WORKSHOP SUMMARY

Sixth ICCT Workshop on Marine Black Carbon Emissions:
Black Carbon Control Policies

A technical workshop hosted by:
The International Council on Clean Transportation

Co-hosted by:
Finnish Transport and Communications Agency

Sponsored by:
The Climate and Clean Air Coalition
Pisces Foundation

September 18-19, 2019
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CLIMATE & CLEAN AIR COALITION TO REDUCE SHORT-LIVED CLIMATE POLLUTANTS

Pisces Foundation

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Table of Contents

Acknowledgements

The ICCT thanks the workshop participants for their contributions and valuable insights. We also thank Anita Mäkinen and Marjut Ahlsted from the Finnish Transport and Communications Agency for their help planning and executing the workshop. The Climate and Clean Air Coalition and Pisces Foundation kindly funded this workshop.

Introduction

The International Council on Clean Transportation (ICCT)[1], hosted its sixth technical workshop on marine black carbon (BC) emissions at the Paasitorni Conference Center in Helsinki, Finland, on September 18th and 19th, 2019 together with the Finnish Transport and Communications Agency (Traficom). This workshop was funded by the Climate and Clean Air Coalition (CCAC) and the Pisces Foundation. The workshop materials are available at https://theicct.org/events/6th-workshop-marine-black-carbon-emissions.

The goal of the workshop was to identify appropriate black carbon control policies and discuss potential standardized sampling, conditioning, and measurement protocols, including a traceable reference method. A detailed agenda is provided in Appendix A. The workshop included 30 participants representing leading researchers and academics, as well as representatives from government, philanthropy, and industry. A full list of participants is included in Appendix B.

Participants identified six appropriate BC control policies (in no particular order):

- BC emissions limit for new ships, globally
- BC emissions limit for new ships, regionally (e.g., in the Arctic)
- BC emissions limit for all ships, regionally (e.g., in the Arctic)
- Modern ship requirement (e.g., prohibit access to the Arctic to higher emitting ships built before a certain date)
- Shore power mandate (e.g., if shore power is available at port, ships must use it)
- Heavy fuel oil (HFO) ban, with a switch to distillate fuel or other cleaner fuels

This report summarizes how participants identified these six appropriate control policies.

Background

In 2011, at its 62nd Marine Environment Protection Committee Meeting (MEPC 62), the International Maritime Organization (IMO) agreed to a work plan to consider the impact on the Arctic of BC emissions from international shipping. MEPC 62 instructed IMO's Bulk Liquids and Gases Sub-Committee – now called Pollution Prevention and Response (PPR) – to:

1. develop a definition for BC emissions from international shipping
2. identify the most appropriate BC measurement methods
3. investigate appropriate BC control measures

The ICCT has convened five previous workshops that have focused on defining, measuring, and controlling BC from international shipping.[2]

The first workshop, held in Ottawa, Canada, in 2014, focused on building consensus on a definition of BC suitable for research purposes. Workshop participants agreed that the Bond et

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[1] The International Council on Clean Transportation is an independent nonprofit organization founded to provide first-rate, unbiased research and technical and scientific analysis to environmental regulators. Its mission is to improve the environmental performance and energy efficiency of road, marine, and air transportation, in order to benefit public health and mitigate climate change. More information can be found at https://theicct.org.

[2] See https://theicct.org/events/5th-workshop-marine-black-carbon-emissions, among others.

al. (2013) definition of BC was suitable for international shipping. The IMO formally accepted that definition at MEPC 68 in May 2015.

The second workshop, held in Utrecht, the Netherlands, in 2015, focused on building consensus on a standardized BC measurement and reporting approach for emission testing campaigns. Outcomes of that workshop included extensive input from participants on ways to refine laboratory and on-board BC research, plus recommendations to improve a measurement reporting protocol for voluntary marine BC emissions testing campaigns presented by the European Association of Internal Combustion Engine Manufacturers (EUROMOT). This measurement reporting protocol was subsequently endorsed by PPR 3 in February 2016.

The third workshop, held in Vancouver, Canada, in 2016, focused primarily on recommending approaches to measure BC from ships and engines. Workshop participants agreed that filter smoke number (FSN), photoacoustic spectroscopy (PAS), laser induced incandescence (LII) and thermal-optical analysis (TOA) showed good agreement. In contrast, two instruments typically used to measure ambient concentrations of BC – multi-angle absorption photometry (MAAP) and aethalometer – were thought to require too much dilution to be useful for marine BC emissions. Participants also discussed potential BC control measures, including diesel particulate filters (DPFs), fuel switching, slow steaming, shore power, and others.

The fourth workshop, held in Washington, DC, USA, in 2017, finalized FSN, PAS, and LII as appropriate BC measurement methods for international shipping. MAAP and TOA were excluded. In 2018, PPR 5 agreed that FSN, PAS, and LII were the most appropriate BC measurement methods for data collection from international shipping.

The fifth workshop was held in San Francisco, California, USA, in 2018. Starting with a list of 41 BC control measures developed by the PPR BC correspondence group, participants identified 13 appropriate BC control technologies, including cleaner fuels, exhaust gas aftertreatment, engine controls, and zero-emission technologies such as batteries and fuel cells, as the most promising. PPR 6 agreed to both lists, in doing so finalizing its BC workplan by agreeing on a definition, most appropriate measurement methods, and appropriate control measures.

