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Re: Comments on the Environmental Assessment Certificate for Tilbury LNG Marine Jetty Project.

Thank you for the opportunity to comment on the Tilbury Marine Jetty project EA. In the face of the climate emergency here in British Columbia and globally, and the shipping industry's emissions being mainly determined by propulsion and fuel choice, we will focus our comments on Liquefied natural gas (LNG) as a marine shipping fuel in vessel combustion engines and its related climate impacts.

90% of goods are transported globally by ship. Vessels are a key enabler of global trade, community re-supply, and economic activity. Shipping accounts for nearly 3%[1] of global greenhouse gas (GHG) emissions, similar to Germany, the world's sixth largest emitter. If left unchecked and unconstrained, this could grow to 17% by 2050[2]. Many development projects, like the Tilbury Phase 2 LNG Expansion, will rely on LNG tankers, fueled by LNG marine fuel, to transport LNG to markets around the world. Understanding the climate impact of these vessels and the implications of the proposed Tilbury Marine Jetty development is a key component of determining regulatory decisions on expanding LNG production in BC.

[1] https://www.imo.org/en/OurWork/Environment/Pages/GHG-Emissions.aspx
[2] https://www.transportenvironment.org/discover/shipping-emissions-17-global-co2-making-it-elephant-climate-negotiations-room/

We have found that the Tilbury Marine Jetty project EA is lacking in robust analysis with respect to the impact of the use of LNG as a Marine Fuel. Our comments are submitted to provide further research and analysis on this topic. In our submission we will clearly demonstrate that LNG should not and does not have a future in any decarbonization pathway for the shipping sector, and shouldn't be ramped up to enable the Tilbury Phase 2 expansion.

Among many social, health, and environmental risks and impacts of LNG production and use, methane escapes during the production, storage, transmission, distribution, and burning, **including unburned methane escaping from marine engines** (i.e., methane slip). Methane is a potent GHG, and even small amounts of leakage can have damaging atmospheric impacts. Using LNG as a marine shipping fuel jeopardizes Canada's ability to meet 1.5 degree aligned GHG emissions reductions and risks stranding LNG infrastructure and vessel assets. It is also contrary to the Global Methane Pledge that Canada has signed on to after COP26, which aims to cut methane emissions by 30% between 2020 and 2030 and to Canada's national target of reducing oil and gas methane emissions by 75% relative to 2012 levels by 2030[3]. Furthermore, methane emissions are associated with over 200,000 premature deaths, more than 20 million tons of crop losses annually by 2030, and increased respiratory emergency room visits[4]. LNG use in the shipping sector hurts people, nature, and the climate, further exacerbating the biodiversity, health, and climate crisis.

For these reasons, expanded upon in detail below, we urge the proponent to withdraw their LNG marine jetty proposal and begin the process of focusing investments on energy systems which contribute to a 1.5 degree Paris aligned pathway not only for shipping but for the BC and Canadian economies.

Our comments in this submission will:

1. Detail key research, sources, and their findings regarding the global warming acceleration impacts of LNG in marine vessels;
2. Emphasize the need for governments and project proponents to 1) include a Global Warming Potential (GWP) of 20 years for any climate impact analysis, 2) include full life cycle emissions analysis form well to wake, and use globally accepted emission factors when considering the safety and climate alignment of of LNG as marine fuel and thus any new LNG infrastructure build out; and
3. Demonstrate the high risk that LNG infrastructure and vessels will rapidly become stranded assets in a Paris- aligned 1.5- degree economy;

Key Research Summary and Findings

[3]https://www.canada.ca/en/environment-climate-change/services/canadian-environmental-protection-act-registry/consultation-reducing-methane-emissions-oil-gas-sector.html
[4]https://www.canada.ca/en/environment-climate-change/news/2021/10/canada-confirms-its-support-for-the-global-methane-pledge-and-announces-ambitious-domestic-actions-to-slash-methane-emissions.html

- **University of Maritime Advisory Services at the University College London**: *LNG as Marine Fuel in the EU*
    - One of the aims of the study is to ascertain the cost/benefit of investing in LNG bunkering infrastructure from a GHG abatement perspective (invested $/tonne CO2 abated).
    - **The study found that there is no significant CO2eq. reduction achieved through the use of LNG as marine fuel** relative to the reduction required to achieve the IMO's 2050 objectives.
    - Reaching Paris temperature goals is only possible with a switch to increased use of non-fossil fuel sources (non-fossil hydrogen, ammonia, battery electrification) from 2030 and with rapid growth thereafter.
    - There is a very uncertain future demand for LNG as a marine fuel over the next 10 years. On the one hand, it is an option for complying with the 2020 sulphur cap, but as it cannot enable the GHG reductions that have been committed to in the IMO's initial strategy for GHG reduction and the Paris temperature goals more generally, it is clear its role can only be transient and not transitional.
    - There is no development of a significant market for LNG as a marine fuel in scenarios modelled, as these new fuel sources require significant demand growth from 2030 at the latest to meet the GHG reduction objectives.

- **International Council on Clean Transportation (ICCT)**: *The Climate Implications of Using LNG as a Marine Fuel*
    - This study compares the life-cycle GHG emissions from LNG, including upstream emissions from leakage during extraction, processing, and transport and downstream emissions from combustion and unburned methane (aka "methane slip"), to those of traditional marine fuels: heavy fuel oil, very low sulfur fuel oil, and marine gas oil (MGO).
    - LNG is mostly methane, a potent GHG that traps more than 80 times more heat in the atmosphere than the same amount of CO_2 over 20 years.
    - There is no climate benefit from using LNG, regardless of the engine technology, when evaluating its use over a 20-year time frame.
    - The most popular LNG marine engine—low-pressure dual fuel (LPDF), medium-speed, four-stroke—is also the leakiest. Using LNG, this technology emitted **70% to 82% more life-cycle GHGs than MGO**.
    - Continued investment in LNG infrastructure on ships and onshore risks making it harder to transition to zero-emission vessels in the future. Investments should instead be focused on technologies that reduce total life-cycle GHG emissions, including energy-saving technologies, wind-assisted propulsion, zero-emission fuels, batteries, and fuel cells.

- **The World Bank**: *The Role of LNG in the Transition Towards Low and Zero Carbon Shipping*
    - Questions this report attempts to answer: What would the role of liquefied natural gas (LNG) as a bunker fuel in the years 2020–2050 look like? Offering significant

air quality benefits, could LNG also contribute to the targets set by Initial IMO GHG Strategy and the sector's transition toward low- and zero-carbon shipping?
    - The conclusions of this report have been developed through a logic that starts with the Paris Agreement's temperature goals, considers shipping's GHG emissions trajectory and the associated fuel mix that would be required to meet those goals, and assumes that appropriate policy would be introduced to achieve those outcomes. The Initial IMO GHG Strategy is consistent with this logic. Within this context, **there is consensus across the literature and industry that LNG cannot form a large proportion of the bunker fuel mix in 2050 due to its carbon intensity**.

- **International Energy Agency**'s Net Zero by 2050 report:
    - A key finding of the landmark report is that no new gas projects can be started if the world is to align with limiting warming to 1.5 degrees.
    - 'Building on the IEA's unrivaled energy modeling tools and expertise, the Roadmap sets out more than 400 milestones to guide the global journey to net zero by 2050. These include, from today, **no investment in new fossil fuel supply projects**, and no further final investment decisions for new unabated coal plants. By 2035, there are no sales of new internal combustion engine passenger cars, and by 2040, the global electricity sector has already reached net-zero emissions.'

Global Warming Potential (GWP) 20 and GWP 100 - Emphasizing <u>near term</u> analysis and action

In a recent submission (attached) on life cycle climate impacts of marine fuels to the International Maritime Organization (IMO), the Inuit Circumpolar Council, Solomon Islands, and Pacific Environment summarized ICCT's research which demonstrates the significant difference when calculating marine fuel climate impacts on a 20 year vs. a 100-year basis. In Figure 1 of that submission, well-to-wake (WtW) climate pollution can more than double for LNG engines that have high methane slip (left panel) when calculating carbon dioxide equivalent emissions using GWP20 (CO2e20) compared with CO2e100.

