICCT), Explicit ApS, and the Netherlands Organization for Applied Scientific Research (TNO). The FUMES project resulted in the most comprehensive dataset of real-world methane emissions from LNG-fueled ships to date. The team conducted three measurement campaigns (plume, onboard, and fugitive) to assess real-world methane emissions associated with LNG-fuelled ships. Based on the results of the FUMES study, the co-sponsors propose that the Group accept at least 6% as the default TtW C_{slip} value for LPDF 4-stroke engines under the IMO's LCA Guidelines.
Strategic direction, if applicable:	3
Output:	3.2
Action to be taken:	Paragraph 13
Related documents:	Resolution MEPC.376(80) and ISWG-GHG 13/6

Introduction

1 MEPC 80 established the Correspondence Group on Further Development of the LCA Framework, under the coordination of Brazil, Japan and the European Commission, that included in its terms of reference developing a template for tank-to-wake default emission factors for the fuel pathways listed in appendix 1 of the LCA Guidelines (resolution MEPC.376(80)).

2 In the correspondence group, CSC, Pacific Environment and WWF proposed using 6% as the default methane slip (Cslip) value for Dual Fuel, 4-stroke, Medium Speed, Low Pressure/Otto Cycle (LPMSDF 4-s Otto) engines based on the results of the Fugitive and Unburned Methane Emissions from Ships (FUMES) project.

3 Under the FUMES project[1], researchers conducted three measurement campaigns (plume, onboard, and fugitive) to assess real-world methane emissions from LNG-fueled ships. For the plume campaign, the team used drones and helicopters to measure 45 plumes from 34 unique ships operating near the coasts of the Netherlands, Denmark, Belgium, and Australia in 2022. During the onboard campaign, researchers measured methane from an LNG-fueled ferry operating between Finland and Sweden in Spring 2023. During the fugitive campaign, researchers used a novel approach to quantify the rate of methane emissions from the LNG cargo unloading operations of three LNG tankers at a European LNG terminal in September 2022.

FUMES plume campaign key results

4 Methane slip from 22 measurements of 18 unique ships that exclusively used LPDF 4-stroke engines[2] (L4 ships) averaged 6.42% with a median of 6.05%, as show in in Figure 1. For six measurements at or above 50% combined main engine load[3], the average was 6.07% and the median was 6.59%. Methane slip was greater than the EU assumption of 3.1% in 77% of the measurements, which is meant to represent methane slip at 50% engine load. These same 77% of measurements were also greater than the *Fourth IMO GHG Study* assumption of 3.5% methane slip, which is meant to represent emissions on the E2/E3 test cycle.

5 Ships with LPDF 2-stroke main engines and LPDF 4-stroke auxiliary engines (L2L4) emitted the lowest ship-level methane slip. L2L4 ships emitted an average of 2.50% methane slip across all engine loads (18 measurements; 12 unique ships) and 1.58% when operating at above 10% main engine load (14 measurements; 8 unique ships), as shown in Figure 1. Median values were 1.47% and 1.35%, respectively. Note that below 10% main engine load, the LPDF 2-stroke main engines were likely switched to diesel mode, leaving only the LPDF 4-stroke auxiliary engines as the source of methane slip. For the L2L4 ships, the researchers found that LPDF 4-stroke auxiliary engine LNG consumption was significantly correlated with methane slip ($p = 0.017$): for every 10-percentage point increase in LPDF 4-stroke auxiliary engine consumption, ship-level methane slip increased by 0.5 percentage points.

6 The researchers could not say whether the EU or IMO methane slip values for LPDF 2-stroke or high-pressure dual-fuel (HPDF) 2-stroke engines were reasonable because they were not able to isolate the methane slip from these engines without interference from methane slip from LPDF 4-stroke auxiliary engines. Additionally, only three measurements from ships with HPDF 2-stroke main engines were obtained. For two of those measurements, the

