In-Use GHG Emission Logging for High-Fidelity Emission Inventory Calculation in LNG Marine Vessels

Jeremy Rochussen[1], Nicolas Jaeger[1], Patrick Kirchen[1]
Ahmed Khan[2], Harly Penner[2]

[1]Department of Mechanical Engineering
University of British Columbia

[2]Seaspan Ferries

jrochussen@mech.ubc.ca

GOAL

Minimize the environmental impact of practical energy conversion systems

Approach

Develop practical technologies

Generate actionable data

Train highly-qualified people

Applications

Internal Combustion Engines

Biofuels
Natural Gas
Hydrogen

Tools

In-cylinder Combustion diagnostics

Emissions sensor development

Numerical modeling

System optimization

Industry Collaboration

jrochussen@mech.ubc.ca

Our Lab Facilities

Optical diagnostics & combustion lab:

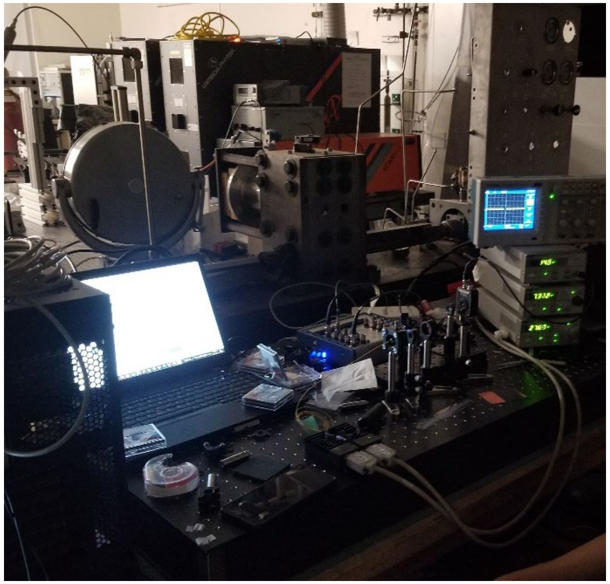
- In-house design-build-test of optical absorption and scattering sensors

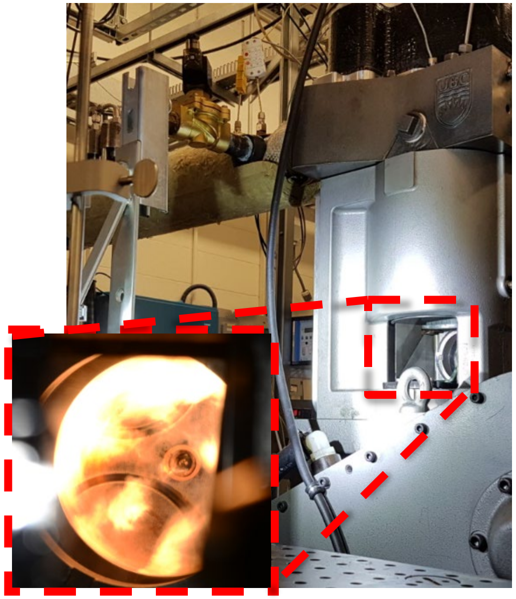
Heavy-Duty Test Engine:

- 14L NG direct-injection test-bed
- Emissions reduction and optimization

Optically-accessible heavy duty engine:

- 2L single cylinder with high-speed in-cylinder imaging
- Port or direction with NG/diesel/ bio-fuels/hydrogen





jrochussen@mech.ubc.ca

SEASPAN FERRIES & THE RELIANT

Vessel
5000 GT RO-RO Cargo Ferry
489’ length x 86’ beam
Capacity: 59 trailers

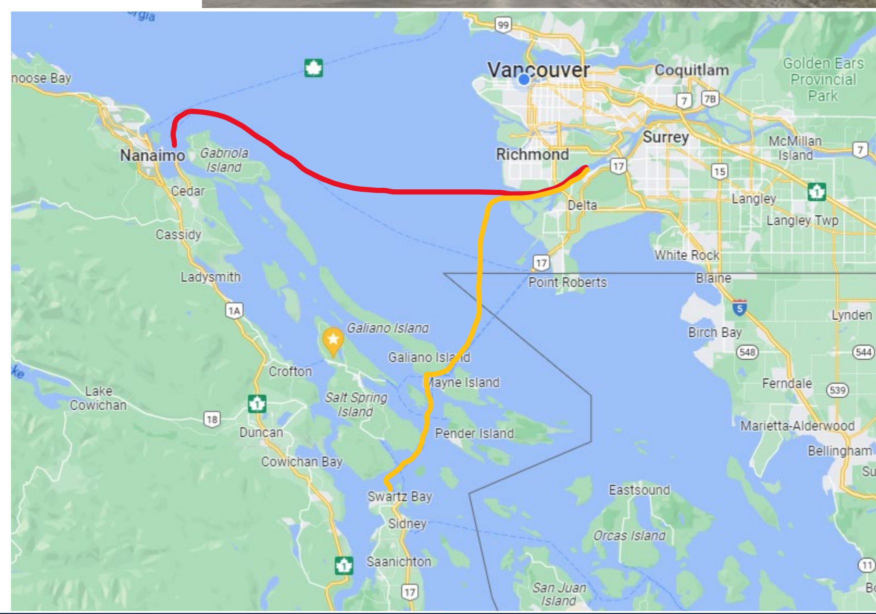
Propulsion Systems
2x Wärtsilä 9L34DF Engines
(2x4.3MW; 4-stroke; med. speed)
LNG and Diesel Fuel Systems
Battery Bank (468 kWh)
Tier II in diesel mode
Tier III in gas mode