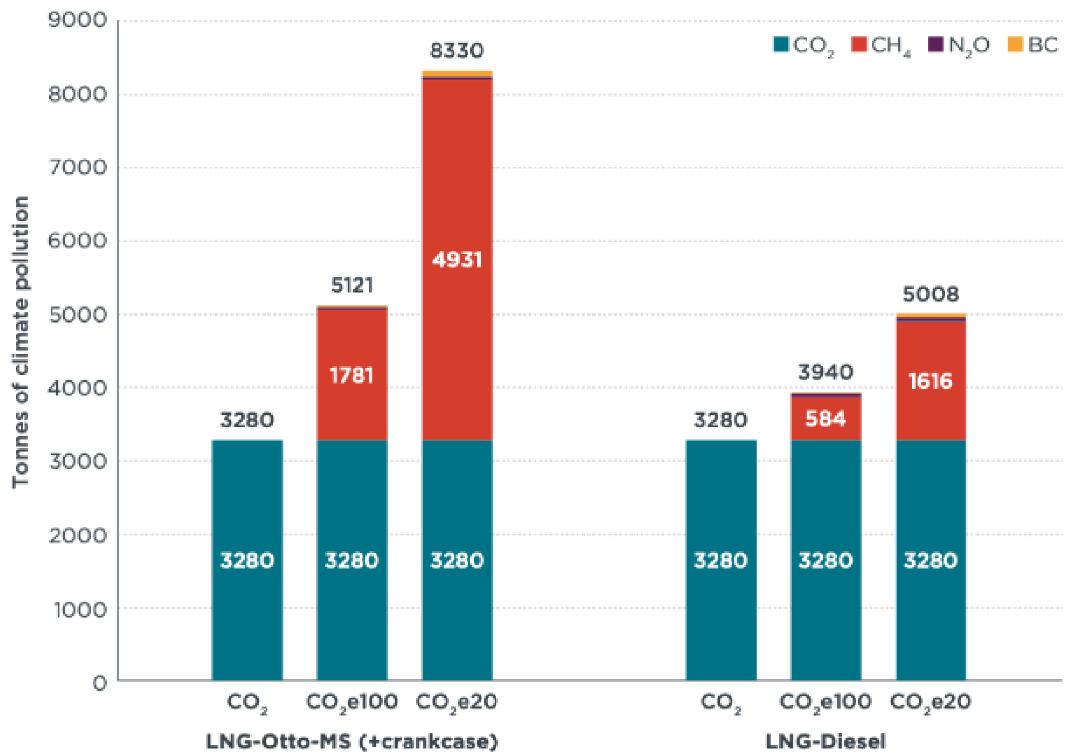

Figure 1. WtW emissions of consuming 1,000 tonnes of LNG in two engines. Source: ICCT

By excluding GWP20 from the Marine Jetty EA, the proponent is misleading the public and regulators on the true and more accurate climate impacts of LNG as a marine fuel. Near-term climate analysis and solutions are urgently needed to address the climate crisis and to align with 1.5-degree decarbonization pathways. Indeed, the IPCC's Sixth Assessment Working Group III report, entitled *Climate Change 2022: Mitigation of Climate Change*, estimates that methane emissions need to be cut by one-third from 2019 levels by 2030 to limit temperature rise to 1.5°C.

The IPCC's Working Group II report entitled *Climate Change 2022: Impacts, Adaptation and Vulnerability,* as summarized in a submission by WWF, Pacific Environment, and the Clean Shipping Coalition to the IMO's Marine Environment Protection Committee (attached), highlights the key need for dramatic action in the near term from 2021 to 2040. The introduction of that report sustains the message outlined in the first IPCC working group report. "Global warming, reaching 1.5°C in the near-term, would cause unavoidable increases in multiple climate hazards and present multiple risks to ecosystems and humans (very high confidence). The level of risk will depend on concurrent near-term trends in vulnerability, exposure, level of socioeconomic development, and adaptation (high confidence). **Near-term** actions that limit global warming to close to 1.5°C would substantially reduce projected losses and damages related to climate change in human systems and ecosystems, compared to higher warming levels, but cannot eliminate them all (very high confidence)".

Importance of Well to Wake (WtW) Life Cycle Analysis and Credible LNG Marine Fuel Climate Emission Factors

To make climate-informed decisions of any future marine fuel and thus any corresponding infrastructure build out, a full accounting of well-to-wake (WtW) emissions needs to be considered for all aspects of the proposed Jetty, including LNG as a marine fuel. However, the EAO appears to have only considered tank-to-wake (TtW) emissions and, moreover, the EAO has derived emission factors that are favorable to LNG without being transparent about how they arrived at these numbers.

In footnote 41 on page 101 of the EA, the EAO explains that the emission factors they derived were based on Pavlenko, et al. (2020), which is a study conducted by the ICCT. The EAO explains that they developed emission factors for three engines, which presumably are the same as the three analyzed by the ICCT, which are a range of high-, medium-, and low-methane slip marine engines, although they do not say.

As shown in the table below, The EAO's draft assessment report seems to focus only on TtW emissions; even then, they are lower than the Pavlenko et al. ICCT study that they are referencing. For example, focusing just on TtW emissions (combustion plus methane slip, but not upstream emissions), the ICCT emissions range from 403–987 gCO_2e/kWh, depending on whether one considers the 100-year climate impacts or 20-year climate impacts and whether methane is escaping from the engine's crankcase, which can be a problem for low-pressure injection dual fuel (LPDF) engines. Compare that to 400–565 gCO_2e/kWh for EAO. As such, TtW emissions for the high-methane slip engines, which are the most common, could be 75% higher than the EAO is estimating. On a WtW basis, the ICCT emission factors range from 547–1309 gCO_2e/kWh; whereas the EAO has not estimated WtW emissions at all. Accounting for WtW emissions could increase EAO's emission estimates by up to 77% for low-methane slip engines, 116% for medium-methane slip engines, and 132% for high-methane slip engines. To put it plainly, emissions from LNG-fueled ships could be more than twice as high as the EAO is estimating.

Table 1. Tank-to-wake (TtW) and well-to-wake (WtW) emission factors (EF) using LNG in three engines (gCO_2e/kWh)

Engine type*	**EAO Marine Jetty draft assessment report (footnote 41)**	**ICCT GWP100 low methane scenario (Fig 3)**	**ICCT GWP100 higher methane scenario (Fig 7)**	**ICCT GWP20 low methane scenario (Fig 4)**	**ICCT GWP20 higher methane scenario (Fig 8)**
LPDF 4-stroke (high methane slip)	565 TtW No WtW EF	626 TtW 786 WtW	662 TtW 846 WtW	902 TtW 1168 WtW	987 TtW 1309 WtW

LPDF 2-stroke (medium methane slip)	474TtW No WtW EF	502 TtW 655 WtW	538 TtW 714 WtW	631 TtW 885 WtW	716 TtW 1023 WtW
HPDF 2-stroke (low methane slip)	400 TtW No WtW EF	403 TtW 547 WtW	403 TtW 568 WtW	418 TtW 657 WtW	418 TtW 706 WtW

*LPDF means low-pressure injection dual fuel; HPDF means high-pressure injection dual fuel.

Lastly, Transport Canada and Environment and Climate Change Canada requested that the EAO also consider, estimate, and account for fugitive methane emissions, including those released during loading and unloading LNG marine fuel. The EAO did not address that request in their response.

High risk that LNG infrastructure and vessels will rapidly become stranded assets in a Paris- aligned 1.5- degree economy

Given LNG's contribution to climate impacts, the investment space looks very poor. Financiers are stopping to lend to fossil gas projects due to pressure for climate action and public opposition[5]. There is a risk that LNG-related projects, like Tilbury, will become unbankable sooner than later. Projects already on their way face the challenge of significant shareholder pullout and no buyers available[6]. As was noted above, the World Bank advised countries to pull back from investing in LNG infrastructure, saying that fossil gas "is likely to play a limited role in the decarbonization of the shipping sector."[7]

Some of the largest container shipping lines have opted to leapfrog over LNG for carbon-neutral fuels, like Maersk, as well as energy companies like Ørsted.

Experts[8] are raising red flags about the ability to repurpose LNG facilities with hydrogen. Sighting high costs, technical challenges, differing gas properties, and years to build leading to more delays and climate impacts, cause experts to instead call for '...directing investments and efforts towards energy efficiency, a circular economy and direct electrification.'[9]

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5 Tani & Imahashi (2022). Asia faces billions in stranded assets if gas becomes energy pariah. Nikkei Asia. Available at: https://asia.nikkei.com/Business/Markets/Commodities/Asia-faces-billions-in-stranded-assets-if-gas-becomes-energy-pariah

6 Mcbeth (2021). No buyers for SE Asia's largest untapped gas field. Asia Times. Available at: https://asiatimes.com/2021/07/no-buyers-for-se-asias-largest-untapped-gas-field/

7 https://www.worldbank.org/en/news/feature/2021/04/15/charting-a-course-for-decarbonizing-maritime-transport?utm_campaign=FR+ACT%3A+EU+fuel+standard+for+shipping+will+increase+fossil+LNG+demands&utm_medium=email&utm_source=autopilot

8 https://www.corporateknights.com/energy/europe-wont-need-canadas-lng/

9 https://www.theglobeandmail.com/business/commentary/article-lng-infrastructure-clean-hydrogen-exports/

LNG projects compete for public funds with investment in zero-emission marine infrastructure. For example, between 2014-2019, LNG bunkering infrastructure received about €250 million from the EU's infrastructure funds compared to only €2.2 million for shore-side electricity stations to eliminate ship air pollution and reduce GHG at berths in European ports[10].

Conclusion

- LNG is predominantly liquefied methane. Methane is a potent greenhouse gas that, in the first 20 years after release into the atmosphere, is more than 80 times more powerful than CO2 at trapping heat[11].

- Methane is emitted to the atmosphere during the extraction, processing, storage, transmission, maintenance, and distribution of natural gas, **including unburned methane released from marine engines** (methane slip).

- When comparing the global warming impact of LNG methane emissions with CO2 emissions from shipping, there is no life-cycle benefit in using LNG for any marine engine technology when accounting for methane's 20-year global warming potential[12].

- LNG as a marine fuel does not deliver emission reductions demanded by the Paris Agreement to keep global temperature below 1.5 degrees.

- Embracing LNG as a marine fuel and building out any new LNG bunkering infrastructure is inconsistent with Canada's goals of cutting economy-wide methane emissions by 30% between 2020 and 2030 as part of the Global Methane Pledge, and contrary to its national goal of cutting methane emissions from oil and gas by 75% relative to 2012 levels by 2030. In reality, using LNG can worsen the climate crisis.

- Methane emissions from ships have grown an astonishing 150% between 2012 and 2018[13] and are expected to continue growing in the near future. The narrative that using LNG as a ship fuel is 'climate-friendly' and helps meet 1.5-degree aligned emissions targets is false.