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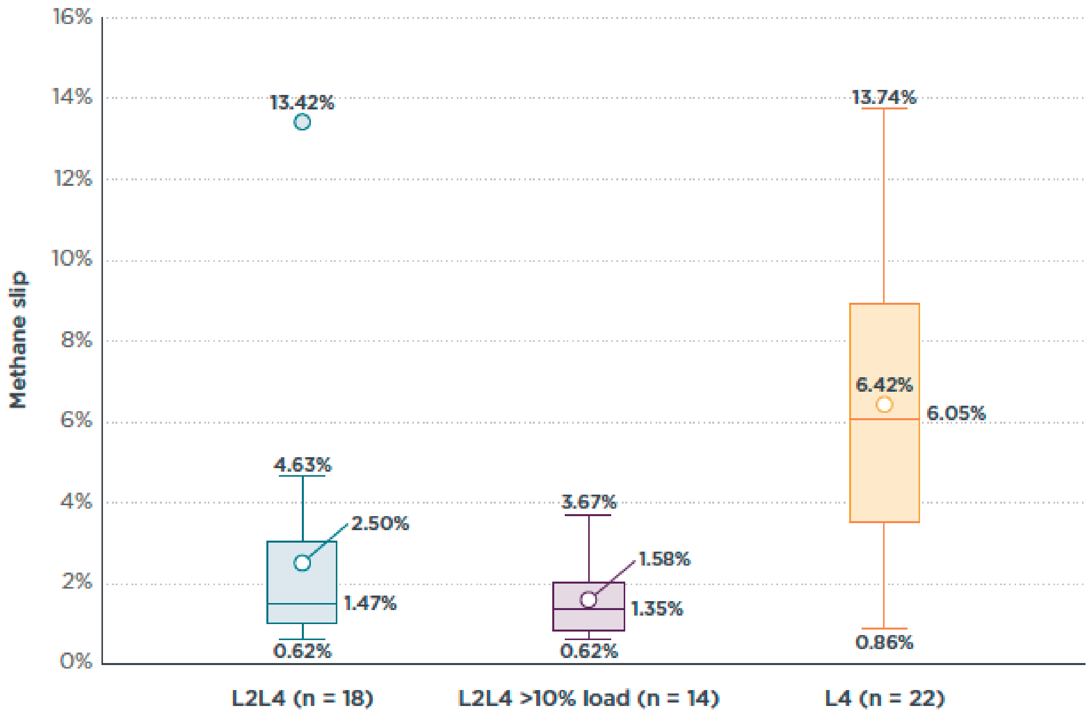
1 Comer et al. (2024). *Fugitive and Unburned Methane Emissions from Ships (FUMES): Characterizing methane emissions from LNG-fueled ships using drones, helicopters, and onboard measurements.* International Council on Clean Transportation. https://www.theicct.org/publication/fumes-characterizing-methane-emissions-from-lng-fueled-ships-using-drones-helicopters-and-on-board-measurements-jan24/

2 LPDF 4-stroke is a simplified abbreviation for Dual Fuel, four-stroke, Medium Speed, Low Pressure/Otto Cycle (LPMSDF 4-s Otto).

3 In the FUMES plume campaign, the researchers estimated combined main engine load (total main engine power demanded at the time the ship was measured divided by total installed main engine power) based on the speed of the ship when it was sampled. For L4 ships, most use multiple LPDF 4-stroke engines. Therefore, even when the combined engine load is low, the engine load for each LPDF 4-stroke engine can be higher if some engines are switched off to optimize engine load and fuel consumption for the remaining engines.

HPDF 2-stroke engines were likely operating in diesel mode, leaving only the LPDF 4-stroke engines operating on LNG when the ship was measured. Measuring methane slip directly from 2-stroke LPDF and HPDF engines remains a goal for future work.



Note: Dot shows outliers; whiskers show minimum and maximum (excluding outliers); circle inside box is the average; horizontal line is the median; box is the interquartile range.

Figure 1: Boxplot of ship-level methane slip for ships with LPDF 2-stroke main engines and LPDF 4-stroke auxiliary engines (L2L4) and ships with only LPDF 4-stroke engines (L4).

