FUMES: Fugitive and Unburned Methane Emissions from Ships

Characterizing methane emissions from LNG-fueled ships using drones, helicopters, and on-board measurements

Presented by:
Bryan Comer, Marine Program Director, ICCT
Jörg Beecken, Senior Research and Project Manager, Explicit ApS
Ruud Verbeek, Senior Technical Consultant, TNO

March 14, 2024

icct
THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

Agenda

1. Motivation for the study
2. Plume campaign results
3. On-board campaign results
4. Fugitive campaign results
5. Policy recommendations

Motivation

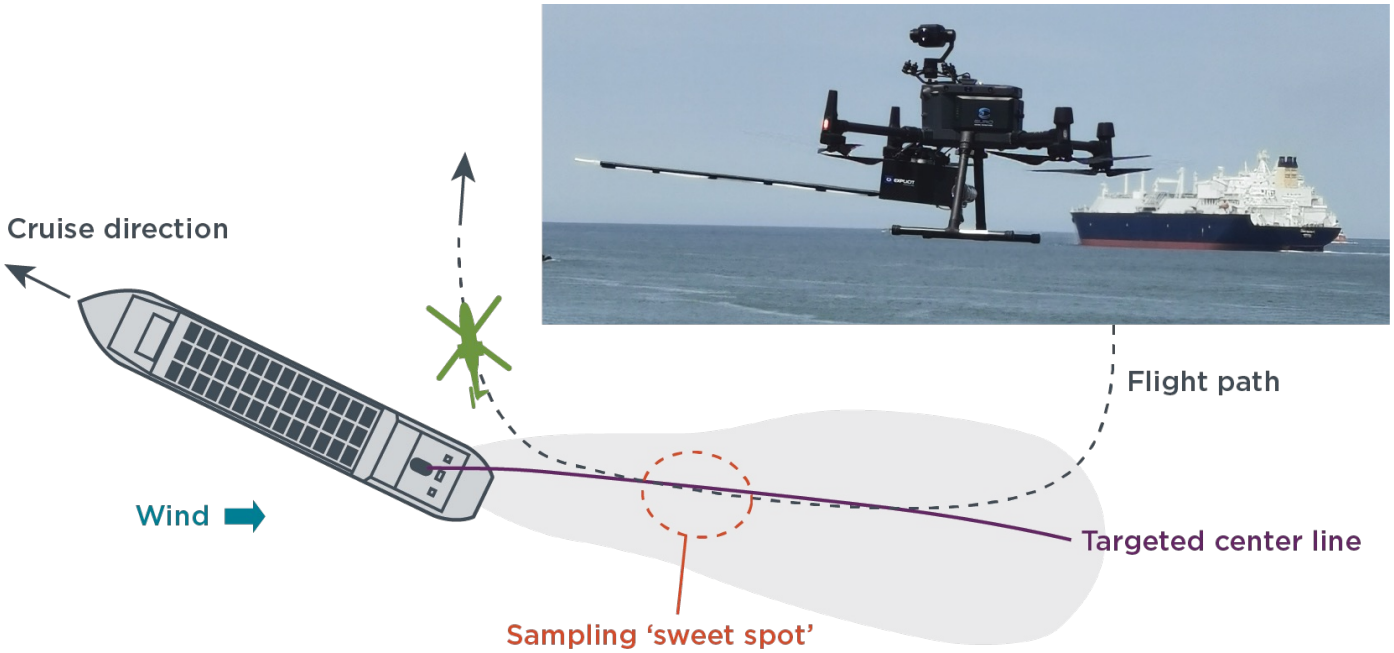
- Methane is a powerful greenhouse gas driving climate change.
- The use of methane (LNG) as a marine fuel is rapidly growing.
- Regulations on methane emissions from ships are coming.
- Real-world methane emissions from LNG-fueled ships are poorly understood.