- To reiterate, LNG won't contribute to reducing global climate impacts, should not be considered in any Paris-aligned decarbonization pathway, and will likely become a

[10] https://lngprime.com/asia/cma-cgm-welcomes-another-lng-powered-vessel-in-its-fleet/29641/

[11] IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press. In Press.

[12] Nikita et al. (2020). The climate implications of using LNG as a marine fuel. The ICCT. Available at: https://theicct.org/wp-content/uploads/2021/06/LNG-as-marine-fuel-working-paper-02_FINAL_20200416.pdf

[13] https://theicct.org/wp-content/uploads/2022/03/FUMES_two_pager.pdf

stranded asset wasting billions of dollars and becoming a barrier to renewable zero emission investments.

Thank you for considering these comments. We would be pleased to answer any questions or provide further information.

Sincerely,

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MARINE ENVIRONMENT PROTECTION COMMITTEE
78th session
Agenda item 7

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REDUCTION OF GHG EMISSIONS FROM SHIPS

Calculating Well-to-Wake carbon dioxide equivalent emissions from marine fuels using both GWP100 and GWP20

Submitted by Solomon Islands, Pacific Environment and Inuit Circumpolar Council

SUMMARY

Executive summary:	This document summarizes the methods for calculating Well-to-Wake (WtW) carbon dioxide equivalent emissions from marine fuels using both 100-year Global Warming Potential (GWP100) and 20-year Global Warming Potential (GWP20), as outlined in a briefing paper published by the International Council on Clean Transportation (ICCT). These methods can inform the development of the IMO LCA guidelines.
Strategic direction, if applicable:	3
Output:	3.2
Action to be taken:	Paragraph 10
Related documents:	MEPC 75/7/15; MEPC 78/7/19; ISWG-GHG 9/2/7; ISWG-GHG 11/WP.1/Rev.1 and PPR 5/INF.16

Introduction

1 ISWG-GHG 11 agreed to further consider developing guidance on how to calculate carbon dioxide equivalent emissions based on 100-year Global Warming Potential (GWP100) and adding 20-year Global Warming Potential (GWP20) for comparative purposes as part of the draft LCA guidelines (ISWG-GHG 11/WP.1/Rev.1, paragraph 58).

2 This document summarizes the methods for calculating Well-to-Wake (WtW) carbon dioxide equivalent emissions from marine fuels using both GWP100 and GWP20, as outlined in a briefing paper published by the International Council on Clean Transportation (ICCT), which is included in the annex, as well as online[1]. The ICCT briefing paper contained in the annex was published in August 2021 and is an update of an earlier version that was published

1 https://theicct.org/publication/update-accounting-for-well-to-wake-carbon-dioxide-equivalent-emissions-in maritime-transportation-climate-policies/

in March 2021 which version was included in the annex to document ISWG-GHG 9/2/7 (WWF et al.). The August 2021 update uses Global Warming Potentials from the IPCC's Sixth Assessment Report.

A table containing GWP100 and GWP20 values

3 At ISWG-GHG 11, several delegations supported the inclusion in the draft LCA guidelines of a table containing default GWP100 and GWP20 values of the substances covered for comparison purposes (ISWG-GHG 11/WP.1/Rev.1, paragraph 50).

4 Table 1 contains the GWP100 and GWP20 values used in the ICCT briefing paper. The GWPs for carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are from the IPCC's Sixth Assessment Report[2]. The GWPs for Black Carbon (BC) are from Bond et al. (2013)[3] and Comer et al. (2017)[4]. The GWP100 value for BC from these studies was used in the *Fourth IMO GHG Study 2020* (MEPC 75/7/15). This table could be included in the IMO's draft LCA guidelines as default GWP100 and GWP20 values, subject to review and revision, as appropriate.

Table 1: Global Warming Potentials for climate pollutants

Pollutant	100-year	20-year	Source
CO_2	1	1	Reference level
CH_4	29.8	82.5	IPCC AR6 Table 7.15
N_2O	273	273	IPCC AR6 Table 7.15
BC	900	3200	Bond et al. and Comer et al.

Estimating WtW CO_2e emissions using both GWP100 and GWP20

5 The ICCT estimated WtW emission factors for four marine fuels and a variety of marine engines. For liquid fuels like heavy fuel oil (HFO), 0.5% sulfur very low sulfur fuel oil (VLSFO), and marine gas oil (MGO), they considered their use in slow-speed diesel and medium-speed diesel engines. For liquefied natural gas (LNG), they considered its use in 4-stroke and 2-stroke Otto-cycle engines, 2-stroke Diesel-cycle engines, lean burn spark ignition engines, and steam turbines. The Otto-cycle and lean-burn engines sometimes have methane slip from the crankcase, so they included scenarios with and without crankcase emissions.

6 Well-to-Tank (WtT) emissions were calculated using emission factors from the United States' Argonne National Laboratory's Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model, and energy content assumptions from the *Fourth IMO*

2 Forster, P., T. Storelvmo, K. Armour, W. Collins, J. L. Dufresne, D. Frame, D. J. Lunt, T. Mauritsen, M. D. Palmer, M. Watanabe, M. Wild, H. Zhang, 2021, *The Earth's Energy Budget, Climate Feedbacks, and Climate Sensitivity. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu and B. Zhou (eds.)], (Cambridge University Press. 2021), www.ipcc.ch/report/sixth-assessment-report-working-group-i/.

3 Bond, T. C., et al., Bounding the role of black carbon in the climate system: A scientific assessment, *J. Geophys. Res. Atmos., 118* (2013) 5380– 5552, https://doi.org/10.1002/jgrd.50171.

4 Comer, B., Olmer, N., Mao, X., Roy, B., and Rutherford, D. *Black carbon emissions and fuel use in global shipping, 2015*, (ICCT: Washington, DC, 2017), https://theicct.org/publications/black-carbon- emissions-global-shipping-2015. This study was submitted in the annex to document PPR 5/INF.16.

GHG Study 2020. For VLSFO, which is not included in GREET or the *Fourth IMO GHG Study 2020*, the ICCT estimated its WtT emission factor by assuming that it is an 80/20 blend of MGO and HFO.

7 Tank-to-Wake (TtW) emissions were calculated based on combustion emissions, as well as un-combusted methane in the case of LNG, based on the emissions factors used in the *Fourth IMO GHG Study 2020* with two exceptions. First, the ICCT estimated emissions factors for VLSFO by assuming that it is an 80/20 blend of marine gas oil and heavy fuel oil. Second, the ICCT added scenarios that account for methane slip from the crankcases of Otto-cycle and lean-burn engines.

8 WtW emissions are the sum of the WtT and TtW emissions. They are shown in table 2. They vary depending on the fuel type, which affects WtT emissions, and by engine type, which affects TtW emissions. In the table, CO_2 accounts for only carbon dioxide emissions, whereas CO_2e100 and CO_2e20 account for emissions of CH_4, N_2O, and BC, based on their GWP100 and GWP20, respectively.

Table 2: WtW carbon dioxide and carbon dioxide equivalent factors for fossil marine fuels (Table 13 in the ICCT briefing)

Fuel type	Engine type	Well-to-wake (g/g fuel)		
		CO_2	CO_2e100	CO_2e20
HFO	SSD	3.545	3.892	4.559
	MSD	3.545	4.159	5.516
VLSFO	SSD	3.734	4.098	4.792
	MSD	3.734	4.366	5.749
MGO	SSD	3.782	4.016	4.372
	MSD	3.782	4.211	5.073
LNG	LNG-Otto-MS	3.280	4.930	7.801
	LNG-Otto-MS + crankcase	3.280	5.121	8.330
	LNG-Otto-SS	3.280	4.385	6.288
	LNG-Otto-SS + crankcase	3.280	4.586	6.845
	LNG-Diesel	3.280	3.940	5.008
	LBSI	3.280	4.663	7.060
	LBSI + crankcase	3.280	4.854	7.589
	Steam Turbine	3.280	3.859	4.856

Why considering GWP20 is important

9 The ICCT stresses that it is important to consider not only CO_2, but also CO_2e100 and CO_2e20. They give the examples in figures 1 and 2 below to explain. Figure 1 shows the WtW emissions of consuming 1000 tonnes of LNG in the engine with the highest emissions (LNG-Otto-MS + crankcase) and the LNG engine with the lowest emissions (LNG-Diesel). Figure 2 shows WtW emissions of consuming 1000 tonnes of VLSFO in SSD and MSD engines. Figure 1 shows that estimates of WtW climate pollution can more than double for LNG engines that have high methane slip when evaluated on CO_2e20 compared with CO_2 (left side of figure 1). Figure 2 shows that the relative contribution of BC emissions depends strongly on whether it is evaluated using 100-year or 20-year global warming potential.