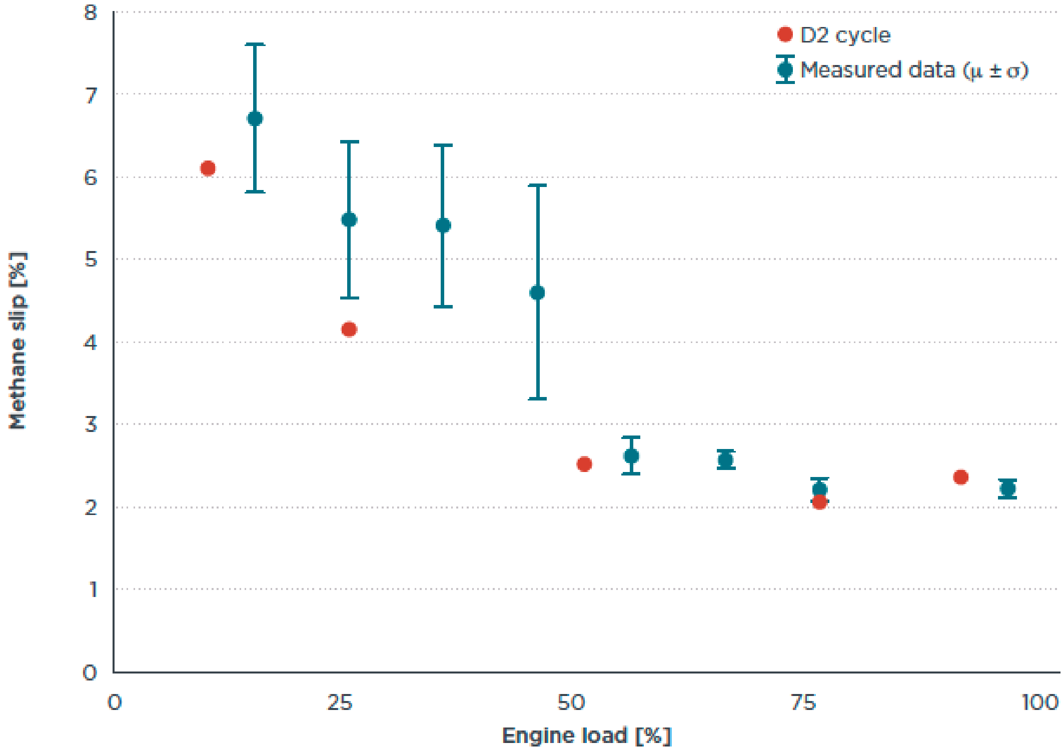
FUMES onboard campaign key results

7 Researchers found that a modern LPDF 4-stroke engine can emit lower methane slip than assumptions from EU regulations (3.1%) and the IMO (3.5%), but methane slip can still be substantial, especially at low engine loads.

8 Figure 2 shows methane slip results in two ways: the red dots show the D2 cycle results, which were measured under constant engine load conditions when the engine was operated at approximately 10%, 25%, 50%, 75%, and 92% engine load (a proxy for the 100% engine load test point for the NTC 2008 D2 and E2 cycle). The vertical bars show the average methane slip (dot) and standard deviation (whiskers) for all real-sailing measurements. They are binned by their nearest engine load at intervals of 15%, 25%, 35%, etc.

9 Methane slip was highest at low engine loads, and it was also more variable below 50% engine load than above. Real-sailing methane slip ranged from a minimum of approximately 2% for measurements near and above 75% engine load to a maximum of 6.7% for measurements near 15% engine load. Methane slip was about 2.5% at approximately 50% engine load. This is lower than the EU assumption of 3.1% at 50% load, and toward the lower end of the literature.

10 The *Fourth IMO GHG Study*'s assumption of 3.5% methane slip is meant to estimate emissions on the E2/E3 test cycle. In Figure 2, the results are presented for the D2 cycle, which includes measurements at 10% load; the E2/E3 cycle omits the 10% load measurement and applies different weighting factors than the D2 cycle when calculating a weighted emission factor. The E2 test cycle is relevant for this engine, and the measurements yielded a weighted methane slip of 2.0% methane slip, lower than IMO's assumption of 3.5%. Typically, ships are operating at lower loads than implied by the E2/E3 weighting factors[4] but, in this case, the ship tended to operate at higher engine loads.



Note: Results shown when measured on the D2 cycle, which were measured at constant load, and results of all measured data binned by engine load (e.g., the first bar is centered at 15% engine load, the second at 25% engine load, etc.).

Figure 2: Methane slip measured onboard a roll-on/roll-off passenger ferry with LPDF 4-stroke engines.

FUMES fugitive campaign key results:

11 The researchers found that LNG cargo unloading operations can release 11 to 21 kilograms of methane per hour (kg/h) for a small, 10,000 cubic meter (m^3) capacity LNG tanker that uses conventional diesel engines (i.e., does not use LNG as a fuel). The unloading operations of large 162,000 to 174,000 m^3 capacity LNG tankers that use LPDF 4-stroke engines can result in fugitive methane emissions between 24 to 40 kg/h, including approximately 8 kg/h of methane slip from the engines. Figure 3**Figure *3*** shows an example, where the hotspot on the left was determined to most likely be methane slip from the ship's LPDF 4-stroke engines, whereas the other areas show methane leaks associated with LNG cargo unloading operations. While the amount of methane released as a percentage of cargo unloaded is small, the methane emissions rates (kg/h) from unloading operations were estimated to be greater than the emissions rates from the LPDF 4-stroke engines used by the large LNG tankers.