The next step was for IMO to consider whether and how BC from international shipping should be controlled. In May 2018, MEPC 74 established a process for IMO on the basis of the proposals made in the document MEPC 74/10/8 (by Finland and co-sponsors Germany, the Netherlands and Republic of Korea) to take a policy decision on BC in 2021, instructing PPR to:

1. Consider regulating or otherwise directly controlling BC
2. Further consider the recommended BC measurement methods
3. Develop a standardized sampling, conditioning, and measurement protocol, including a traceable reference method and uncertainty analysis.
4. Report back to MEPC 77, which will be held in 2021

This workshop aimed to identify appropriate BC control policies and to discuss potential standardized sampling, conditioning, and measurement protocols, including a traceable reference method. IMO member states and international organizations are invited to consider the six appropriate BC control policies identified by the workshop participants in submissions to PPR's February 2020 meeting (PPR 7).

The ICCT intends to hold a 7th workshop in the fall of 2020 to continue expert coordination on BC.

Presentations and Key Themes

Fourteen speakers presented on the first day of the workshop; their biographies can be found in Appendix C. Full materials are available on the ICCT's website at https://theicct.org/events/6th-workshop-marine-black-carbon-emissions.

Dan Rutherford from the ICCT and **Anita Mäkinen** from the Finnish Transport and Communications Agency (Traficom) welcomed the participants to the workshop and to Helsinki. Dr. Mäkinen explained that black carbon is enhancing climate change, especially in Arctic waters and that we need to cut emissions from all sources, including international shipping. She explained that the Finnish president has noted the need to cut emissions in the UN General Assembly and in bilateral meetings with Arctic states. Dr. Rutherford introduced the workshop goals and agenda. He also thanked Traficom for hosting the workshop and the Pisces Foundation and the Climate and Clean Air Coalition for their financial support.

Bryan Comer from the ICCT explained IMO's progress on regulating BC. He emphasized that urgent action is needed to cut BC emissions from all sectors, including international shipping, if the world is to achieve the Paris Agreement temperature goals. He showed that BC emissions in and near the Arctic are increasing along with Arctic shipping. He then explained that after beginning its work on BC in 2011, IMO is now poised to make a decision on how best to regulate BC. Much of IMO's progress on how to define, measure, and control BC can be attributed to the work done by the experts that have participated in the ICCT workshops, he explained. Dr. Comer concluded by urging participants to seize the opportunity to identify appropriate BC control policies.

Daniel Peitz presented on Hug Engineering's work to outfit ships with diesel particulate filters (DPFs). He explained that luxury yachts are usually outfitted with DPFs to keep soot from soiling the surfaces of the ship. Dr. Peitz said that DPF uptake, in this case, was originally driven by aesthetics, not climate protection. He gave an example of a Swiss regulation that, in effect, controls BC by limiting particle number (PN) concentrations of non-road machinery, including ships for inland navigation. DPFs reduced PN by more than 97% on ultra-low-sulfur diesel (ULSD) or marine gas oil (MGO) for a small engine (<3 MW). In this case, PN is similar to BC because this equipment uses EN 590, a distillate fuel, whose particulate matter (PM) emissions are largely carbonaceous particles. Ships are complying by using DPFs in combination with distillate fuels. Hug's lab testing shows good correlation among condensation particle counter (CPC), photoacoustic spectroscopy (PAS) using an AVL micro soot sensor (MSS), and filter smoke number (FSN) using an AVL filter smoke meter when measuring filtration efficiency of a DPF on a laboratory test bed.

Munekatsu Furugen from Furugen and Makino Lab, Inc., Japan, presented work to develop an electrostatic precipitator and cyclone (ESP-C) technology to reduce PM and BC emissions from marine diesel engines. He explained that the ESP-C is low maintenance; it does not clog, and the PM collected in the cyclone is removed by burning it onboard. It also has low engine pressure loss and requires relatively little power to operate. In the Lab, Dr. Furugen and colleagues found that the ESP-C reduced BC emissions by 80% for a 2-stroke 1,275 kW, 162 rpm, 3-cylinder engine at 75% load, using either HFO (2.26% S) or marine diesel oil (MDO), measured using the FSN method. They observed similar lab results with a 4-stroke, 3,500 kW, 750 rpm, 6-cylinder engine operating at 75% load and using either HFO (1% S) or MDO; they measured PM/BC concentration using an Electrical Low Pressure Impactor (ELPI+). On board, using the ISO 8178-2 dilution tunnel method, they found that the ESP-C reduced PM by 90% from the exhaust of a 3,900 kW, 2-stroke engine operating at 70% load and using MDO. Black carbon emissions were not directly measured, but they would have decreased as PM decreased. Dr. Furugen also explained that ESP-C can be installed upstream of selective catalytic reduction (SCR) and exhaust gas cleaning system (EGCS) which lessens SCR system wear and reduces EGCS washwater contaminants, including heavy metals, by 75%.

Jana Moldanova from IVL Environmental Research Institute presented on how Sulfur Emission Control Areas (SECAs) have affected BC emissions. Dr. Moldanova's team measured BC onboard and in the plumes of ships operating on SECA-compliant fuels – such as MGO, LNG, methanol, and hybrid fuels – or HFO with scrubbers. On-board measurements used an AE33 Aethalometer (with a thermodenuder for HFO and HFO with a scrubber) and the EC/OC method with a quartz filter. Plume measurements were taken at stationary locations on the coast of Sweden using an EEPS. They found lower BC emissions using MGO than HFO. LNG had very low PM and BC emissions, with most of it originating from burning lube oil. Methanol had lower BC emissions than HFO. Hybrid fuels that comply with the SECA fuel quality standards (<0.1% S) emitted less BC than HFO in some cases but about the same in others. Reductions from scrubbers were highly variable, ranging from 0 to 50%. In all, they found that the European SECA has BC reduction co-benefits, with BC emissions falling by about a factor of 3 between 2010 (pre-SECA) and 2015 (post-SECA).