Route(s) provide ~75% of the goods required by the industry and ~900k inhabitants of Vancouver Island

1. Delta (Mainland) → Nanaimo → Delta

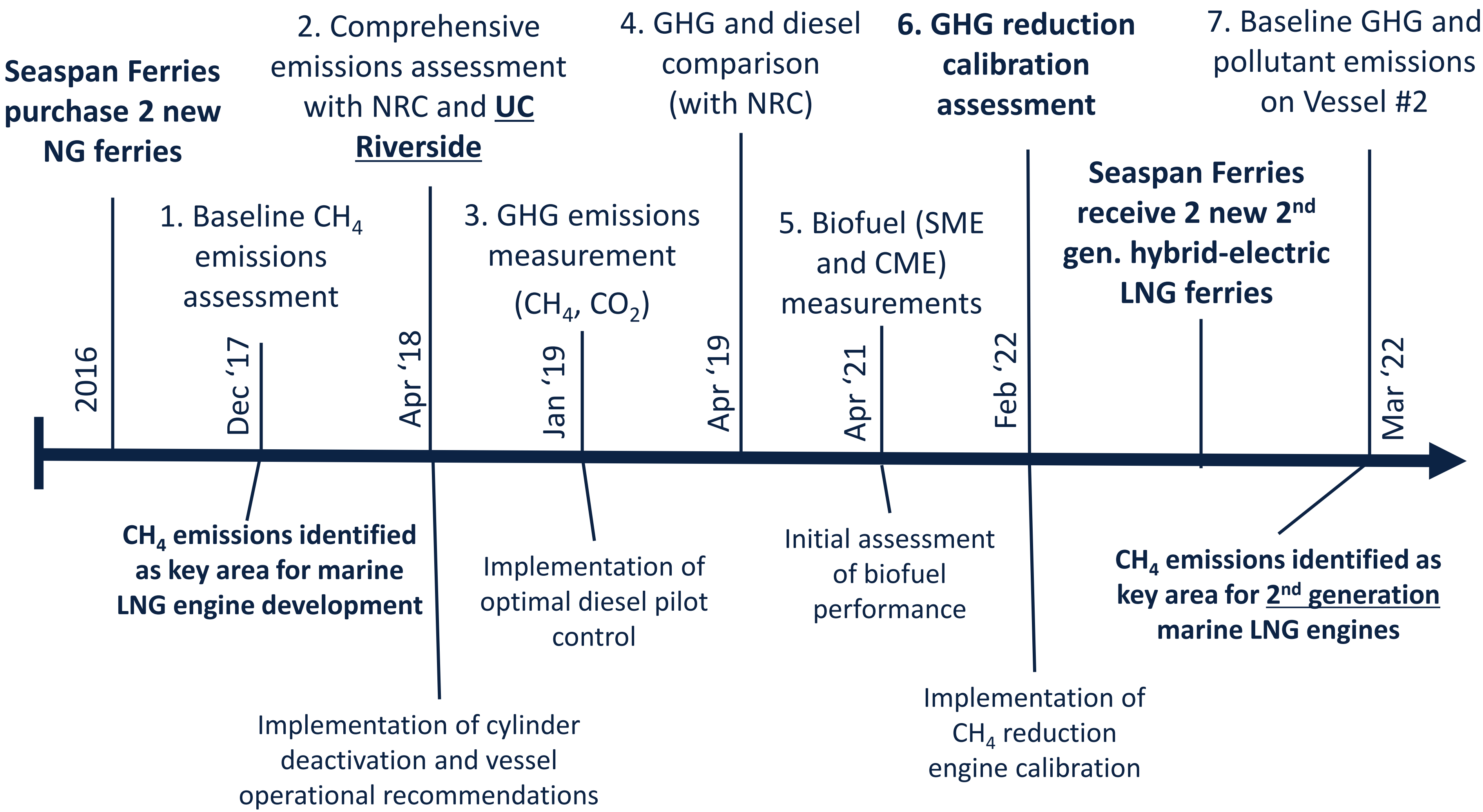
2. Delta → Swartz Bay (Victoria) → Delta