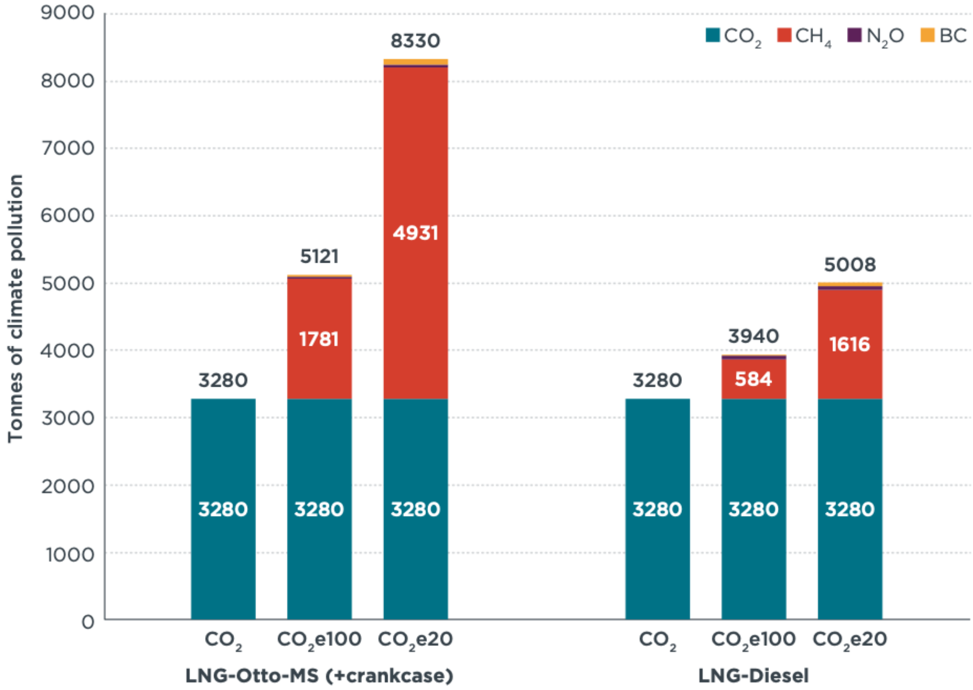

Figure 1: WtW emissions of consuming 1,000 tonnes of LNG in two engines.

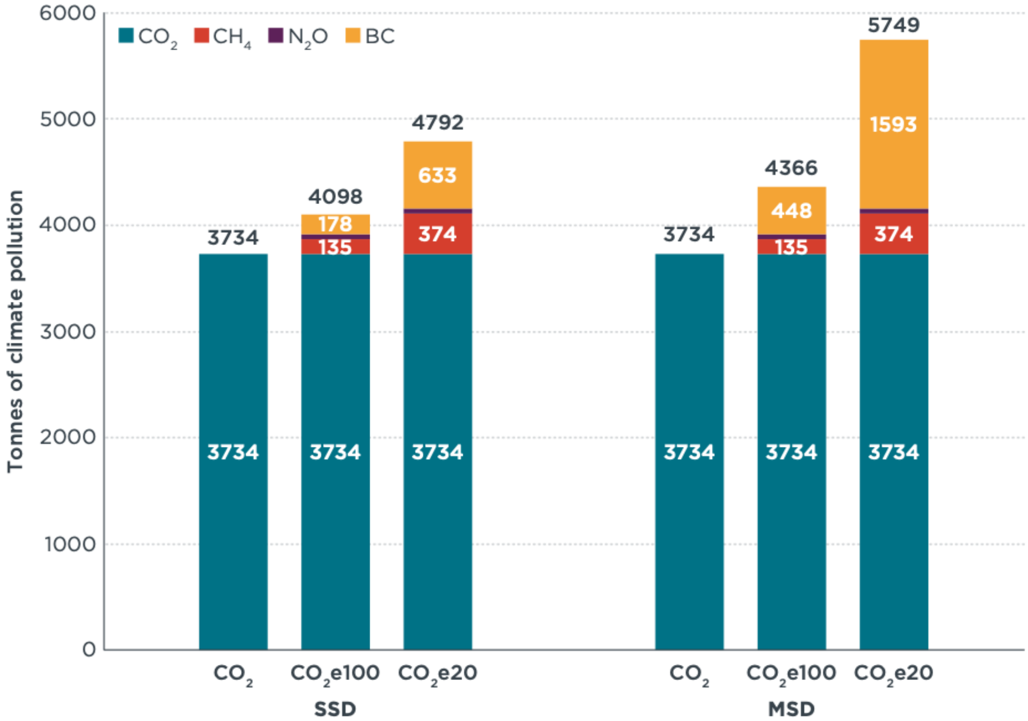

Figure 2: WtW emissions of consuming 1,000 tonnes of VLSFO in two engines.

Action requested of the Committee

10 The Committee is invited to note the information provided in this document, especially the GWP100 and GWP20 values in table 1, and to note the briefing in the annex, as the Organization develops draft LCA guidelines.

***

ANNEX

BRIEFING

AUGUST 2021

Update: Accounting for well-to-wake carbon dioxide equivalent emissions in maritime transportation climate policies

Prepared by Bryan Comer, PhD, and Liudmila Osipova, PhD

INTRODUCTION

This briefing paper explains how policymakers can account for well-to-wake (WTW) carbon dioxide equivalent (CO_2e) emissions in strategies that aim to monitor or regulate climate-warming pollutants from ships. Well-to-wake emissions, or life-cycle emissions, are the sum of upstream (well-to-tank) and downstream (tank-to-wake) emissions. In addition to carbon dioxide (CO_2), carbon dioxide equivalents include greenhouse gases (GHGs) such as methane (CH_4) and nitrous oxide (N_2O), as well as particles like black carbon (BC). By focusing solely on CO_2 and ignoring other pollutants, regulators would significantly underestimate climate pollution from maritime transport which would work against achieving the Paris Agreement goal to limit global warming to 1.5°C compared to pre-industrial levels.

The European Union (EU) intends to add maritime shipping emissions to its Emissions Trading Scheme (ETS) and is currently deciding if only CO_2 emissions will be covered or if other climate pollutants, including CH_4, BC, and N_2O, should also be considered to account for CO_2-equivalent emissions. The emission factors presented in this briefing can be used by the EU and other regulatory bodies to calculate well-to-wake CO_2e emissions from marine fuel consumption. This briefing updates a previous version in order to incorporate well-to-tank black carbon emission factors and new global warming potentials from the IPCC's Sixth Assessment Report.[1]

1 Bryan Comer and Liudmila Osipova, *Accounting for well-to-wake carbon dioxide equivalent emissions in maritime transportation climate policies*, (ICCT: Washington, DC, 2021), https://theicct.org/publications/well-to-wake-co2-mar2021.

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THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

APPROACH FOR CALCULATING WELL-TO-WAKE EMISSIONS BASED ON FUEL CONSUMPTION

Well-to-wake CO_2e emissions (CO_2e_{WTW}) account for the amount of climate pollutants emitted upstream well-to-tank (WTT) and downstream tank-to-wake (TTW). This briefing reports CO_2e_{WTW} based on both 100-year and 20-year global warming potentials. As upstream and downstream pollutants vary according to the type of fuel and engines that are used, the analysis determines the emissions factors for four different marine fuels and multiple engine types. Fuels include heavy fuel oil (HFO), very-low sulfur fuel oil (VLSFO), marine gas oil (MGO), and liquefied natural gas (LNG). Engine types include slow speed diesel (SSD); medium speed diesel (MSD); two-stroke, slow-speed, Otto-cycle, dual fuel LNG (LNG-Otto-SS); four-stroke, medium-speed, Otto-cycle, dual fuel LNG (LNG-Otto MS); lean-burn spark ignition LNG (LBSI); two-stroke, slow-speed, Diesel-cycle LNG (LNG-Diesel), and steam turbines.

The global warming potentials listed in Table 1 represent the relative amount of heat each pollutant traps compared with the heat trapped by the same amount of CO_2 over a given period after emission.

Table 1. Global warming potentials for climate pollutants.

Pollutant	100-year	20-year	Source
CO_2	1	1	Reference level
CH_4	29.8	82.5	IPCC AR6 Table 7.15
N_2O	273	273	IPCC AR6 Table 7.15
BC	900	3200	Bond et al. and Comer et al.

As shown in Table 1, CO_2 is used as the reference and has a global warming potential equal to one. For CH_4 and N_2O, values were obtained from the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6).[2] For BC, values were obtained from Bond et al.[3] and Comer, Olmer, Mao, Roy, and Rutherford.[4]

A ship's CO_2e_{WTW} can be calculated based on the mass of fuel the ship consumed and a well-to-wake carbon dioxide equivalent factor (CEF_{WTW}) for that fuel, as shown in Equation 1. Although the equation determines grams of CO_2e, the same equation can be used with any other unit of mass. For example, if one gram of heavy fuel oil results in 4.6 grams of CO_2e_{WTW}, one tonne will emit 4.6 tonnes of CO_2e_{WTW}. For the EU ETS and other policies based on the fuel consumption of large ships, tonnes will be a more appropriate unit.

2 Forster, P., T. Storelvmo, K. Armour, W. Collins, J. L. Dufresne, D. Frame, D. J. Lunt, T. Mauritsen, M. D. Palmer, M. Watanabe, M. Wild, H. Zhang, 2021, *The Earth's Energy Budget, Climate Feedbacks, and Climate Sensitivity. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu and B. Zhou (eds.)], (Cambridge University Press. 2021), www.ipcc.ch/report/sixth-assessment-report-working-group-i/.

3 Bond, T. C., et al., Bounding the role of black carbon in the climate system: A scientific assessment, *J. Geophys. Res. Atmos., 118* (2013) 5380– 5552, https://doi.org/10.1002/jgrd.50171.

4 Bryan Comer, Naya Olmer, Xiaoli Mao, Biswajoy Roy, and Dan Rutherford, *Black carbon emissions and fuel use in global shipping, 2015*, (ICCT: Washington, DC, 2017), https://theicct.org/publications/black-carbon-emissions-global-shipping-2015.