Kåre Press-Kristensen from the Danish Ecological Council, and on behalf of the Clean Arctic Alliance, presented on the BC reduction benefits of switching to distillates under an Arctic HFO ban. He pointed out that ships can easily switch from HFO to distillate fuels, and even pair that with slow steaming. A switch to distillate can reduce BC by 30% to 40%. Within the next several years, ships could use distillates or methanol with a filter, which can reduce BC by 80-95% or more. Ships can eliminate BC emissions using future zero-emission fuels, such as hydrogen or ammonia, but ammonia could pose a spill risk (acutely toxic). Dr. Press-Kristensen argued that, given IMO's decarbonization ambitions, there is no future for LNG in shipping, despite its low BC emissions. He highlighted other benefits of an Arctic HFO ban, including reduced risks from a residual oil spill and enabling the use of DPFs. A ban is possible now and would provide a cost-efficient way to reduce BC deposition in the Arctic.

Kaarle Kupiainen from the Finnish Ministry of the Environment presented on the importance of policy-relevant research on Arctic shipping and BC emissions and how it relates to ongoing work on BC at the Arctic Council. To date, scientists have shown that BC emitted anywhere can be a threat to the Arctic but the higher north one goes the more likely BC will affect the Arctic climate and the more likely the source will be a ship. State-of-the-art science-based information can help policymakers at the Arctic Council and IMO design smarter policies to regulate emissions, Dr. Kupiainen said. He explained that AC member states have non-binding targets to reduce their BC emissions by 25% to 33% below 2013 levels by 2025. The Arctic Council's Expert Group on Black Carbon and Methane is now developing new policy recommendations for BC and could benefit from new research on emissions from ships globally and in the Arctic.

Thomas Brewer, an academic studying BC regulations for ships, presented on how new digital technologies (NDTs) can help ensure regulatory compliance. The Internet of Things (IoT), Distributed Ledger Technologies (DLT), Artificial Intelligence (AI), Machine Learning (ML), and Big Data (BD) may and perhaps should interact with one another to help record emissions from ships, keep track of them, report them, and facilitate compliance and enforcement. He pointed out that the international shipping sector already generates big data through the Automatic Identification System (AIS). The volume of data generated and how to review to ensure compliance with a regulatory scheme varies depending on several factors, including the design of the regulation and the metric against which the ship is evaluated. A BC emissions limit might require measuring, recording, storing, and transmitting emissions data, for instance. Dr. Brewer cautioned that the ability for NDTs to improve regulatory compliance depends heavily on the quality of the input data: "garbage in, garbage out," so to speak.

Monica Tutuianu presented on AVL's expertise in measuring BC emissions. She explained the calibration of equivalent BC (eBC) measurement instruments including the Micro Soot Sensor (MSS), which uses the PAS method. She also discussed the Smoke Meter 415SE, which uses the FSN method. Calibration means to use a traceable standard to determine measurement deviation without any technical interventions on the device. The MSS is calibrated with a CAST aerosol, using EC as a reference and the traceability of the MSS calibration is documented according to ISO 9001. MSS can measure BC from a large variety of combustion engines and is a standard reference instrument to certify aircraft engines. The AVL Smoke Meter 415SE measures FSN but is correlated to eBC mass concentrations using an internal AVL correlation formula that is incorporated into ISO 8178-3.

Dr. Tutuianu gave specific recommendations on the elements of a standardized sampling, conditioning, and BC measurement protocol. She noted that correct sampling of the exhaust gas is essential for reproducible measurements. Dr. Tutuianu suggests that the probe be positioned in an exhaust duct where the soot concentration distribution is homogenous and free of pressure fluctuations. She recommends a 45° beveled stainless steel probe with the opening facing the exhaust stream flow. The sampling line should be straight, short (less than 3 m) and very smooth on the inside. Thermophoretic losses should be calculated and corrected for. Condensation can be minimized by using heated instruments and sampling lines. Dr. Tutuianu concluded by saying that the technical expertise to sample and measure BC is available, appropriate BC measurement instruments have been commercialized, and that a test procedure for measuring BC emissions from marine engines on the test-bed and on-board is possible.

Peter Lauer from MAN Energy Solutions ES gave a presentation that was also prepared by **Ralf Oldenburg**, the head of the EUROMOT delegation to IMO. Mr. Lauer presented on the range of

BC measurement results, correlation between instruments, and drew conclusions related to both BC control policies and standardized BC measurement protocols. He began by noting that EUROMOT has developed a measurement and reporting protocol that has been used by many BC measurement campaigns to systematically record and report the conditions under which measurements were taken. He showed that FSN and MSS can correlate well and he noted that only the FSN method has an ISO standard for reciprocating internal combustion engines. Additionally, FSN does not require sampling preconditioning, whereas PAS has internal dilution. He went on to show that the measurement results that have been reported to IMO show a wide range of BC emissions across three orders of magnitude depending on the engine size, type, and fuel and one order of magnitude within the same engine type operating on the same fuel. He noted a general trend that the larger the engine, the lower the BC emission factor (g/kg fuel) tends to be. Finally, he pointed out that 0.50% sulfur fuels may produce higher BC emissions than HFO, especially when they have high aromatic content. Therefore, 2020-compliant fuels may result in higher BC emissions, suggesting that regulating fuels on characteristics beyond sulfur content, such as aromatic content, could be warranted.