2 vessels per route perform 2 roundtrips per day



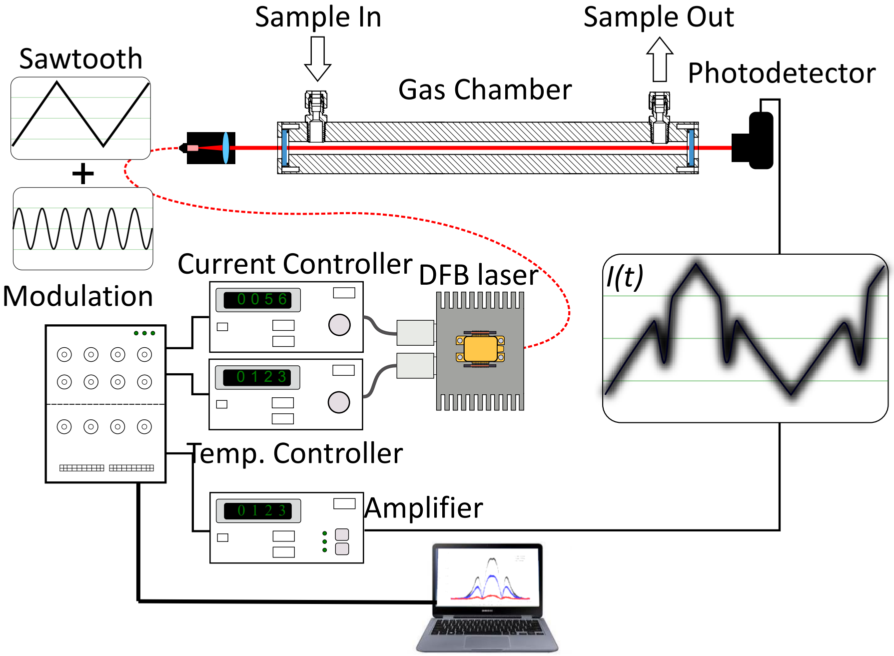
jrochussen@mech.ubc.ca

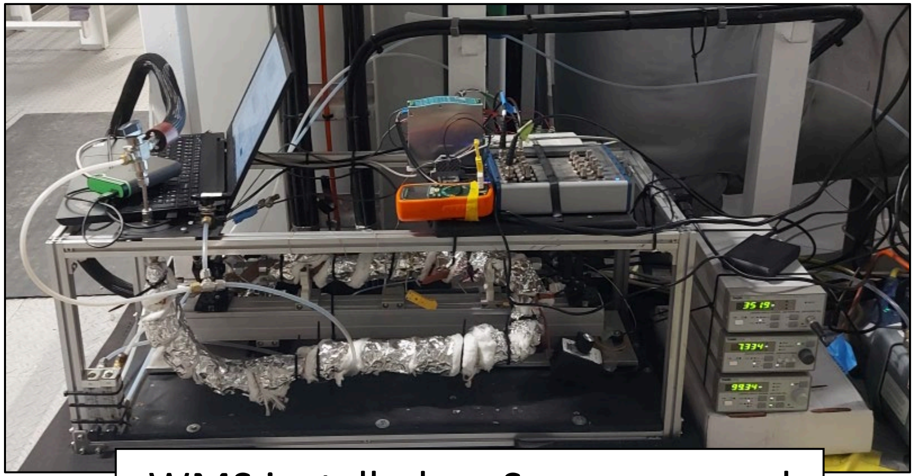
HISTORY OF SEASPAN AND UBC COLLABORATION



jrochussen@mech.ubc.ca

METHANE MEASUREMENT
UBC WAVELENGTH MODULATION SPECTROSCOPY (WMS)