icct
THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

Plume Campaign

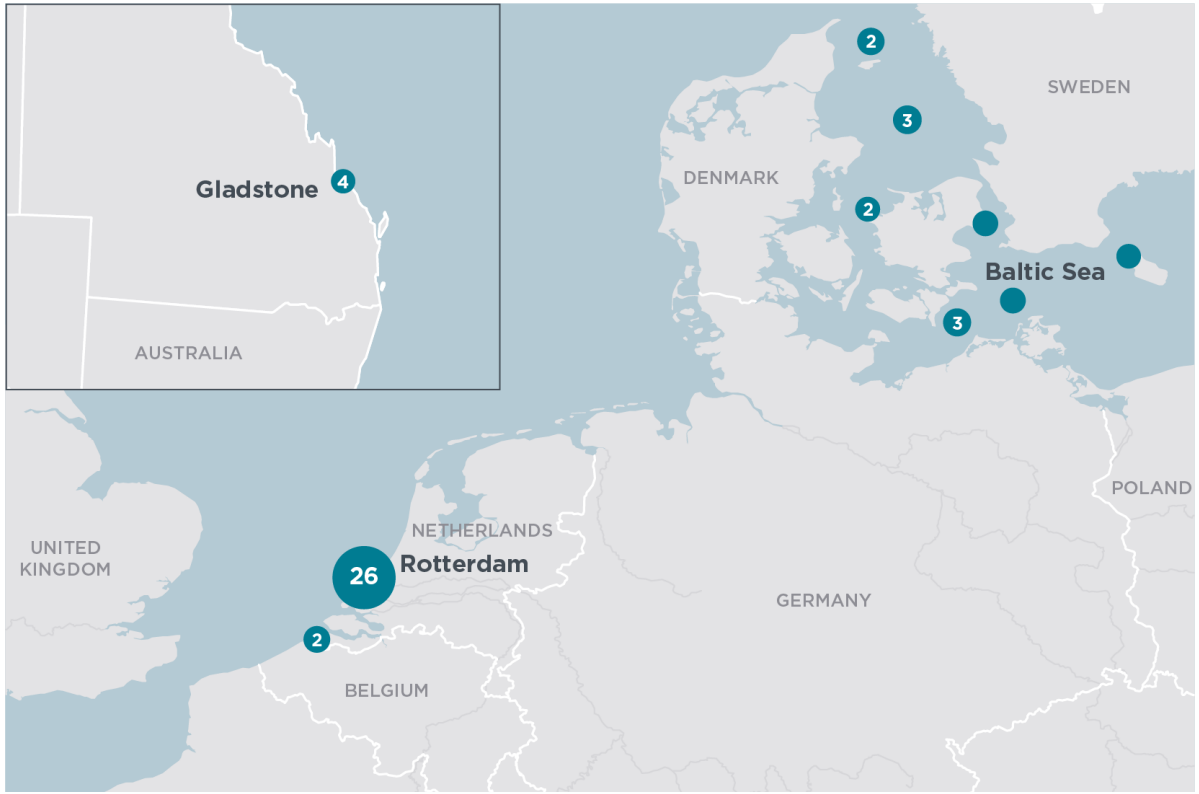
icct
THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

Sniffers were mounted to drones and helicopters



icct
THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

Measured 45 plumes from 34 ships in Europe and Australia



icct
THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

Four engine combinations

LBSI

- LBSI ME
- Diesel AE
- 2 ships
- 2 plumes

H2L4

- HPDF 2S ME
- LPDF 4S AE
- 2 ships
- 3 plumes

L2L4

- LPDF 2S ME
- LPDF 4S AE
- 12 ships
- 18 plumes

L4

- LPDF 4S ME & AE
- 18 ships
- 22 plumes

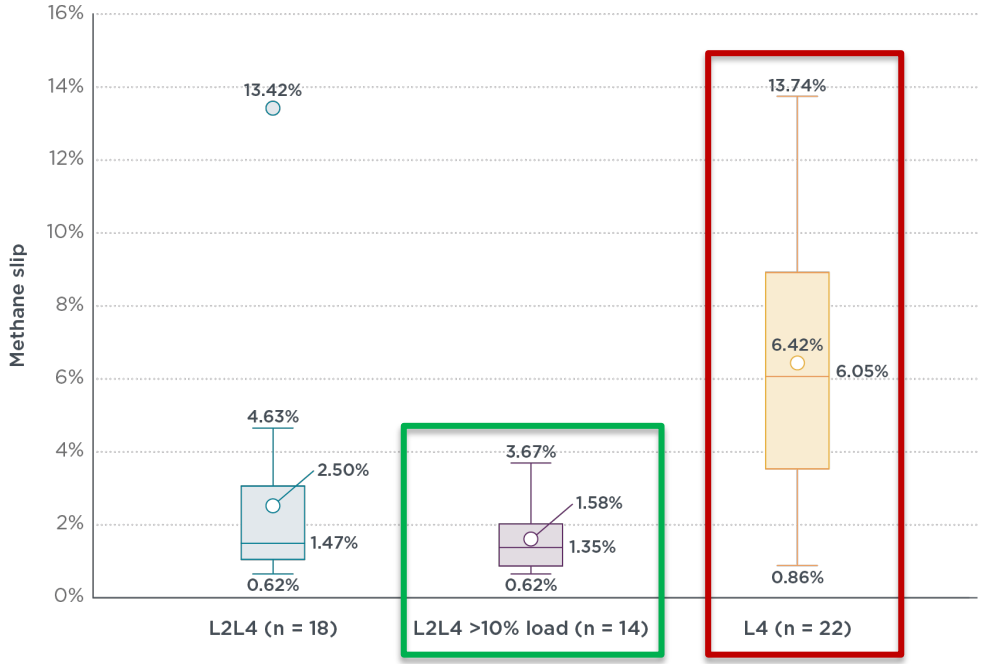
icct
THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