Hilkka Timonen and **Päivi Aakko-Saksa** presented on the traceability of BC measurements and the results of the VTT Finland SEA-EFFECTS BC project from 2015-2016. Dr. Timonen explained that traceability means that the result of a measurement can be related to a reference through a documented, unbroken chain of calibrations, each of which contribute to measurement uncertainty. She said that traceability for BC measurement is desperately needed, but there are several challenges: (1) BC is not a single compound and there is no standard BC certified reference material (CRM); (2) there are no reference instruments yet; (3) instruments are based on different techniques; and (4) that calibration factors or multipliers are needed to calculate mass of BC from the measured values. The EMPIR project, among other goals, aimed to develop traceability for aerosol light absorption and to identify reference materials representative of atmospheric aerosols. The project determined that a standard BC reference material depends on the BC source and will differ for fresh and aged atmospheric aerosols. Work remains to develop traceable measurements for marine BC. Ms. Aakko-Saksa explained that some instruments are designed for measuring BC concentrations of engine exhaust gases, while some are designed for measuring BC from ambient air. BC concentrations are often more than 1000 times higher in exhaust from marine diesel engines than in ambient air, and verifying very high dilution ratios (e.g. >600) is extremely challenging. Overall, estimating uncertainties over whole chain from source, through dilution, sampling and transport of sample until the measurement device needs to be evaluated when discussing reliability of the BC emission results.

Stéphanie Gagné from NRC-Canada made the case for developing a standardized measurement system for marine BC to support BC control policies. Dr. Gagné began by explaining that BC is already regulated in the aviation (non-volatile PM standards for particle mass and number) and automotive (PM mass and non-volatile PM number) sectors. PM number and mass are also regulated in the rail sector. These regulations were put in place to address air quality concerns, but the measurement principles used can be adapted for climate-motivated marine regulations. She then stated that BC emissions limits, rather than prescribing specific control technologies, are appropriate because they are goal-based, enable progressive BC reduction, promote innovation, and allow ship owners to choose how they wish to comply. Implementing such a policy would require a standard measurement system, including a traceable reference method.

Dr. Gagné then explained what the traceability chain might look like for BC. From the BC mass measurement instrument, which could be calibrated with another method, such as thermal-optical analysis (TOA) which could then enable traceability to an SI unit, in this case, the kilogram. Reference fuels, reference methods, certifying engines, and certifying aftertreatment must also be considered. Dr. Gagné emphasized that these questions do not mean that we need to hold off on developing a regulation; in fact, standardizing the measurement protocol would benefit from knowing how BC would be controlled. Instead, Dr. Gagné suggested that an international technical working group outside of the IMO should be established to develop a standardized traceable BC measurement method adapted to marine engine exhaust emissions that include sampling, conditioning and the measurement of BC.

The following key themes were distilled from the presentations:

- Policy-related
    - We're near the finish line on BC at the IMO. PPR is scheduled to report back to MEPC 77 (2021) on:
        - How to regulate or otherwise control BC
        - Standardized measurement protocols
    - Building blocks for regulation exist:
        - Technical expertise on BC sampling and measurement is available
        - Appropriate BC measurement instruments are available
        - A test procedure for measurement of BC emissions from marine engines (on test-bed as well as on-board) is possible
    - Shipping is one of the few BC emission sources in the high Arctic.
    - Better understanding of links between BC and climate/health/air quality would help set standard limit.
    - BC or a close proxy like non-volatile PN/PM is already regulated in other sectors, e.g. aviation, LDVs, HDVs, and small marine engines.
    - Currently, there is no regulatory driver for direct BC control e.g. cosmetics, not climate, driving DPFs in yachts.
    - Policymakers (IMO, Arctic Council) and others need state of the art science-based information to design smart policies to regulate emissions.
    - New Digital Technologies (IoT, DLTs, AI, BD) interact with one another and could help record, track, and report emissions from ships and help with enforcement. But watch out for "garbage in, garbage out."
- BC Control measures
    - DPFs: 97% or greater BC reductions, applicable to high speed and MSD engines on ULSD/MDO/MGO, work starting on medium-speed engines + HFO.
    - ESP: can achieve 80% collection efficiency with continuous operation, minimal maintenance, and small power demand.
    - SECA fuels: BC reductions in moving from HFO to MGO and for some hybrid fuels.
    - Removing BC upstream of aftertreatment devices has co-benefits by reducing damage to SCR and scrubbers and resulting in cleaner washwater for scrubbers.
    - Baltic plume studies support SECAs as a BC control measure: 50% reduction in nvPM; 60% reduction in BC.