Equation 1

$$CO_2e_{WTW} = FC \times CEF_{WTW}$$

CO_2e_{WTW} = well-to-wake emissions, in gCO_2e

FC = fuel consumption, in g

CEF_{WTW} = well-to-wake carbon dioxide equivalent factor for that fuel, in gCO_2e/g fuel

Fuel consumption is reported by ship owners or operators. In the case of the EU ETS, fuel consumption will be based on EU Monitoring Reporting and Verification data. The CEF_{WTW} is calculated based on WTT emissions associated with extracting, processing, and transporting the fuel and TTW emissions associated with using the fuel on board the ship. The TTW emissions include combustion and non-combustion emissions, such as methane slip from marine engines that use LNG. Equation 2 shows that CEF_{WTW} is the sum of the WTT and TTW carbon dioxide equivalent factors, labeled CEF_{WTT} and CEF_{TTW}, respectively.

Equation 2

$$CEF_{WTW} = CEF_{WTT} + CEF_{TTW}$$

CEF_{WTW} = well-to-wake carbon dioxide equivalent factor, in gCO_2e/g fuel

CEF_{WTT} = well-to-tank carbon dioxide equivalent factor, in gCO_2e/g fuel

CEF_{TTW} = tank-to-wake carbon dioxide equivalent factor, in gCO_2e/g fuel

As shown in Equation 3, CEF_{WTT} is calculated based on the emission factors for each climate pollutant (EF_{WTT_p}) and the associated 100-year or 20-year global worming potential for each pollutant (GWP_p). The CEF_{TTW} is calculated in the same manner, per Equation 4.

Equation 3

$$CEF_{WTT} = \sum (EF_{WTT_p} \times GWP_p)$$

CEF_{WTT} = well-to-tank carbon dioxide equivalent factor, in gCO_2e/g fuel

EF_{WTT_p} = well-to-tank emission factor of pollutant p, in g/g fuel

GWP_p = the 100-year or 20-year GWP of pollutant p,

Equation 4

$$CEF_{TTW} = \sum (EF_{TTW_p} \times GWP_p)$$

CEF_{TTW} = tank-to-wake carbon dioxide equivalent factor, in gCO_2e/g fuel

EF_{TTW_p} = tank-to-wake emission factor of pollutant p, in g/g fuel

GWP_p = the 100-year or 20-year GWP of pollutant p

The EF_{WTT} and EF_{TTW} include CO_2, CH_4, N_2O, and BC. Table 2 shows EF_{WTT} by fuel type and engine type for each pollutant, as well as CEF_{WTT}, calculated in accordance with Equation 3 and the 100-year or 20-year global warming potentials listed in Table 1.

Table 3 shows EF_{TTW} for each pollutant by fuel type and engine type, as well as CEF_{TTW}, calculated in accordance with Equation 4 and the GWPs in Table 1. Summing them together, Table 4 shows well-to-wake emission factors for each pollutant and CEF_{WTW}. The following two sub-sections explain in detail how we determined EF_{WTT} and EF_{TTW}.

Table 2. Well-to-tank emission factors for each pollutant (EF_{WTT}) and associated carbon dioxide equivalent factors (CEF_{WTT}).

Fuel type[a]	Engine type	Well-to-tank (g/g fuel)					
		EF_{WTT}				CEF_{WTT}	
		CO_2	CH_4	N_2O	BC	CO_2e100	CO_2e20
HFO	SSD	0.4311	0.00399	0.00001	0.000007	0.559	0.786
	MSD	0.4311	0.00399	0.00001	0.000007	0.559	0.786
VLSFO	SSD	0.5457	0.00448	0.00001	0.000008	0.689	0.943
	MSD	0.5457	0.00448	0.00001	0.000008	0.689	0.943
MGO	SSD	0.5757	0.00460	0.00001	0.000008	0.723	0.983
	MSD	0.5757	0.00460	0.00001	0.000008	0.723	0.983
LNG	LNG-Otto-MS	0.5300	0.01810	0.00001	0.000006	1.077	2.043
	LNG-Otto-MS + crankcase	0.5300	0.01810	0.00001	0.000006	1.077	2.043
	LNG-Otto-SS	0.5300	0.01810	0.00001	0.000006	1.077	2.043
	LNG-Otto-SS + crankcase	0.5300	0.01810	0.00001	0.000006	1.077	2.043
	LNG-Diesel	0.5300	0.01810	0.00001	0.000006	1.077	2.043
	LBSI	0.5300	0.01810	0.00001	0.000006	1.077	2.043
	LBSI + crankcase	0.5300	0.01810	0.00001	0.000006	1.077	2.043
	Steam Turbine	0.5300	0.01810	0.00001	0.000006	1.077	2.043

Table 3. Tank-to-wake emission factors for each pollutant (EF_{TTW}) and associated carbon dioxide equivalent factors (CEF_{TTW}).

Fuel type	Engine type	Tank-to-wake (g/g fuel)					
		EF_{TTW}				CEF_{TTW}	
		CO_2	CH_4	N_2O	BC	CO_2e100	CO_2e20
HFO	SSD	3.114	0.00006	0.00017	0.00019	3.334	3.774
	MSD	3.114	0.00005	0.00016	0.00049	3.601	4.731
VLSFO	SSD	3.188	0.00006	0.00018	0.00019	3.410	3.850
	MSD	3.188	0.00006	0.00017	0.00049	3.677	4.807
MGO	SSD	3.206	0.00006	0.00018	0.00004	3.293	3.389
	MSD	3.206	0.00006	0.00017	0.00026	3.489	4.090
LNG	LNG-Otto-MS	2.750	0.03526	0.00013	0.00002	3.854	5.758
	LNG-Otto-MS + crankcase	2.750	0.04167	0.00013	0.00002	4.045	6.287
	LNG-Otto-SS	2.750	0.01689	0.00014	0.00002	3.308	4.244
	LNG-Otto-SS + crankcase	2.750	0.02365	0.00014	0.00002	3.510	4.802
	LNG-Diesel	2.750	0.00148	0.00022	0.00001	2.864	2.965
	LBSI	2.750	0.02628	0.00013	0.00002	3.586	5.017
	LBSI + crankcase	2.750	0.03269	0.00013	0.00002	3.777	5.546
	Steam Turbine	2.750	0.00014	0.00007	0.00001	2.782	2.813

Table 4. Well-to-wake emission factors for each pollutant (EF_{WTW}) and associated carbon dioxide equivalent factors (CEF_{WTW}).

Fuel type	Engine type	Well-to-wake (g/g fuel)					
		EF_{WTW}				CEF_{WTW}	
		CO_2	CH_4	N_2O	BC	CO_2e100	CO_2e20
HFO	SSD	3.545	0.00404	0.00018	0.00020	3.892	4.559
	MSD	3.545	0.00404	0.00017	0.00050	4.159	5.516
VLSFO	SSD	3.734	0.00453	0.00019	0.00020	4.098	4.792
	MSD	3.734	0.00453	0.00018	0.00050	4.366	5.749
MGO	SSD	3.782	0.00466	0.00019	0.00005	4.016	4.372
	MSD	3.782	0.00466	0.00018	0.00027	4.211	5.073
LNG	LNG-Otto-MS	3.280	0.05336	0.00014	0.00003	4.930	7.801
	LNG-Otto-MS + crankcase	3.280	0.05977	0.00014	0.00003	5.121	8.330
	LNG-Otto-SS	3.280	0.03499	0.00014	0.00003	4.385	6.288
	LNG-Otto-SS + crankcase	3.280	0.04175	0.00014	0.00003	4.586	6.845
	LNG-Diesel	3.280	0.01958	0.00023	0.00002	3.940	5.008
	LBSI	3.280	0.04438	0.00014	0.00003	4.663	7.060
	LBSI + crankcase	3.280	0.05079	0.00014	0.00003	4.854	7.589
	Steam Turbine	3.280	0.01824	0.00008	0.00002	3.859	4.856

DETERMINING WELL-TO-TANK EMISSION FACTORS FOR EACH POLLUTANT

The WTT emission factors in Table 2 are obtained by multiplying the upstream energy-based emission factors for marine fuels in in Table 5 (g pollutant/megajoule) by the fuel energy content assumption in Table 6 (MJ/g fuel). The upstream (well-to-tank) emissions in Table 5 are based on the US Argonne National Laboratory's 2020 GREET model,[5] with the exception of VLSFO and the upstream CH_4 value. VLSFO is not incorporated into GREET; we therefore assume that VLSFO is an 80/20 blend of MGO and HFO, consistent with previous work.[6] The upstream CH_4 emissions for liquefied natural gas in Table 5 (0.38 gCH_4/MJ) are consistent with the findings in a previous study which finds that upstream methane leakage from liquefied natural gas production is higher than the 0.30 gCH_4/MJ assumed by the U.S. Environmental Protection Agency.[7] The energy content assumptions for HFO, MGO, and LNG are consistent with the Fourth IMO GHG Study.[8]

Table 5. Well-to-tank emissions for marine fuels (g/MJ)

Pollutant	Fuel			
	HFO	VLSFO	MGO	LNG
CH_4	0.10	0.11	0.11	0.38
N_2O	0.00018	0.00022	0.00023	0.00016
CO_2	10.72	12.93	13.48	11.04
BC	0.00018	0.00019	0.00019	0.00012

Table 6. Energy content of marine fuels

Fuel	Energy content (MJ/g fuel)
HFO	0.0402
MGO	0.0427
VLSFO	0.0422
LNG	0.0480

DETERMINING TANK-TO-WAKE EMISSION FACTORS FOR EACH POLLUTANT

The TTW emission factors for each pollutant are shown in Table 3, and CO_2 is consistent with the carbon dioxide factors used in the Fourth IMO GHG Study[9] for HFO, MGO, and LNG and Comer et al.[10] for VLSFO, as shown in Table 7.