Main findings

L2L4 >10% main engine load emitted the lowest ship-level methane slip.

L4 emitted the highest methane slip.

LBSI & H2L4 require more data.



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 ES1. 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).

icct
THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

On-board campaign

icct
THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

Measured the Aurora Botnia ferry between Finland and Sweden

Built 2020;
in service 2021

4x 4.8 MW LPDF 4-stroke engines

2 MWh battery

icct
THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

Sensors measured exhaust in the stack

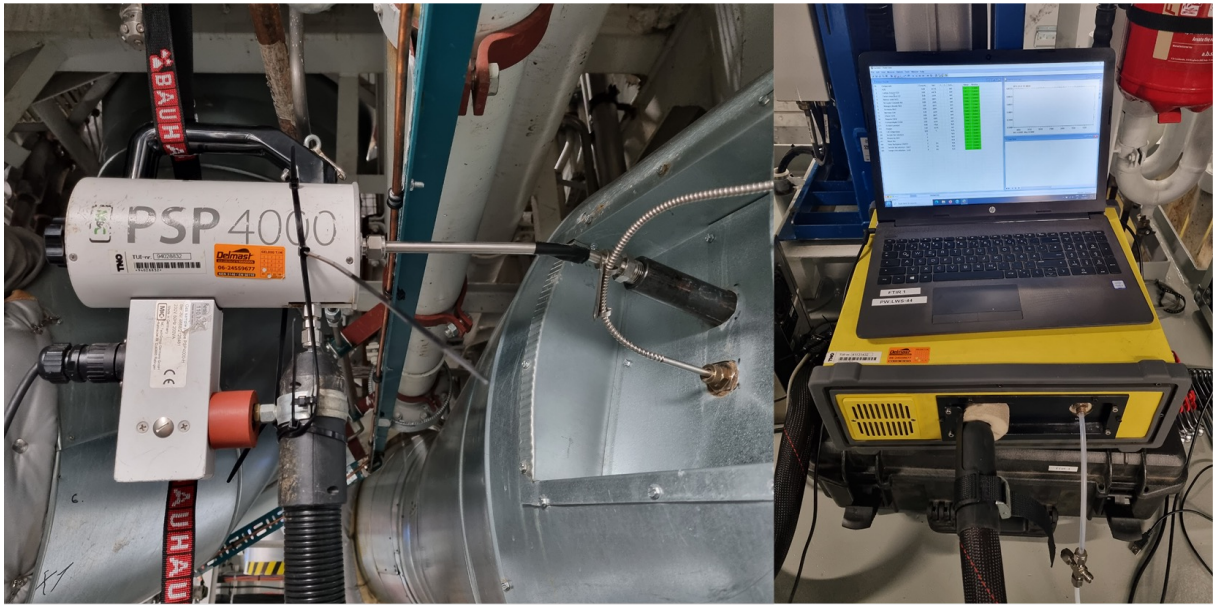


Figure 7. Left: heated probe sampling hot gas from the exhaust after the turbine of main engine 4. Right: the FTIR instrument used to measure the concentrations of CO_2, CH_4, and NO_X ($NO+NO_2$).