    - General trend: The larger the engine, the lower the BC emissions intensity (g eBC/kg fuel).
    - Banning HFO and using distillate fuels reduces BC, residual oil spill risk, enables the use of filters, and is a cost-effective way of controlling BC deposition in the Arctic. Desulfurized residual fuels or VLSFO may not reduce BC and could be more toxic than conventional fuels because of high aromatic contents.
    - Fuel standard may be needed on maximum aromatic content or minimum hydrogen content to control BC from blended fuels, such as VLSFO.
- Standardized measurement protocol
    - BC measurement protocols will benefit from knowing what policies we might pursue (engine only? engine plus aftertreatment? on-board testing?).
    - A standardized measurement approach would enable a flexible, progressive control policy that pushes technology forward.
    - Proper sampling, calibration, adjustment, and traceable reference methods are important for accurate and reproducible measurement of marine BC.
    - Correlations of different instruments that are robust to different fuel types can/have been developed under reference conditions (fuel and test bed).
    - Much larger variation in emission factors across engines (3 orders of magnitude overall, 1 order within an engine family under various test conditions) exists than across measurement approaches.
    - We need traceability of measurements, comparability between instruments, metrics and climate and health impact, in order to set a good emission limit.
    - Pay attention to the building blocks of measurement uncertainty.
    - Key issues for standardization
        - Takes all variables into account: fuels, technology, engine size, etc.
        - Get truly comparable measured values regardless of the conditions of the emissions.
        - Good repeatability and reproducibility.
        - Know the uncertainty of the measurement precisely.
    - Could be value in an international technical working group to coordinate efforts to standardize the measurement approach.

Summary of Discussions

After the presentations, participants brainstormed potential policies to reduce BC emissions from ships; discussed considerations for what constitutes an appropriate BC control policy; evaluated control policies against these considerations; and finalized a list of appropriate BC control policies. A full description of those discussions is provided in the sections below.

A short discussion followed relating potential standardized measurement protocols and reference methods to appropriate control policies. However, participants agreed that the issue of standardized measurement protocols and reference methods deserved in-depth consideration and that the remaining time was not sufficient to make meaningful progress. Workshop participants agreed that there could be value in an international technical working group to coordinate standardization efforts. To that end, some participants are organizing a discussion among experts on a standardized measurement protocol to submit to the International Organization for Standardization (ISO). The IMO could refer to an ISO standard in regulations.

Brainstorming Potential BC Control Policies

Participants identified eight potential BC control policies in three categories, six of which **(bolded)** were ultimately deemed appropriate by the group:

1. New Ships
    - **a. BC emissions limit for new ships, globally**
    - b. **BC emissions limit for new ships, regionally**
        - i. The group originally discussed this as BC Emission Control Area (BCECA); however, it became clear that the real goal was to have a more stringent BC emissions limit for ships operating in and/or near the Arctic rather than an "ECA" per se.
2. All Ships
    - a. **BC emissions limit for all (new plus in-service) ships, regionally**
    - b. Arctic ECA
        - i. SECA requirements in the Arctic but disallowing the use of scrubbers as an equivalent compliance option because scrubbers have unclear BC reduction potential, if any, and they also enable the use of HFO, which may not deliver BC reduction benefits.
    - **c. Modern ship requirement**
        - i. e.g., prohibit access to the Arctic for ships built before a certain date because they may emit more BC than newer ships.
    - d. **Shore power mandate**
        - i. e.g., if shore power is available, ships must use it.
3. Fuels
    - **a. HFO ban, with a switch to distillates or other cleaner fuels**
    - b. Fuel quality standard
        - i. e.g., limit aromatic or mandate a minimum hydrogen content because high aromatic / low hydrogen content fuels, are linked to high BC emissions.

Identifying Appropriate BC Control Policies

Participants evaluated each potential BC control policy against measurement, enforceability, and other considerations, as defined in Table 1. Participants noted that considerations developed at the 5th ICCT workshop (e.g. effectiveness, feasibility, availability, applicability, and co-emitted pollutants) could be linked to each policy through the control technologies it promotes.[3]

Table 1. Considerations to identify appropriate black carbon control policies.

Consideration	Definition
Measurement	Whether black carbon must be measured to demonstrate compliance
Enforceability	Can be enforced in a way that ensures compliance
Other	Other considerations, including conditions and caveats

A summary of the workshop participants' evaluation of each potential BC control policy against each consideration is found in Table 2. The far right-hand column indicates whether participants deemed the policy appropriate, not appropriate, or needs more work.

[3] A detailed summary of that discussion can be found in the 5th workshop summary document, available at https://theicct.org/events/5th-workshop-marine-black-carbon-emissions.

Table 2. Potential black carbon control policies evaluated against each consideration, with an indication of whether the policy is appropriate, not appropriate, or needs more work.

Target	Policy	Description	Measurement required	Enforceability[1]	Other	Decision
New Ships	BC emissions limit, global	BC emissions limit, certified as part of the emission certification process	Yes	Medium to High: EIAPP certificate for engine and/or IAPP certificate for ship	Enforceability medium if a new test procedure needs to be defined; High if the NO_x certification regime can be adapted	Appropriate
	BC emissions limit, regional	BC emissions limit within a defined geographic area (e.g., Polar Code Arctic), more stringent than a global standard	Yes	Low to High: depends on means of compliance; easier if the ship always uses fuels and/or aftertreatment that comply with the standard; harder if the ship switches outside the region	May require a new regulatory framework, which would take considerable time and effort to develop.	Appropriate
All ships	BC emissions limit, regional	BC emissions limit within a defined geographic area (e.g., Polar Code Arctic), more stringent than a global standard	Yes	Medium to High: Similar process as a new ship emissions limit, but need to develop a regional and retrofit verification scheme	Retrofits may be difficult, costly, or time-consuming; could it be paired with incentives?	Appropriate
	Arctic ECA	SECA fuel requirements but disallow scrubbers and high aromatic / low hydrogen content fuels as means of compliance.	No BC measurement, but fuel samples could be required.	High	1. Would need to ensure that compliance actually resulted in BC emissions reductions. This means that scrubbers, which allow the use of HFO, desulfurized residual fuels, and other hybrid fuels that emit higher BC than distillates or other alternative fuels may need to be prohibited as compliance options. 2. Could be effective if paired w/ maximum aromatic content / minimum hydrogen content for fuel. 3. Unclear if an ECA could be established given that an	Not appropriate[2]