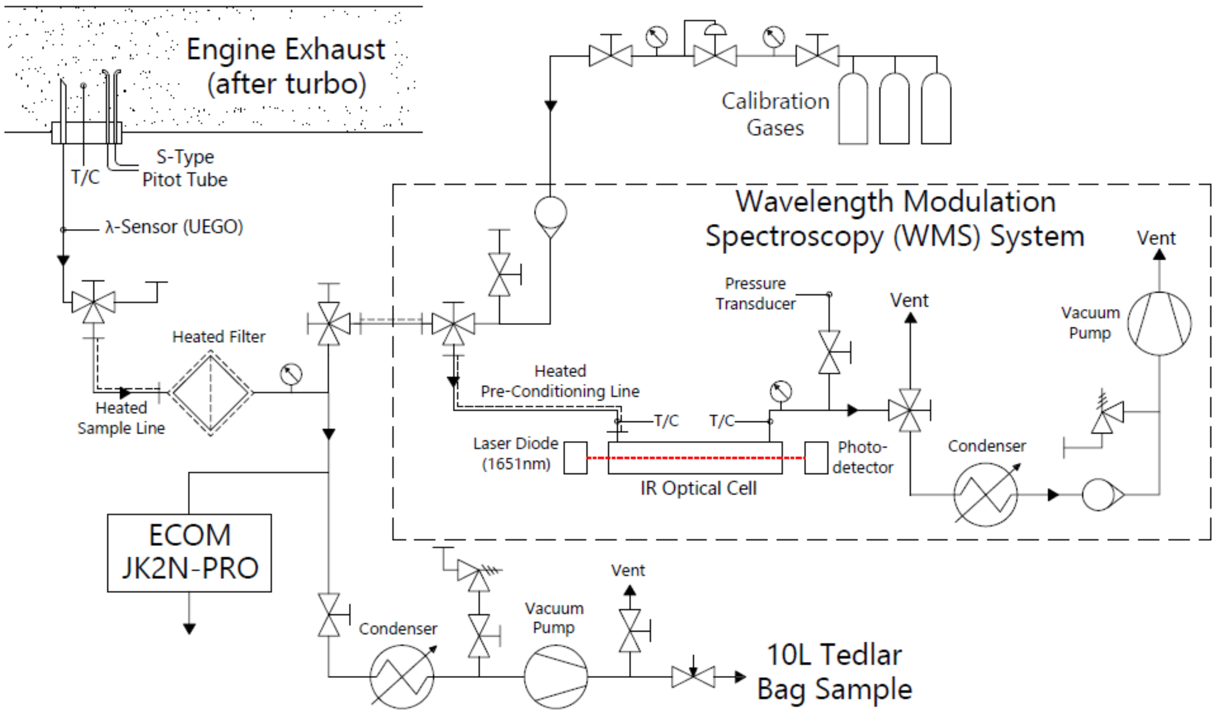
WMS installed on Seaspan vessel

- IR absorption technique at 1651 nm
- 10Hz laser scan + **<u>20kHz sinusoid modulation</u>** enables very high noise rejection through frequency domain analysis (unfiltered and wet exhaust measurements)
- WMS is low cost, robust, specific, and fast method for CH_4 measurement
- Validated against FTIR, FID, GC, MS with CH_4 standards *and* exhaust (~100ppm to >10,000ppm)

Sommer, et al. Environmental Science and Technology. 2019
Sommer, et al. CIMAC 2019
Cohen-Sacal, et al. SAE 2021
Jaeger, et al. CICS 2022
Jaeger, et al. under preparation

jrochussen@mech.ubc.ca

THE ON-BOARD EMISSION MEASUREMENT SYSTEM BEGAN TO GROW…



Pitot Tube: Exhaust flowrate

O2 + NOx: solid-state sensors

ECOM: Commercial instrument (O_2, CO_2, CO, ~~CH_4~~, NO_x)

WMS: Custom UBC instrument (CH_4)