icct
THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

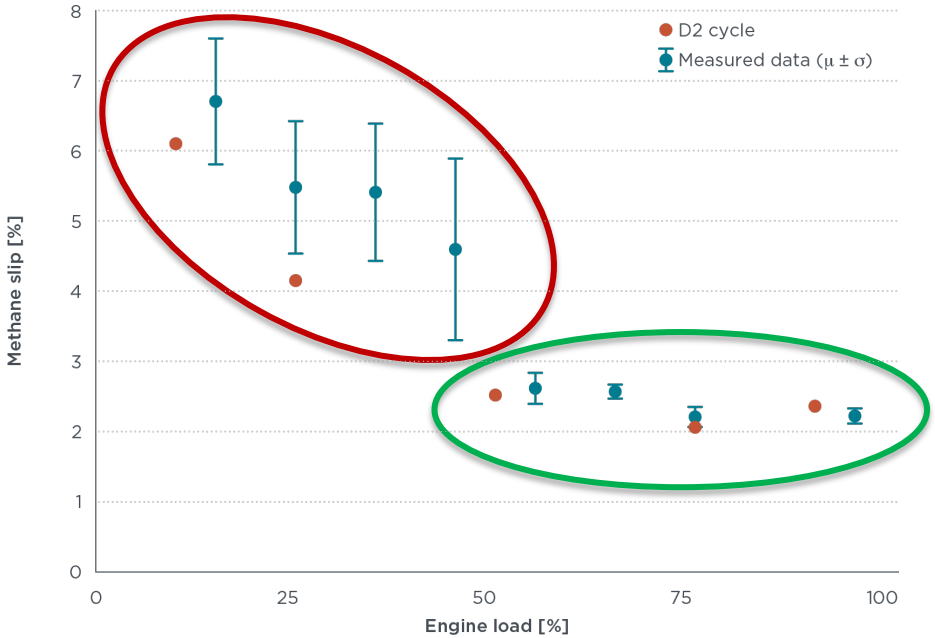
Main findings

Lowest methane slip was measured at ≥ 50% engine load (2-3%)

Higher, more variable methane slip was measured at <50% engine load (4-7%)

NO_x was 18 g/kWh near 10% load compared to 1.8 g/kWh near 75% load.

Simultaneous drone/stack measurements of CH_4-to-CO_2 ratio had a correlation (r) of > 0.95.



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.).

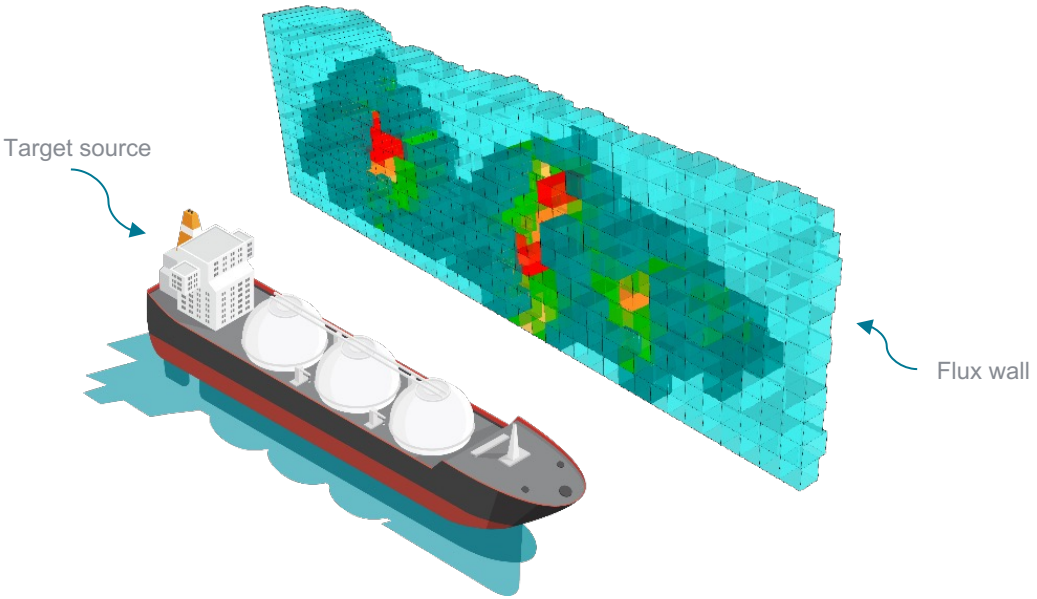
Figure ES2. Methane slip measured onboard a roll-on/roll-off passenger ferry with LPDF 4-stroke engines.