					important criterion is health benefits, which would be real, but small, in the Arctic.	
	Modern ship requirement	Only ships built after a certain year (e.g., 2011) allowed in a defined geographic area (e.g., Polar Code Arctic)	No	High	1. Goal is to encourage the use of newer ships with lower BC emissions in the Arctic. 2. Need to consider keel laid date pre-buy issue.	Appropriate
	Shore power	If shore power is available, ships must use it	No	High	1. Few ports in the Arctic 2. Effectiveness depends on power generation source and grid capacity. 3. Has health co-benefits. 4. Not all ships are shore-power equipped, but this could be required.	Appropriate
Fuels	HFO ban with a switch to distillates or other cleaner fuels	Use distillates instead of HFO. Do not use very low sulfur fuel oil (VLSFO). Do not use desulfurized residual fuels. Non-residual fuels that emit less BC or no BC would be allowed.	No BC measurement, but fuel samples could be required.	High	1. Bunker delivery note and fuel log inspection would be easier than having to measure a fuel sample as for SECA. 2. Must prohibit fuels with high aromatic / low hydrogen content, prohibit VLSFO, and prohibit desulfurized residual fuels to be effective as a BC control policy.	Appropriate
	Fuel Quality Standard	Promotion of cleaner fuels. Could be an aromatic content limit or a minimum hydrogen content.	No BC measurement, but fuel samples could be required.	Unclear	Potential areas of investigation: aromatic/hydrogen content linked to BC; ISO 8217 revision.	Needs more work

[1] Qualitative scale where High means a policy can be enforced by using or modifying existing verification methods; Medium means that it could be enforced but new verification methods would be needed; Low means that it is difficult to ensure compliance.

[2] Not appropriate with existing ECA criteria which limits sulfur content of marine fuels for all ships and NO_x emissions for new ships. Black carbon would fall under the broader category of particulate matter, but PM is controlled indirectly by sulfur content. BC emissions are rather linked to other fuel characteristics such as aromatic and hydrogen content.

Appropriate BC Control Policies

Workshop participants identified six appropriate black carbon control policies for international shipping after evaluation against each consideration (Table 3). Additionally, the participants identified one control policy that was not appropriate (Arctic ECA, with current ECA criteria), one that needed more work (fuel quality standard), and one that was noted but not evaluated (integration with existing policies like the Energy Efficiency Design Index, or EEDI). Please refer to Table 2 for a detailed evaluation of each potential control policy.

Table 3. Appropriate black carbon control policies and those that are not appropriate, need more work, or not evaluated.

Appropriate[1]	Not appropriate	Needs more work	Not evaluated
BC emissions limit for new ships, globally BC emissions limit for new ships, regionally BC emissions limit for all ships, regionally Modern ship requirement Shore power mandate HFO ban, with a switch to distillates or other cleaner fuels	Arctic ECA[2]	Fuel quality standard	Integration with existing policies, such as EEDI

[1] Order does not indicate priority.
[2] Not appropriate with existing ECA criteria which limits sulfur content of marine fuels for all ships and NO_x emissions for new ships. Black carbon would fall under the broader category of particulate matter, but PM is controlled indirectly by sulfur content and other fuel characteristics, such as aromatic content, control BC emissions, not sulfur content.

Next Steps

The outcomes of the workshop, including the results summarized in Table 3, will be submitted to IMO's PPR 7 meeting, which will be held in February 2020. We anticipate that PPR will consider the information summarized above under its terms of reference, which includes considering regulating or otherwise directly controlling BC and developing a standardized sampling, conditioning, and measurement protocol, including a traceable reference method. The ICCT plans to convene a seventh workshop at a to-be-determined location in autumn 2020. The topic will depend on the outcomes of PPR 7 but could include prioritizing BC control policies ahead of PPR 8.

Appendix A: Workshop Agenda

6th ICCT Workshop on Marine Black Carbon Emissions

September 18-19, 2019
Paasitorni Conference Center, Juho Rissanen Conference Room (1 ½ floor)
Paasivuorenkatu 5 A, FIN-00530, Helsinki, Finland
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Agenda

Workshop Goal: Identify appropriate black carbon control policies and discuss potential standardized sampling, conditioning, and measurement protocols, including a traceable reference method.

Output: A workshop summary document to inform ongoing efforts at the International Maritime Organization to regulate or otherwise directly control black carbon emissions from international shipping.