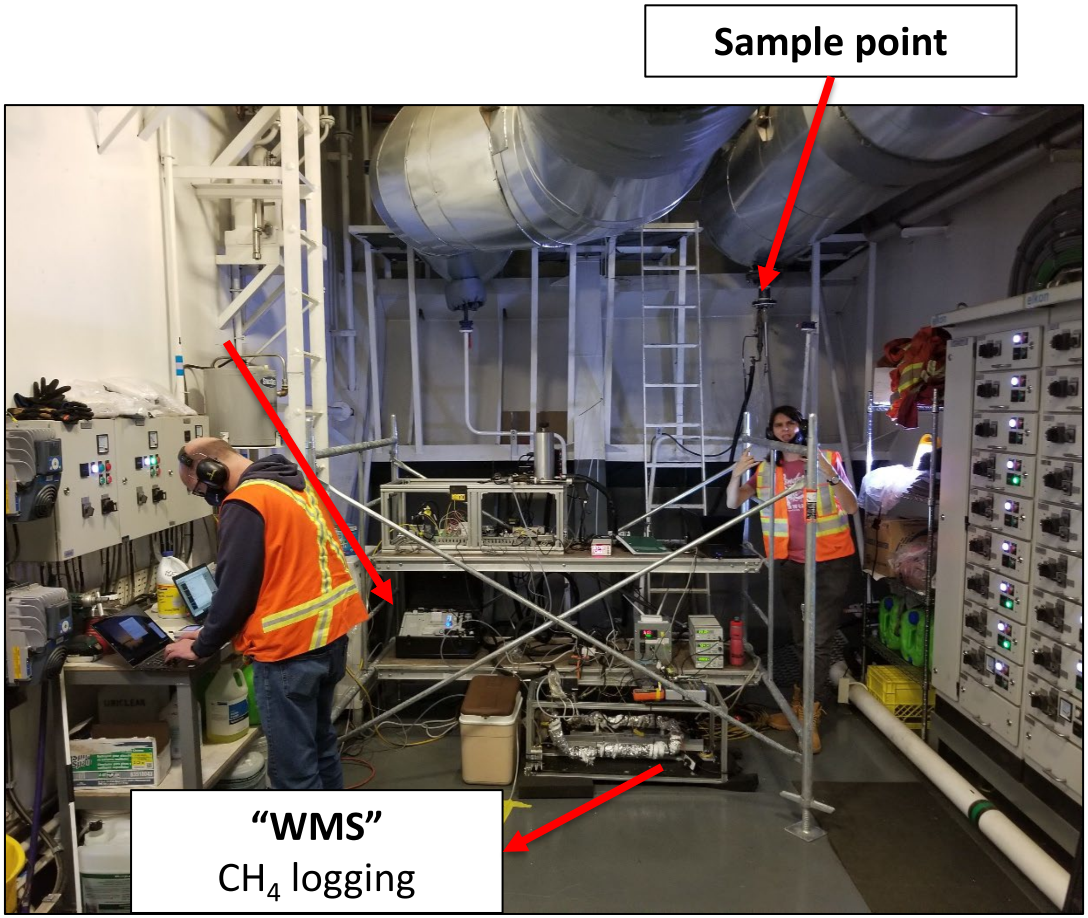
FTIR: Fourier Transform Infrared

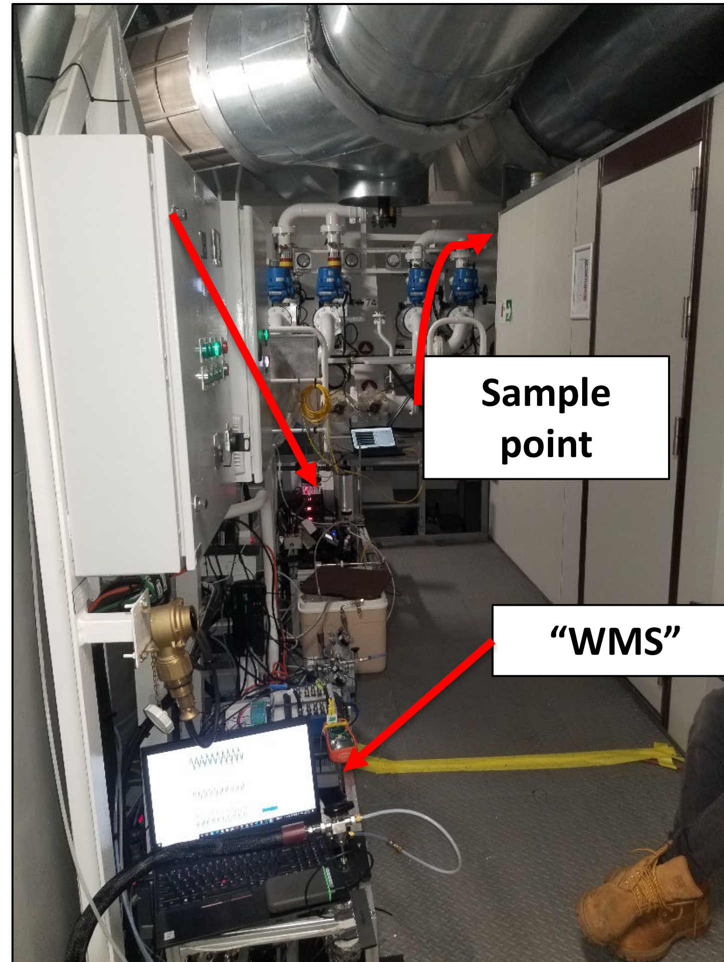
Bag Sample: 10L samples of exhaust gas to be analyzed at UBC (FTIR, gas chromatograph) for quality control and additional emissions species

Calibration gases: Multiple on-line calibrations of instruments per measurement day