5 Michael Wang, Amgad Elgowainy, Uisung Lee, Adarsh Bafana, Pahola T. Benavides, Andrew Burnham,... and Guiyan Zang, *Greenhouse gases, regulated emissions, and energy use in technologies model*, (US DOE EERE: Washington, DC, 2020), https://greet.es.anl.gov/net. The authors acknowledge Greg Zaimes from Argonne National Laboratory for providing us with the well-to-tank black carbon emission factors from GREET.

6 Bryan Comer, Elise Georgeff, and Liudmila Osipova, Air emissions and water pollution discharges from ships with scrubbers, (ICCT: Washington, DC, 2020), https://theicct.org/publications/air-water-pollution-scrubbers-2020.

7 Nikita Pavlenko, Bryan Comer, Yuanrong Zhou, Nigel Clark, and Dan Rutherford, The climate implications of using LNG as a marine fuel, (ICCT: Washington, DC, 2020), https://theicct.org/publications/climate-impacts-LNG-marine-fuel-2020.

8 Jasper Faber, Shinichi Hanayama, Shuang Zhang, Paula Pereda, Bryan Comer, Elena Hauerhof,... and Hui Xing, "Fourth IMO greenhouse gas study," (International Maritime Organization, 2020), https://www.imo.org/en/OurWork/Environment/Pages/Fourth-IMO-Greenhouse-Gas-Study-2020.aspx.

9 Faber et al., "Fourth IMO greenhouse gas study."

10 Comer, Georgeff, and Osipova, *Air emissions and water pollution discharges from ships with scrubbers*.

Table 7. Carbon factors for marine fuels.

Fuel	Carbon factor (gCO_2/g fuel)
HFO	3.114
MGO	3.206
VLSFO	3.188
LNG	2.750

Black carbon TTW emission factors are consistent with those used in the Faber et al.[11] and Comer et al.[12] We assume that the BC emission factors for VLSFO are the same as for HFO. Black carbon emission factors are a function of fuel type, engine type, and engine load. The BC TTW emission factors for HFO, VLSFO, and MGO in Table 3 assume that ships operate at 50% load, corresponding to the gray shaded row in Table 8, and are divided by 1000 to convert from units of gBC/kg fuel to gBC/g fuel. Emission factors for LNG are the same as those in Faber et al. and Comer et al., as shown in Table 9.[13]

Table 8. Black carbon emission factors for oil-based fuels (g/kg fuel)

Engine load	HFO or VLSFO		MGO	
	SSD	MSD	SSD	MSD
0.05	0.44	4.54	0.10	3.48
0.1	0.34	2.32	0.08	1.60
0.2	0.27	1.19	0.06	0.73
0.25	0.25	0.96	0.05	0.57
0.3	0.23	0.80	0.05	0.46
0.4	0.21	0.61	0.04	0.34
0.5	0.19	0.49	0.04	0.26
0.6	0.18	0.41	0.04	0.21
0.7	0.17	0.35	0.04	0.18
0.75	0.17	0.33	0.03	0.17
0.8	0.16	0.31	0.03	0.15
0.9	0.16	0.28	0.03	0.14
1	0.15	0.25	0.03	0.12

Table 9. Black carbon emission factors for LNG (g/kg fuel)

Engine type	BC (g/kg LNG)
LNG-Otto-MS, LNG-Otto-SS, LBSI	0.02
LNG-Diesel	0.01
Steam Turbine	0.01

11 Faber et al., "Fourth IMO greenhouse gas study."

12 Bryan Comer, Naya Olmer, Xiaoli Mao, Biswajoy Roy, and Dan Rutherford, *Black carbon emissions and fuel use in global shipping, 2015*. (ICCT: Washington, DC, 2017) https://theicct.org/publications/black-carbon-emissions-global-shipping-2015.

13 Faber et al., "Fourth IMO greenhouse gas study;" Comer, Georgeff, and Osipova, *Air emissions and water pollution discharges from ships with scrubbers*.

Methane TTW emission factors are consistent with those use in the Fourth IMO GHG Study.[14] To calculate CH_4 TTW emissions factors, we divide the CH_4 energy-based emission factors used in Faber et al.,[15] which can be found in Table 10 and are in units of gCH_4/kWh, by the specific fuel consumption (SFC) of each fuel-engine pair in Table 11, which are in units of g fuel/kWh. This results in TTW CH_4 emission factors in units of gCH_4/g fuel. The SFC assumptions reflect 2001 and newer model year engines and are taken from the Fourth IMO GHG Study.[16] The Fourth IMO GHG Study's LNG engine SFC assumptions are consistent with Pavlenko et al., which reflects modern LNG engines built in the last several years.[17] We assume that ships using VLSFO emit the same amount of CH_4 as those using HFO. Some ships using low-pressure injection engines, including LNG-Otto and LBSI may have open crankcases; if so, Pavlenko et al. estimate that there could be an additional 1 gCH_4/kWh escaping unburned from the crankcase.[18] Therefore, in Table 3, we include rows that show the impact on CH_4 and CO_2e from these additional crankcase emissions for LNG-Otto and LBSI engines in Table 10.

Table 10. Methane emission factors (g/kWh)

Engine type	Fuel type	Methane (g/kWh)
SSD or MSD	HFO, VLSFO, MGO	0.01
LNG-Otto-MS	LNG	5.5[a]
LNG-Otto-SS	LNG	2.5[a]
LNG-Diesel	LNG	0.2
LBSI	LNG	4.1[a]
Steam Turbine	HFO, VLSFO, MGO	0.002
	LNG	0.04

[a] This table shows methane emission factors used in the Fourth IMO GHG Study; however, low-pressure injection engines, such as LNG-Otto-MS, LNG-Otto-SS, and LBSI, may have open crankcases, which could emit an additional 1.0 gCH_4/kWh.

Table 11. Specific fuel consumption (g/kWh) for marine engines.

Fuel type	Engine type	Specific fuel consumption (g fuel/kWh)
HFO	SSD	175
	MSD	185
VLSFO	SSD	167
	MSD	177
MGO	SSD	165
	MSD	175
LNG	LNG-Otto-MS	156
	LNG-Otto-SS	148
	LNG-Diesel	135
	LBSI	156
	Steam Turbine	285

14 Faber et al., "Fourth IMO greenhouse gas study."
15 Faber et al., "Fourth IMO greenhouse gas study."
16 Faber et al., "Fourth IMO greenhouse gas study."
17 Pavlenko et al., *The climate implications of using LNG as a marine fuel*.
18 Pavlenko, et al., *The climate implications of using LNG as a marine fuel*.

Nitrous oxide TTW emission factors are consistent with those use in the Fourth IMO GHG Study.[19] To calculate N_2O TTW emissions factors, we divide the N_2O energy-based emission factors used in Faber et al.,[20] which can be found in Table 12 and are in units of gN_2O/kWh, by the SFC of each fuel-engine pair in Table 11, which are in units of g fuel/kWh. This results in TTW N_2O emission factors in units of gN_2O/g fuel. We assume that ships using VLSFO emit the same amount of N_2O as those using HFO.

Table 12. Nitrous oxide emission factors (g/kWh)

Engine	Fuel	N_2O (g/kWh)
SSD or MSD	HFO, VLSFO, MGO	0.03
Steam Turbine	HFO, VLSFO, MGO	0.04
LNG-Otto-MS, LNG-Otto-SS, LBSI	LNG	0.02
LNG-Diesel	LNG	0.03
Steam Turbine	LNG	0.02

RESULTS

Table 13 presents WTW emission factors for fossil marine fuels developed according to the methodology described in this briefing. These WTW emission factors include both upstream well-to-tank (WTT) and downstream tank-to-wake (TTW) emission factors.

In Table 13, CO_2 accounts for only carbon dioxide emissions, whereas CO_2e100 and CO_2e20 account for emissions of other climate pollutants based on their 100-year or 20-year global warming potential. Comparing the three metrics, one can see that focusing solely on CO_2 and ignoring other climate pollutants can significantly underestimate climate pollution from maritime transport. We suggest policymakers consider not only CO_2e100 but also CO_2e20 for policies intended to be aligned with the Paris Agreement. In addition to reducing CO_2 emissions, reducing pollutants with large 20-year global warming potential, such as CH_4, BC, and N_2O, can help prevent additional near-term warming.

19 Faber et al., "Fourth IMO greenhouse gas study."

20 Faber et al., "Fourth IMO greenhouse gas study."

Table 13. Well-to-wake carbon dioxide and carbon dioxide equivalent factors (CEF_{WTW}) for fossil marine fuels.