Day 1

Time	Activity	Details
8:30-9:00	**Registration, coffee/tea and light breakfast**	
9:00-9:15	**Welcome** Anita Mäkinen, Finnish Transport and Communication Agency, Traficom, Finland and Dan Rutherford, ICCT	
9:15-9:35	**Review of agenda and workshop goals** Dan Rutherford, ICCT	
9:35-10:00	**Taking stock: IMO's progress on Black Carbon** Bryan Comer, ICCT	Brief review of the progress to date
10:00-10:30	**BC after Diesel Particulate Filters** Daniel Peitz, HUG Engineering	BC after wall-flow DPFs; experience and outlook for potential IMO regs
10:30-10:45	**Coffee/tea break**	
10:45-11:15	**BC after Electrostatic Precipitators** Munekatsu Furugen, Furugen & Makino Lab, Japan	BC after ESP-C
11:15-11:45	**BC after various emissions control technologies** Jana Moldanova, IVL	BC after various emission control technologies including scrubbers and alternative fuels
11:45–12:00	**Group Photo**	
12:00-1:00	**Lunch** (provided)	
1:00-1:30	**Potential BC Control Policy** Kåre Press-Kristensen, DEC & Clean Arctic Alliance	Banning HFO in the Arctic and impacts on BC
1:30-2:00	**BC from shipping in the Arctic – Work at the science-policy interface of the Arctic Council** Kaarle Kupiainen, Finnish Ministry of Environment	BC work at the science-policy interface of the Arctic Council
2:00-2:30	**Enhancing BC Regulations with New Digital Technology** Thomas Brewer, MIT	How new digital technologies can enhance BC regulations
2:30-3:05	**BC sampling, conditioning and measurement** Monica Tutuianu, AVL	
3:05-3:20	**Coffee/tea Break**	

3:20-3:55	**BC Measurement Correlations** Ralf Oldenburg & Peter Lauer, EUROMOT/MAN	Correlation among measurement methods
3:55-4:30	**Traceable BC Reference Method** Hilkka Timonen, Finnish Meteorological Institute	SI traceability to BC measurements
4:30-5:05	**Standardized Marine BC Measurement Protocol** Stéphanie Gagné, NRC-Canada	Idea for a standardized marine BC measurement protocol & relating it to control policy approaches
5:05-5:20	**Day 1 Closing remarks** Dan Rutherford, ICCT and Anita Mäkinen, Traficom	Closing remarks; preview of Day 2 agenda; logistics for dinner
5:20	**Adjourn for the day**	
7:00	**Group Dinner** (complimentary) Meripaviljonki, Säästöpankinranta 3, 00530 Helsinki	Join your colleagues for dinner.

Day 2

9:00-9:30	**Coffee/tea and light breakfast**	
9:30-9:45	**Recap of Day 1** Dan Rutherford, ICCT	Brief recap of Day 1
9:45-10:15	**Discussion 1: Brainstorming policy measures to reduce BC emissions from ships** Bryan Comer and Dan Rutherford, ICCT, Facilitators	Generate a list of potential policy measures to reduce BC for further discussion; identify which policies require BC measurement to ensure compliance
10:15-11:15	**Discussion 2: Criteria for appropriate BC control policies** Bryan Comer and Dan Rutherford, ICCT, Facilitators	Identify criteria for appropriate BC control policies
11:15-11:30	**Coffee/tea break**	
11:30-12:00	**Discussion 3, part 1: Crosswalk control policies against criteria** Bryan Comer and Dan Rutherford, ICCT, Facilitators	Begin evaluating control policies against each criterion
12:00-1:00	**Lunch** (Provided)	
1:00-2:00	**Discussion 3: part 2: Crosswalk control policies against criteria** Bryan Comer and Dan Rutherford, ICCT, Facilitators	Finish evaluating control policies against each criterion
2:00-2:15	**Coffee/tea break**	
2:15-3:40	**Discussion 4: Relating potential standardized measurement protocols and reference methods to appropriate control policies**	For policies that require BC to be measured to ensure compliance, what does that imply for a measurement protocol and reference method?
3:40-4:00	**Coffee/tea break**	Facilitators summarize workshop outcomes and outstanding issues
4:00-4:30	**Summary of workshop outcomes and outstanding issues** Dan Rutherford, ICCT	Agree on key workshop outcomes and outstanding issues
4:30-4:45	**Closing remarks** Dan Rutherford, ICCT and Anita Mäkinen, Traficom	
4:45	**Adjourn**	
5:00+	**Happy Hour** Juttutupa Pub, Säästöpankinranta 3, 00530 Helsinki	Join us for complimentary drinks and snacks.

Appendix B: Participants

Participants – 6th ICCT workshop on Marine Black Carbon Emissions
6th ICCT Workshop on Marine Black Carbon Emissions
18-19 September 2019
Helsinki, Finland

Name	Organization	Email
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Dan Rutherford	International Council on Clean Transportation	dan@theicct.org
Daniel Peitz	Hug Engineering	daniel.peitz@hug-engineering.com
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Vladislav Lytoff	Institute of Global Climate an Ecology	vladislav.lytoff@gmail.com

Appendix C: Speaker Biographies

Speaker biographies, in order of presentation:

Dan Rutherford s the program director for the International Council on Clean Transportation's Marine and Aviation programs. He is the ICCT's chief representative to the environmental committees of the International Maritime Organization and the International Civil Aviation Organization. He works to developing policies to reduce air pollution and greenhouse gas emissions from ships and planes. His work focuses on aircraft and airline fuel efficiency, technologies to reduce air pollution from ships, emission policies for new and in-use heavy-duty vehicles, and global passenger vehicle efficiency standards. Dr. Rutherford holds a B.A. in Chemistry from the University of Minnesota at Morris and a M.S. and Ph.D. in Environmental Engineering and Science from Stanford University.

Anita Mäkinen is the Chief Adviser to the Director General of the Maritime Sector at the Finnish Transport and Communications Agency. Dr. Mäkinen is also the Vice Chair of the IMO's Pollution Prevention and Response Sub-Committee. She holds the Adjunct Professor Degree on Marine Biology at Helsinki University.