jrochussen@mech.ubc.ca

ON-VESSEL EMISSION MEASUREMENT



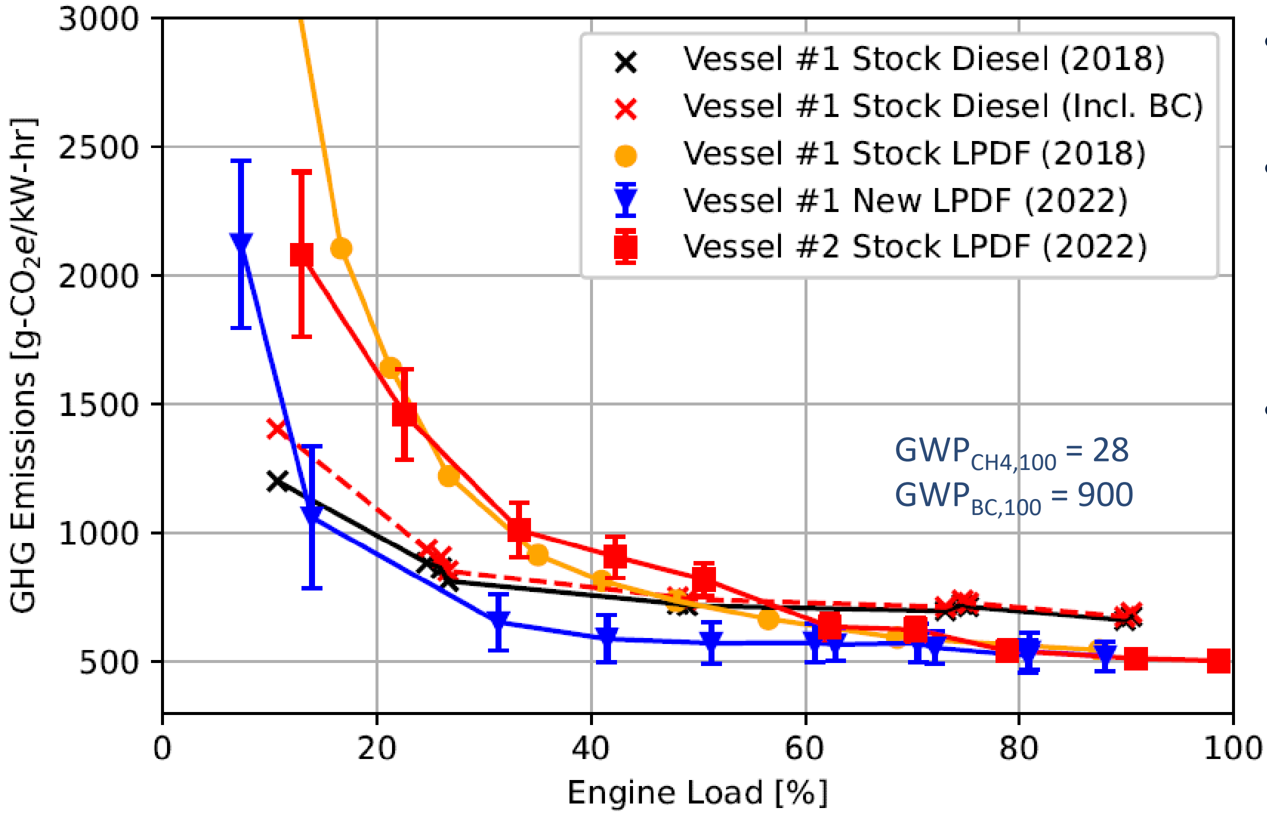


jrochussen@mech.ubc.ca

Collaboration Results: GHG Emissions Reduction

A 57% reduction in the total GHG emissions was obtained with no hardware modifications to the vessel (relative to the original LPDF engine)

- GHG reduction results from improved engine calibration and optimized vessel operations
- Equivalent to removing ~3000 cars (9.9kT CO_2e) from the road per year per vessel



- Methane slip significantly reduced at load < 75%
- The new engine calibration is now offered as standard equipment on all new engines
- Air quality benefits of switching from diesel to NG: full load NOx and PM are reduced by 92% and 96%, respectively

Sommer, et al. Environmental Science and Technology. 2019
Sommer, et al. CIMAC 2019
Rochussen, et al. Submitted to Fuel
Peng, et al. Environmental Pollution. 2018

jrochussen@mech.ubc.ca

Keys to The Emission Reduction Achievement

1. A 'pro-activist' approach:
    - Seaspan and UBC worked with the engine manufacturer to iteratively improve NG engine technology with supporting in-use emissions measurements
2. On-board emissions logging measurements during commercial sailings:
    - Approximately 50% of the achieved emissions reduction resulted from understanding and then improving the vessel operating strategies
    - Current marine emissions legislation and emission inventories do not represent the actual usage of marine propulsion systems

Marine emission factors are typically represented as a single value (e.g. g-CO_2e/kW-hr) using very simple legislated duty cycles + steady-state engine test-stand measurements

What are the consequences for legislation and fleet operators due to systematic errors in GHG emission inventories evaluated using coarse measurement methods?

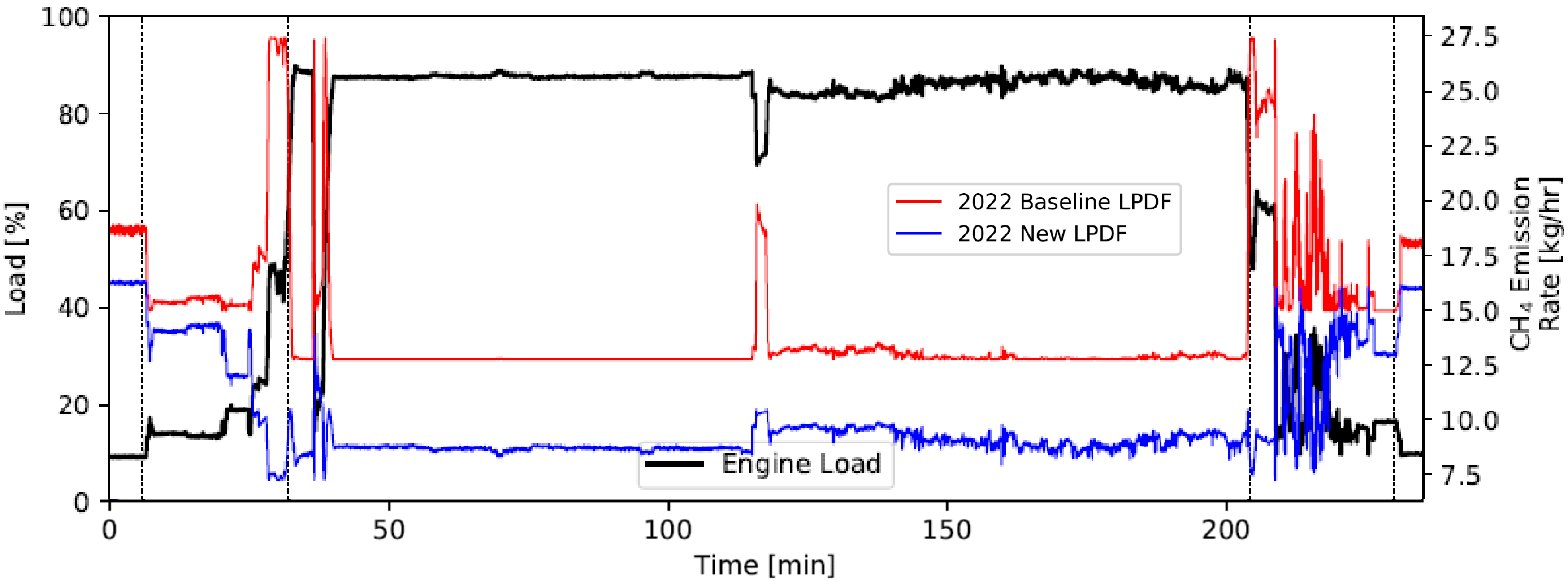
jrochussen@mech.ubc.ca

LEGISLATED DUTY-CYCLE DOES VS. ACTUAL DUTY-CYCLE

- For this class of engine (constant speed main propulsion), the Marpol 'E2' test cycle is used to calculate emission factors (NOx technical code):