4 Comer et al. (2023). *Real-world NO_x emissions from ships and implications for future regulations*. International Council on Clean Transportation. https://theicct.org/publication/real-world-nox-ships-oct23/

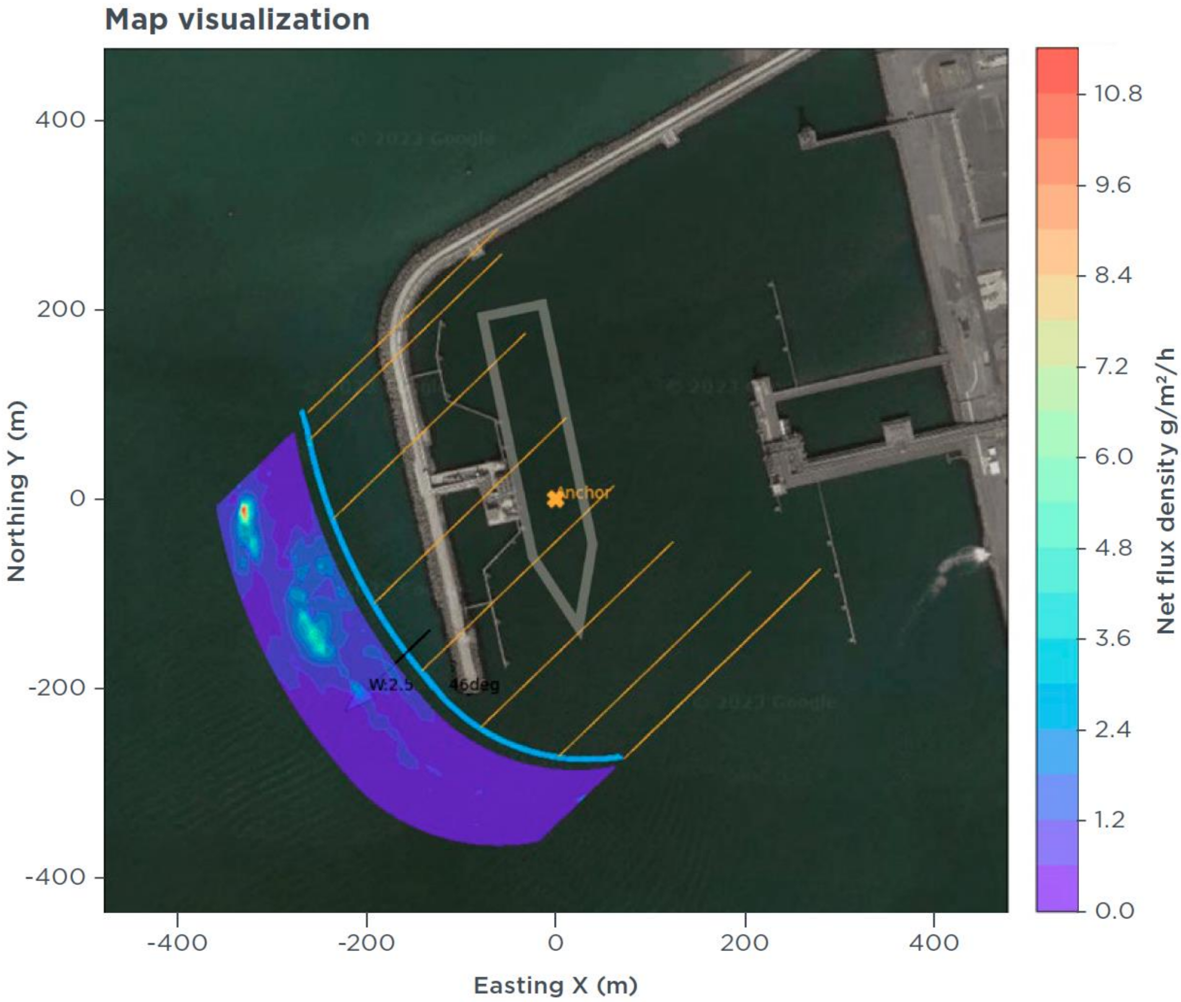


Figure 3: Example of measured fugitive methane emissions from LNG cargo unloading operations that were visualized on a satellite map to identify the sources of methane.

Proposal

12 Based on the results of the FUMES study, the co-sponsors propose that the Working Group agree to a default methane slip (C_{slip}) value for Dual Fuel, 4-stroke, Medium Speed, Low Pressure/Otto Cycle (LPMSDF 4-s Otto) engines of at least 6%. This is based on the finding that the average and median methane slip for these engines was greater than 6%, even for measurements at higher combined main engine loads. Shipowners will have the opportunity to certify engines to lower-than-default values under the procedures that will be established in the LCA Guidelines.

Action requested of the Working Group

13 The Working Group is invited to consider the proposal in paragraph 12 and the study referred in this document and to take action as appropriate.

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