Fuel type	Engine type	Well-to-wake (g/g fuel)		
		CO_2	CO_2e100	CO_2e20
HFO	SSD	3.545	3.892	4.559
	MSD	3.545	4.159	5.516
VLSFO	SSD	3.734	4.098	4.792
	MSD	3.734	4.366	5.749
MGO	SSD	3.782	4.016	4.372
	MSD	3.782	4.211	5.073
LNG	LNG-Otto-MS	3.280	4.930	7.801
	LNG-Otto-MS + crankcase	3.280	5.121	8.330
	LNG-Otto-SS	3.280	4.385	6.288
	LNG-Otto-SS + crankcase	3.280	4.586	6.845
	LNG-Diesel	3.280	3.940	5.008
	LBSI	3.280	4.663	7.060
	LBSI + crankcase	3.280	4.854	7.589
	Steam Turbine	3.280	3.859	4.856

DISCUSSION

To give an example of why it is important to consider not only CO_2 but also CO_2e100 and CO_2e20, consider the figures below. Each figure applies Equation 1, and fuel consumption (*FC*) is assumed to be 1000 tonnes. Figure 1 shows the CO_2e_{WTW} emissions of consuming 1,000 tonnes of LNG in the engine with the highest WTW emissions (LNG-Otto, MS + crankcase) and the LNG engine with the lowest WTW emissions (LNG-Diesel). The exercise is repeated for SSD and MSD engines running on VLSFO (Figure 2) and MGO (Figure 3). Notice that estimates of WTW climate pollution can more than double for LNG engines that have high methane slip when evaluated on CO_2e20 compared with CO_2 (left side of Figure 1). Figure 2 and Figure 3 show that the relative contribution of black carbon emissions to WTW emissions depends strongly on whether it is evaluated using 100-year or 20-year global warming potential. When BC is accounted for, using MGO results in lower WTW emissions than VLSFO.

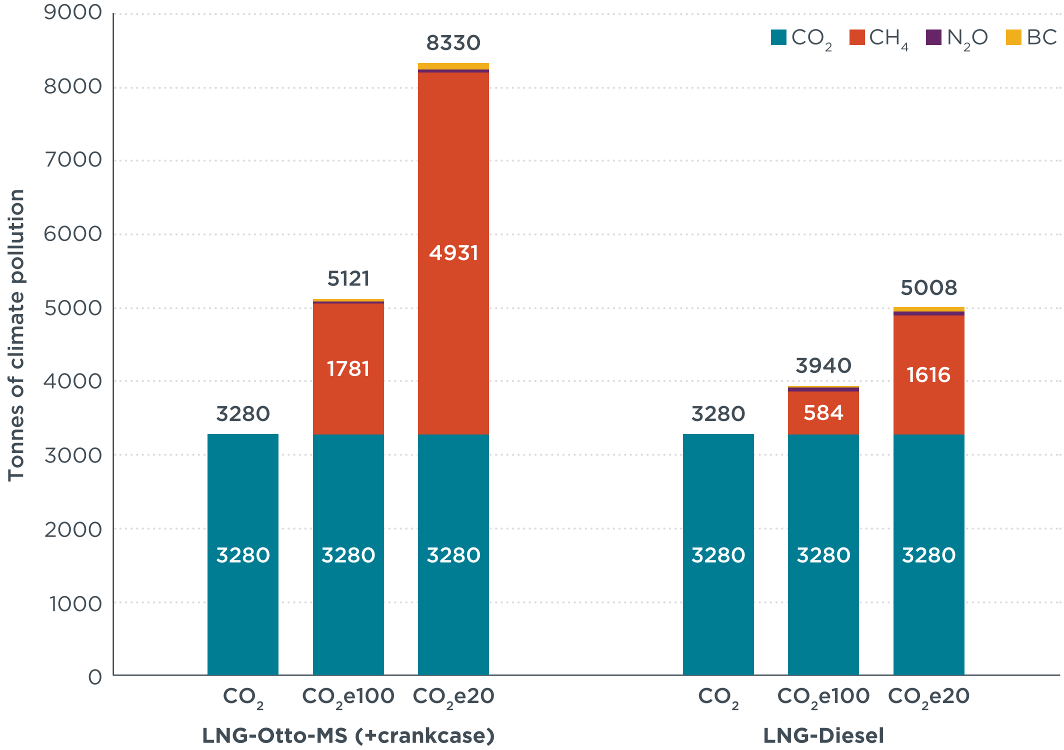

Figure 1. Well-to-wake emissions of consuming 1000 tonnes of liquefied natural gas in two engines.

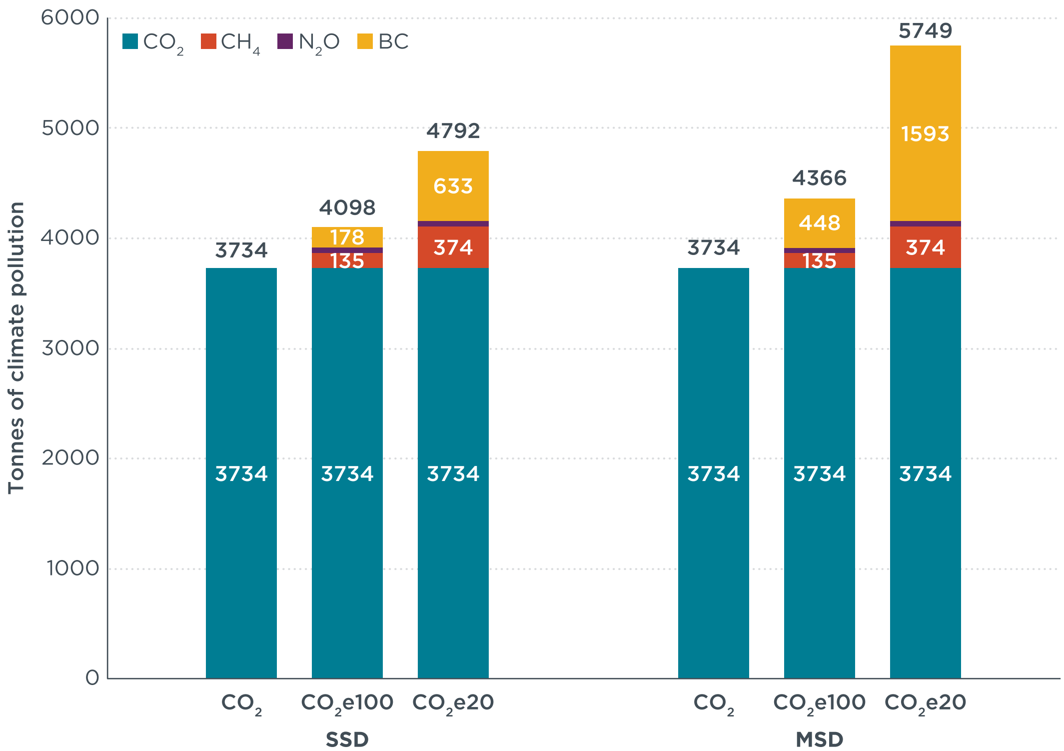

Figure 2. Well-to-wake emissions of consuming 1000 tonnes of VLSFO in two engines.

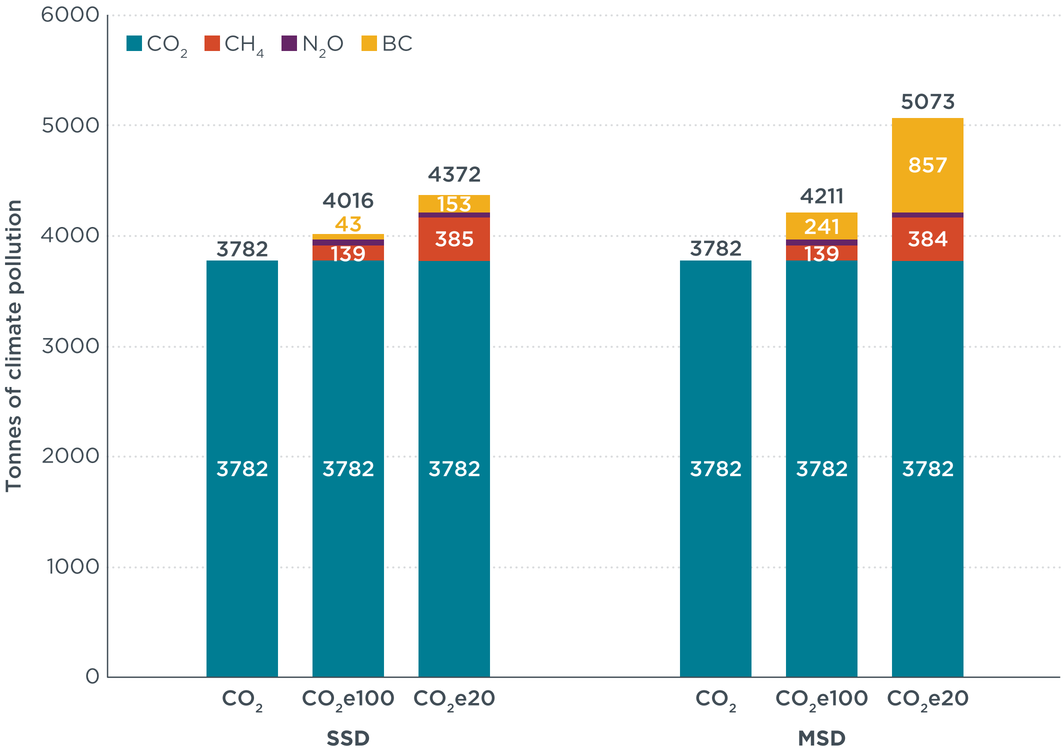

Figure 3. Well-to-wake emissions of consuming 1000 tonnes of MGO in two engines.

CONCLUSIONS

This briefing paper outlines a methodology for calculating well-to-wake carbon dioxide equivalent emissions from four fossil marine fuels: heavy fuel oil, very low sulfur fuel oil, marine gas oil, and liquefied natural gas. Well-to-wake emission factors for these fuels are presented in Table 13. While the EU Emissions Trading Scheme presents the most immediate opportunity to apply this methodology, it can also be applied to policies being developed at the International Maritime Organization and in other regions and countries that aim to reduce shipping's climate impacts.