icct
THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

Fugitive campaign

icct
THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

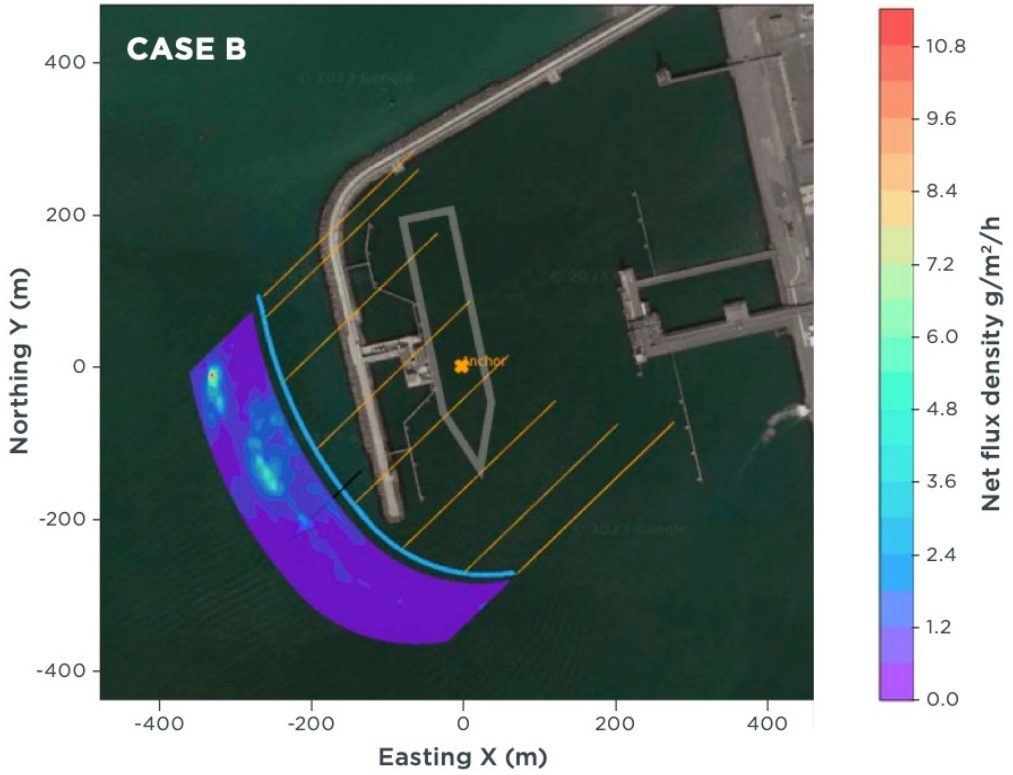
Drone-mounted sensors measured methane while LNG carriers were unloading LNG in Europe



icct
THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

Main findings

Unloading large LNG carriers can result in **fugitive methane emissions of 24–40 kg/h**, including **8 kg/h of methane slip** from their LPDF 4-stroke engines.



icct
THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

Policy Recommendations

EU and IMO policymakers should consider **increasing the default methane slip value for LPDF 4-stroke engines** from 3.1% (EU) or 3.5% (IMO) **to at least 6%.**

EU policymakers should consider requiring LNG-fueled ships **to plug into shore power** or otherwise eliminate their at-berth emissions.

EU policymakers should consider requiring **monitoring, reporting, and verification of methane emissions at LNG storage and refueling points**.

IMO policymakers should consider **adding a low-load test point to all engine emission certification test cycles.**

icct
THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

Questions?