Bryan Comer is a senior researcher in the International Council on Clean Transportation's Marine Program. His research informs policies that reduce the environmental and human health impacts of pollution from marine vessels and ports, including black carbon. Bryan holds a Ph.D. in Environmental Science and Policy from the SUNY College of Environmental Science and Forestry, as well as an M.S. and B.S. in Public Policy from the Rochester Institute of Technology.

Daniel Peitz holds a Ph.D. in Chemical Engineering from ETH Zurich and has been working on exhaust gas aftertreatment for 12 years. He is Product Manager at Hug Engineering in Switzerland since 2017, prior positions were in the development departments of the marine engine companies Wärtsilä and Winterthur Gas & Diesel (WinGD).

Munekatsu Furugen holds a doctor of engineering from the University of Tokyo. He is the president of Furugen and Makino Lab Inc. He conducts research and development on exhaust gas aftertreatment technologies, including electrostatic precipitators. Recently, he conducted joint experiments with universities in Japan and two engine manufacturers in Europe the for ESP-C technology that he will speak about today.

Jana Moldanova holds a Ph.D. in atmospheric chemistry from University of Gothenburg. She is a senior scientist at IVL, Environmental Research Institute. Jana is experienced with atmospheric chemistry modelling and measurements with focus on the transport sector, especially shipping and aviation.

Kåre Press-Kristensen has a master of science and a Ph.D. in environmental engineering. Kare is senior advisor on air quality and climate change in the Danish Ecological Council. He works with international regulation of air pollution and national implementation. He teaches air pollution at the Technical University of Denmark as external professor and still measure air pollution on exotic locations. The Danish Ecological Council is a member of the Clean Arctic Alliance.

Kaarle Kupiainen is a Senior Specialist at the Finnish Ministry of the Environment where he works on international co-operation on black carbon and methane issues, including in the Arctic Council and the Climate and Clean Air Coalition. He has long-standing research experience from his earlier duties as a senior research scientist at the Finnish Environment Institute and as a research scholar at the International Institute for Applied Systems Analysis in Austria, where he has studied emissions of air pollutants and greenhouse gases, as well as black carbon and other short-lived climate pollutants (SLCPs); he has also studied their impacts on human health and climate locally, regionally and globally.

Thomas Brewer is on the Emeritus Faculty of Georgetown University in Washington, DC. He was recently a Visiting Scholar at the MIT Center for Energy and Environmental Policy Research (CEEPR), where he began applying his current research on the potential contributions of new digital technologies to regulating black carbon emissions from ships. His recent publications include a 2019 article on "Black Carbon Emissions and Regulations in Transportation" in the journal *Energy Policy*; a chapter on "Melting Ice in the Arctic Ocean: Managing Black Carbon," in the book *Climate Change and Ocean Governance* and a forthcoming chapter on "Options for Reducing International Maritime Shipping Emissions: Opportunities and Constraints in an Era of Transformative Technologies," in the book *Cool Heads in a Warming World*.

Monica Tutuianu holds a PhD in chemistry from University of Heidelberg, Germany. Currently, she works as Senior Application Engineer at AVL, in the Business Segment Instrumentation and Test Systems group, providing technical expertise on test systems for measuring particulate emissions from passenger cars, light-duty and heavy-duty engines, and marine engines. Before joining AVL she was a Scientific Officer at JRC, Institute for Energy and Transport, in the Sustainable Transport Unit providing scientific and technical support to the European Commission. She was a member of the DHC technical group working on developing the world-wide harmonized light-duty test cycle (WLTC).

Peter Lauer & Ralf Oldenburg
Peter Lauer holds a Dipl.-Ing. (M.S.) in mechanical engineering from the Leibniz University of Hannover, Germany. He has been with MAN Energy Solutions ES, Augsburg, since 1995 in the department of basic research & development, engineering, emissions and after-treatment technology.

Ralf Oldenburg is a Marine Engineer at MAN Energy Solutions ES and holds a Ships Officer's license. Ralf has been at MAN Energy Solutions ES for 14 years and currently serves as its Head of Regulatory Office. Ralf has spent more than 7 years in MAN's Advanced Engineering 4-stroke medium speed engine division. Ralf is the Chairman of the EUROMOT working group for Seagoing Ships and Head of the EUROMOT delegation at IMO.

Hilkka Timonen and Päivi Aakko-Saksa

Hilkka Timonen is a senior research scientist at the Finnish Meteorological Institute. She has been working at FMI for over 15 years, focusing mainly on aerosol composition studies and on black carbon. She has extensive experience from ambient measurements as well as emission measurements from different vehicles, ships, and power plants.

Päivi Aakko-Saksa is a principal scientist at VTT Technical Research Centre of Finland. She worked from 1990 to 1993 as a research scientist in the oil refinery industry in Finland. Since 1993 Mrs. Aakko-Saksa has worked at VTT Technical Research Centre of Finland. She studies fuels and exhaust emissions and has contributed to a number of national and international research programs.

Stéphanie Gagné holds a PhD in Atmospheric Physics from the University of Helsinki. Before joining the NRC, she has worked on atmospheric particle nucleation, cloud physics and scientific software development as well as on superconductors. Upon joining the Black Carbon Metrology team at the NRC, she has been focusing on marine black carbon emissions. She has been collaborating closely with Canadian regulatory bodies, namely Transport Canada, through which she contributed to numerous papers submitted to the PPR sub-committee at the IMO. As Project Manager for the Marine BC emissions project at the NRC, she has organized, designed and participated in 8 marine emissions measurement campaigns on engines of different sizes.