The WTW carbon dioxide equivalent factors developed in this briefing cover existing marine fuels but could be expanded to new fuels including hydrogen and ammonia, two fuels where the WTT component is particularly important when evaluating their life-cycle climate consequences. No matter which fuel is used, WTT emissions will depend on the feedstock and production pathway. In addition, the TTW emissions will depend on whether the fuel is used in a fuel cell, combusted in an engine, or used in some other way. As new fuels and energy sources for shipping are researched and developed, it will be important to develop WTW emission factors that encompass their full life-cycle emissions in order to accurately judge their climate credentials.

INTERNATIONAL MARITIME ORGANIZATION

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REDUCTION OF GHG EMISSIONS FROM SHIPS

Climate Change 2022: Impacts, Adaptation and Vulnerability

Submitted by WWF, Pacific Environment and CSC

SUMMARY

Executive summary:	This document draws attention to the UN Intergovernmental Panel on Climate Change's (IPCC) publication of the second part of three working group reports published as part of the Sixth Assessment Cycle. The Working Group II report entitled *Climate Change 2022: Impacts, Adaptation and Vulnerability* focuses on the physical science basis of climate change. The Committee is invited to note the findings from the report, together with the views of the co-sponsors, and is urged to support the urgent action outlined.
Strategic direction, if applicable:	3
Output:	3.2, 3.3
Action to be taken:	Paragraph 17
Related documents:	MEPC 77/7/18 and MEPC 77/7/3

1 The UN body responsible for assessing the science related to climate change - the Intergovernmental Panel on Climate Change (IPCC) - has released the second part of its Sixth Assessment Report.[1][2][3] At the time of submission, the IPCC was also set to release its third report *Mitigation of Climate Change* on 4 April 2022. This document draws attention to the results of this second report, *Climate Change 2022: Impacts, Adaptation and Vulnerability,* and urges further action to reduce the impacts of catastrophic climate change.

[1] *Climate Change 2022 Impacts, Adaptation and Vulnerability, Summary for Policymakers* (https://report.ipcc.ch/ar6wg2/pdf/IPCC_AR6_WGII_SummaryForPolicymakers.pdf)

[2] Technical Summary (https://report.ipcc.ch/ar6wg2/pdf/IPCC_AR6_WGII_FinalDraft_TechnicalSummary.pdf)

[3] Full Report (https://report.ipcc.ch/ar6wg2/pdf/IPCC_AR6_WGII_FinalDraft_FullReport.pdf)

2 The report highlights the key need for dramatic action in the near term from 2021 to 2040. The introduction sustains the message outlined in the first working group report. "Global warming, reaching 1.5°C in the near-term, would cause unavoidable increases in multiple climate hazards and present multiple risks to ecosystems and humans (*very high confidence*). The level of risk will depend on concurrent near-term trends in vulnerability, exposure, level of socioeconomic development and adaptation (*high confidence*). Near-term actions that limit global warming to close to 1.5°C would substantially reduce projected losses and damages related to climate change in human systems and ecosystems, compared to higher warming levels, but cannot eliminate them all (*very high confidence*)".

3 Here we highlight areas identified by the report that are particularly pertinent to the Organization: impact on the Arctic and Arctic communities from climate change as well as increased industrial activity like shipping, as well as potential threats to maritime and coastal infrastructure.

The Arctic continues to warm at nearly three times the global average

4 The report confirms that the Arctic is warming at nearly three times the global average. This pace of warming is creating a cascading web of local, regional and global impacts within and beyond polar regions. Changes in the Arctic not only affect global ocean circulation and climate regulation, but also facilitate new Arctic transportation routes and support transboundary resources with geopolitical, environmental and cultural implications as conditions change. The report goes on to note that rapid warming and extreme temperatures in the Arctic are leading to unprecedented seasonal sea ice loss, permafrost thaw and increasing ocean temperatures. Amplified warming in the Arctic has caused September sea ice extent to decline at a rate of -13% per decade (Serreze and Meier, 2019) and reduced sea ice thickness by 66% (2 m) between 1958-1976 and 2011-2018 (Kwok, 2018).

5 These changes in sea ice create safety hazards for Indigenous Peoples who rely on frozen seas and rivers for transportation and subsistence hunting. There is high confidence that increased weather and climate extreme events are exposing Arctic communities to acute food insecurity and that the Arctic is a global hotspot of high human vulnerability. There is also high confidence that there are high to very high near-term risks for biodiversity loss within Arctic sea ice ecosystems. Permafrost thaw, sea-level rise, and reduced sea ice protection is projected to damage or cause loss to many cultural heritage sites, settlements and livelihoods across the Arctic, while Indigenous Peoples and local communities will continue to experience changes in cultural opportunities.

6 Newly ice-free shipping routes are increasing regional and geopolitical tensions and may facilitate novel threats like the spread of invasive species and safety hazards to local hunters and fishers. In the absence of immediate regulatory action, growth in Arctic maritime trade will result in increased emissions for black carbon (Stephenson et al., 2018; Zhang et al., 2019; Wang et al., 2021) and increases in ship-source underwater noise impacts of marine mammals (Halliday et al., 2017). Furthermore, higher rates of accidents and incidents from increasingly mobile sea ice and newly accessible ice-free waters that have not been charted can be expected (Haas and Howell, 2015; Howell and Brady, 2019).

Beyond the Arctic

7 These changes also impact the rest of the world as the Arctic serves as a regulator of global climate and other ecological processes through large-scale patterns related to air and ocean circulation. There is high confidence that these processes are nearing points beyond which rapid and irreversible changes (on the scale of multiple human generations) are possible. The magnitude of cascading changes over the next two centuries includes regional warming and temperature extremes, permafrost thaw and sea ice loss beyond that experienced in human existence.

8 There is very high confidence that under all climate and socio-economic scenarios, low-lying cities and settlements, small islands, Arctic communities, remote indigenous communities, and deltaic communities will face severe disruption by 2100 - and as early as 2050 in many cases.

Impacts from climate change will disrupt supply chains and heavily impact ports and coastal communities

9 Ports, as well as cities and settlements by the sea are also particularly vulnerable to severe disruption by 2050. Projected climate risks will increase with, "exposure to climate and ocean driven hazards such as heat waves, droughts, pluvial floods, and impacts due to sea level rise, tropical cyclones, marine and land heatwaves, and ocean acidification."

10 By 2050, over a billion people will be at risk of coast-specific climate hazards, along with $7 trillion to $14 trillion of coastal infrastructure assets by 2100. These include maritime trade and its supporting infrastructure, which could in turn severely compromise global supply chains and maritime trade with its own cascading impacts. As one example, maritime ports are considered at the greatest risk from climate hazards within North America in terms of supply-chain infrastructure. Ports and supporting infrastructure are already affected by rising sea levels and the increasing frequency of storms, but hazards have not been systematically incorporated into planning.

11 However, the report also suggests that the timing is ripe for a transformational change in ports planning: "[…] a transformational adaptation approach to address climate impacts on maritime activities and increase security (Germond and Mazaris, 2019) [...] reduce shipping distances, or shorten supply chains (*medium agreement*) (Walsh et al., 2019; Monios and Wilmsmeier, 2020) as well as decrease marginalization of vulnerable groups, develop polycentric governance systems and eliminate maladaptive environmental policies and resource loss (Belhabib et al., 2020; O'Keeffe et al., 2020)."

12 Notably adaptational planning could be leveraged on the back of anticipated investment costs which, "to accommodate port growth and adapt to sea level rise amount to $223 billion to $768 billion before 2050, presenting opportunities […] to build climate resilience"

Co-sponsors commentary

13 The IPCC's newest report strongly reiterates the need for immediate and swift mitigation actions in order to keep even the possibility of viable adaptation strategies within reach. The timescales necessary to remain within a 1.5°C or 2°C warming scenario will require very substantial reductions in emissions from all sources this decade. Thus far these needed reductions have not been demonstrated by the maritime sector. More work is needed this decade in order to place shipping on a more viable 1.5°C aligned pathway.

14 It is also important to acknowledge the words of the IPCC Working Group II Co-Chair: "The scientific evidence is unequivocal: climate change is a threat to human well-being and the health of the planet. Any further delay in concerted global action will miss a brief and rapidly closing window to secure a liveable future".

15 With this in mind, the co-sponsors reiterate the need for the Organization to:

.1 make immediate cuts to Black Carbon emissions from shipping in and near the Arctic, and urgently develop measures to reduce black carbon emissions from shipping globally;

.2 revise the levels of ambition in the recently agreed short-term carbon intensity reduction measures to include a 1.5°C-compatible improvement in the carbon intensity of ships; and

.3 revise its climate targets to ensure full decarbonization of international shipping well before 2050, with intermediate absolute emission reduction targets that provide a clear trajectory for the industry.

Conclusions

16 The Committee is invited to note the findings listed in paragraphs 4 to 12 from the first part of the Intergovernmental Panel on Climate Change's Sixth Assessment report, *Climate Change 2021: Impacts, Adaptation and Vulnerability*, together with the views expressed in paragraphs 13 to 14 and is urged to support the urgent action outlined in paragraph 15 and to implement without delay the immediate measures recommended.

Action requested of the Committee

17 The Committee is invited consider the information contained in this document, in particular the conclusions set out in paragraph 16, and to take action as appropriate.

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