Engine Load	25%	50%	75%	100%
Weighting	0.15	0.15	0.5	0.2

Actual (measured) duty-cycle:



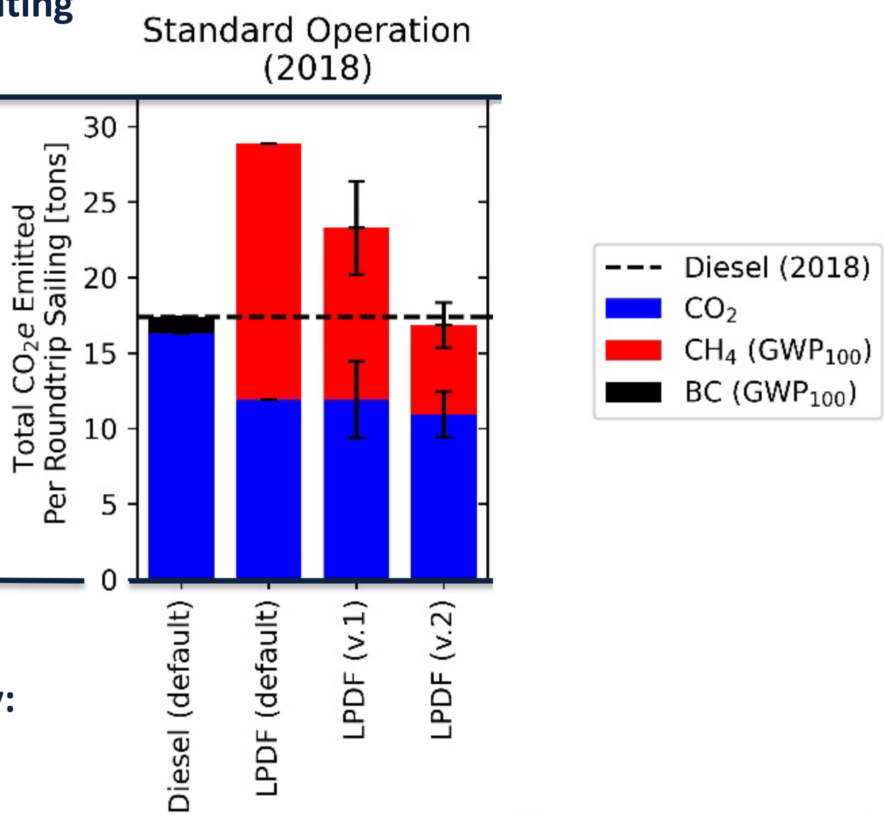
Rochussen, et al. Submitted to Fuel

OSAR 2023
jrochussen@mech.ubc.ca

COMBINING VESSEL OPERATING STRATEGIES & BEST ENGINE TECHNOLOGY (SEASPAN RELIANT)

Vessel Operating Strategy:

Tank to Wake



Engine Technology:

How an LNG-powered vessel is operated is as important to emissions as the engine technology that is installed

$GWP_{CH4,100} = 28$
$GWP_{BC,100} = 900$

Rochussen, et al. Submitted to Fuel

OSAR 2023
jrochussen@mech.ubc.ca

IMPACT OF DUTY-CYCLE ON GHG EMISSION FACTOR CALCULATIONS

Vessel	Fueling mode (software version)	Cycle-weighted Emission Factors [g-CO_2e/kW-hr] (% difference relative to certification cycle)		
		Certification (IMO E2)	**Actual** (2018 standard operation)	**Actual** (2022 optimized operation)
#1	Diesel (default)	639		
#1	LPDF (default)	708		
#1	LPDF (v.1)	675		
#1	LPDF (v.2)	568		
#2	LPDF (default)	713		

Note: Maximum GHG benefit for switching from diesel to LNG is approx. -25% CO_2e

Without considering vessel usage, a generalized emission factor can not be relied upon for decision making.

- Critical for LPDF LNG engines with a high sensitivity of emissions to engine load

Rochussen, et al. Submitted to Fuel

jrochussen@mech.ubc.ca

Opportunity for Further Improvement to Emission Factor Calculations

Data collection and emission factor calculation methods:

1) Legislated duty cycles + steady-state engine test-stand measurements

2) Actual duty cycles + steady-state in-use emissions measurements

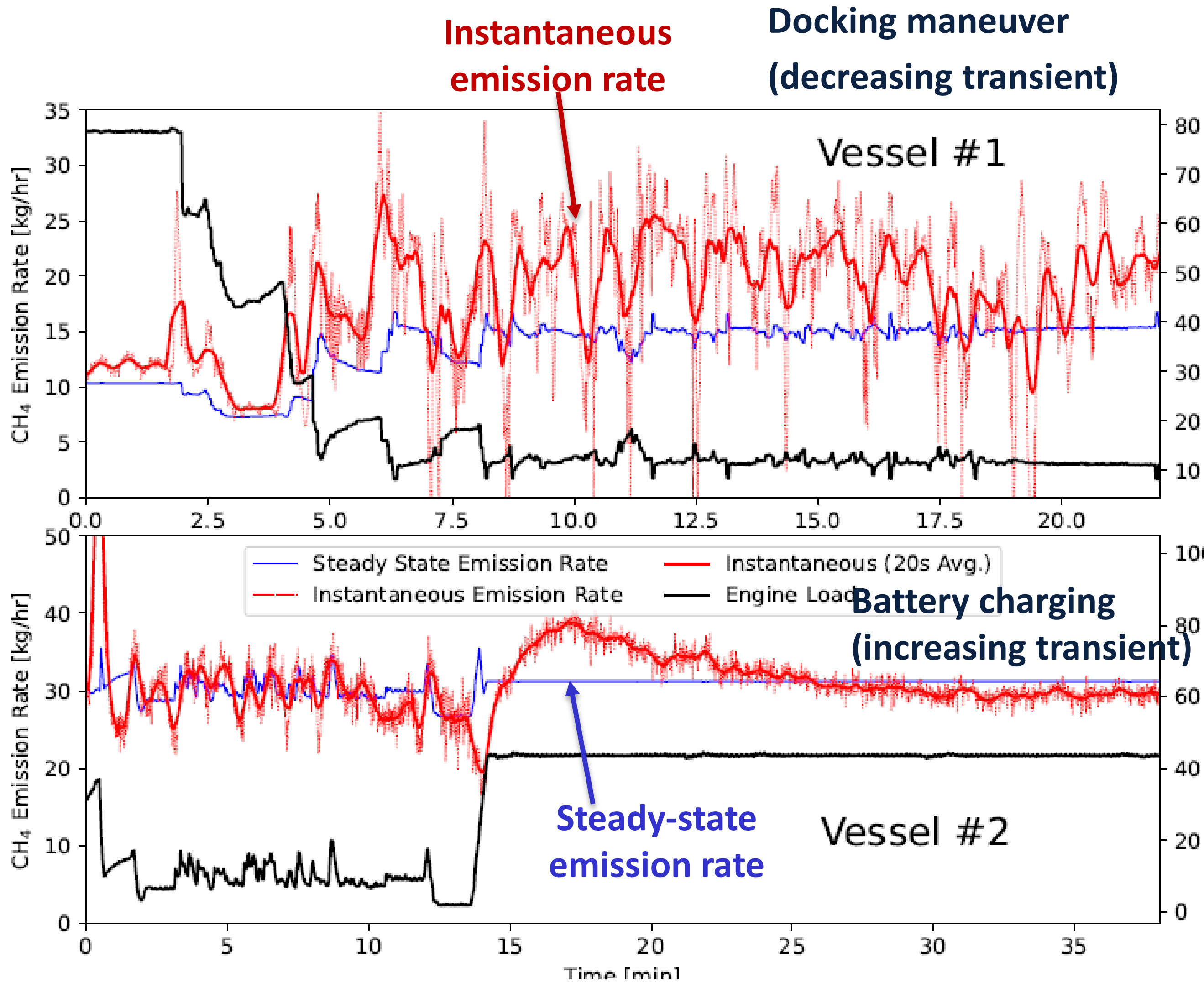
3) Integration of instantaneous in-use emissions measurements

Increasing fidelity of calculated emission factor to environmental impact of vessel

jrochussen@mech.ubc.ca

Instantaneous Vs. Steady-State Emission Factors

- Accounting for increased CH_4 emission rates during docking resulted in an 11% increase in recorded CO_2e emissions
- Outlook: Development of a larger dataset of measured sailing activities is needed



Rochussen, et al. Submitted to Fuel

OSAR 2023
jrochussen@mech.ubc.ca

CONCLUSIONS

1. There is significant low-hanging fruit for decarbonization in coastal marine applications

2. For dual-fuel LNG vessels, the operating strategies are as important as installed technology for real-world emissions reduction

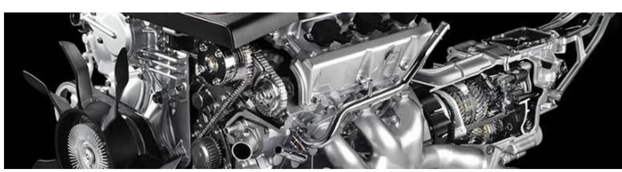
3. Current marine emission inventories are not reliable data for fleet operators or policy makers

4. Improving these marine emission inventories requires larger datasets of emissions logging measurements enabled by robust, low-maintenance on-board systems

jrochussen@mech.ubc.ca

THANK YOU TO OUR SPONSORS & PARTNERS

- seaspan
- NSERC CRSNG
- FORTIS BC™ Energy at work
- Solaris Management Consultants
- CERC Clean Energy Research Centre
- NRC·CNRC
- UC Riverside
- WÄRTSILÄ
- CMC Microsystems



NSERC CREATE Program:

Clean Combustion Engines

jrochussen@mech.ubc.ca