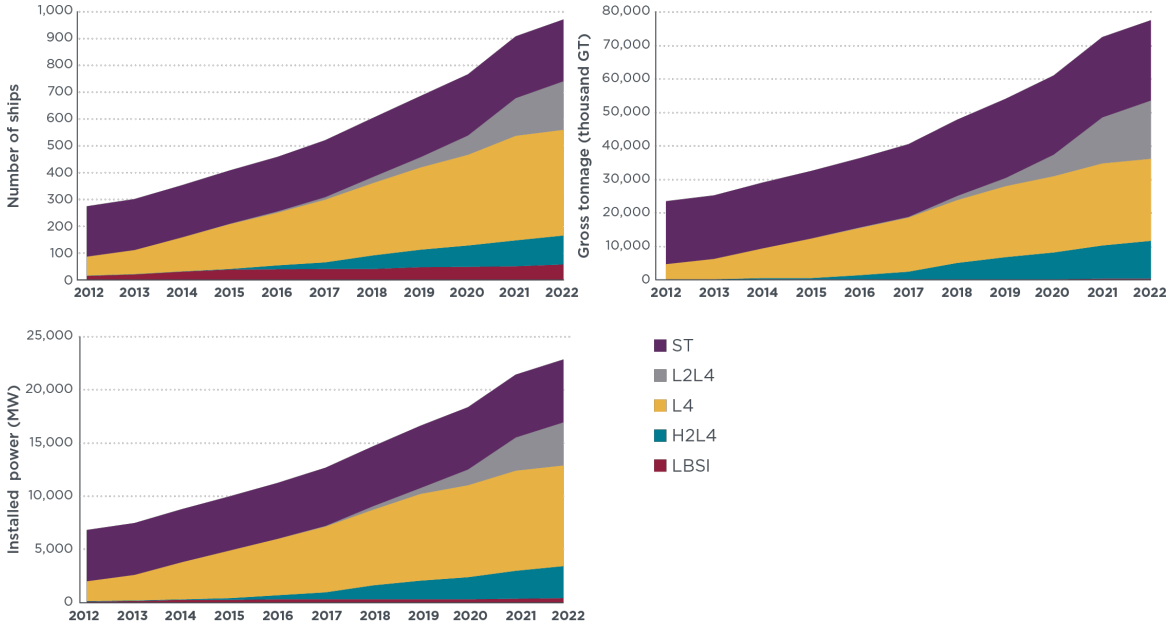
bryan.comer@theicct.org

icct

THE INTERNATIONAL COUNCIL
ON CLEAN TRANSPORTATION

Supplemental Slides

Trends in LNG-fueled fleet by engine types



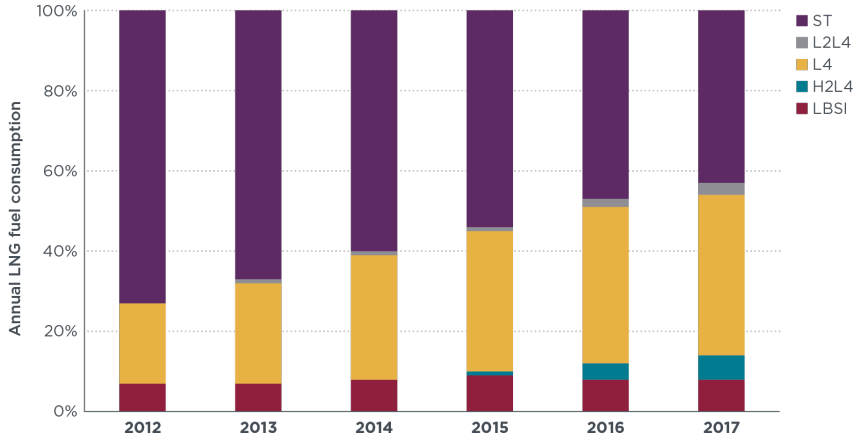
LBSI is lean-burn spark ignition; H2L4 is high-pressure, dual-fuel, 2-stroke (HPDF 2-stroke) main engines with low-pressure, dual-fuel, 4-stroke (LPDF 4-stroke) auxiliary engines; L4 is LPDF 4-stroke for all engines; L2L4 is low-pressure, dual-fuel 2-stroke (LPDF 2-stroke) main engines with LPDF 4-stroke auxiliary engines; ST is steam turbine.

Figure 1. LNG-fueled fleet by number of ships, gross tonnage, and installed engine power, by ship type, for 2012–2022. Source: IHS Markit data as of July 2023.

icct
THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

LNG consumption by engine type

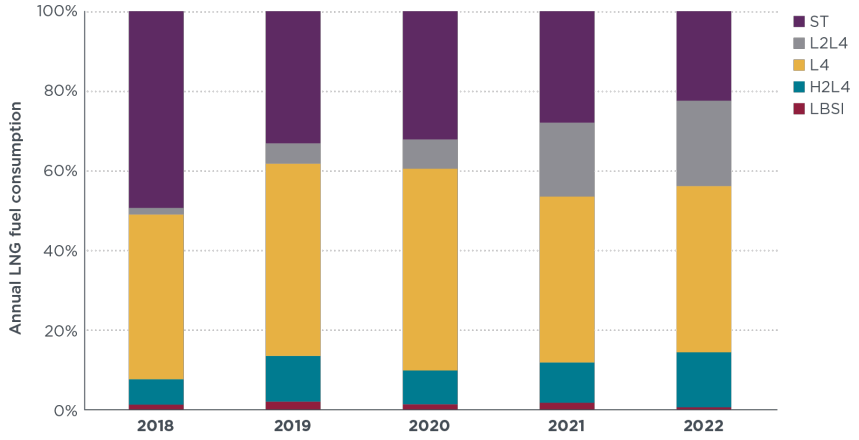
Global LNG fuel consumption 2012-2017



LBSI is lean-burn spark ignition; H2L4 is high-pressure, dual-fuel, 2-stroke (HPDF 2-stroke) main engines with low-pressure, dual-fuel, 4-stroke (LPDF 4-stroke) auxiliary engines; L4 is LPDF 4-stroke for all engines; L2L4 is low-pressure, dual-fuel 2-stroke (LPDF 2-stroke) main engines with LPDF 4-stroke auxiliary engines; ST is steam turbine.

Figure 2. Global LNG fuel consumption by main engine types, 2012–2017. Source: Faber et al. (2020).

EU MRV LNG fuel consumption 2018-2022

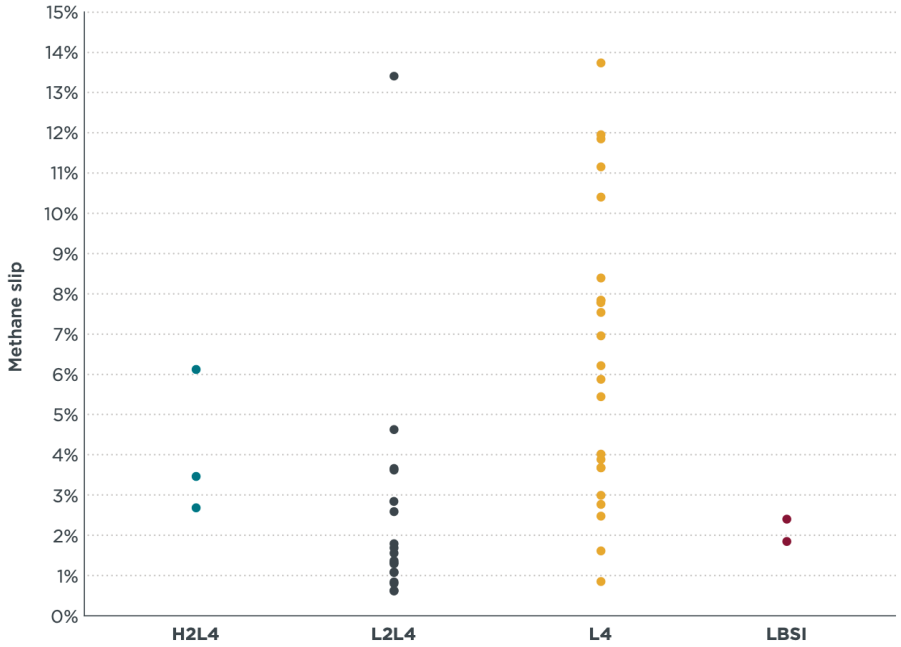


LBSI is lean-burn spark ignition; H2L4 is high-pressure, dual-fuel, 2-stroke (HPDF 2-stroke) main engines with low-pressure, dual-fuel, 4-stroke (LPDF 4-stroke) auxiliary engines; L4 is LPDF 4-stroke for all engines; L2L4 is low-pressure, dual-fuel 2-stroke (LPDF 2-stroke) main engines with LPDF 4-stroke auxiliary engines; ST is steam turbine.

Figure 3. Proportion of LNG fuel consumption by ships reporting to the EU Monitoring Reporting and Verification program, by engine type, 2018–2022. Source: Fuel consumption data from the EU Monitoring Reporting and Verification system paired with engine information from the ICCT's SAVE model (Olmer et al., 2017).

icct
THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

Ship-level methane slip measurements



Note: H2L4 are ships with HPDF 2-stroke main engines and LPDF 4-stroke auxiliary engines; LBSI ships are those with only LBSI LNG-fueled engines; L2L4 are ships with LPDF 2-stroke main engines and LPDF 4-stroke auxiliary engines; L4 are ships are those with only LPDF 4-stroke engines.

Figure 20. Ship-level methane slip from all engine sources measured.

icct
THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

icct
THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION