WORKSHOP SUMMARY

Fifth ICCT Workshop on Marine Black Carbon Emissions:
Appropriate Black Carbon Control Measures

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

With support from:
Energy Foundation

Sponsored by:
The Climate and Clean Air Coalition
Pisces Foundation

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CLIMATE & CLEAN AIR COALITION TO REDUCE SHORT-LIVED CLIMATE POLLUTANTS

Pisces Foundation

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Acknowledgements

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Introduction

The International Council on Clean Transportation (ICCT),[1] hosted its fifth technical workshop on marine black carbon (BC) emissions at the Energy Foundation offices in San Francisco, California, USA on September 19th and 20th, 2018. This workshop was funded by the Climate and Clean Air Coalition (CCAC) and the Pisces Foundation. The workshop materials are available at https://www.theicct.org/events/5th-workshop-marine-black-carbon-emissions.

The goal of the workshop was to identify appropriate BC control measures for international shipping for the purpose of informing IMO discussions related to the third item of its BC work plan: to investigate appropriate control measures to reduce the impact of BC emissions from international shipping. A detailed agenda is provided in Appendix A. The workshop had 27 participants including leading shipping BC researchers and academics, as well as representatives from government, philanthropy, and industry. A full list of participants is included in Appendix B.

The ICCT has convened four previous workshops. 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 most suitable definition of BC for research purposes was defined in Bond et al. (2013). The International Maritime Organization (IMO) formally accepted the Bond et al. definition of BC 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 voluntary marine BC emissions testing campaigns. Outcomes of that workshop included extensive input from participants on ways to refine laboratory and on-board BC research and 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 the IMO's 3rd session of its Pollution Prevention and Response Sub-Committee (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. Multi-angle absorption photometry (MAAP) and aethalometer, on the other hand, are typically used to measure ambient concentrations of BC and thought to require too much dilution to be useful. Participants also discussed several 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 a list of appropriate BC measurement methods. Workshop participants agreed that FSN, PAS, and LII were appropriate for measuring BC for international shipping and that MAAP and TOA were not. IMO's Pollution Prevention and Response (PPR) subcommittee agreed in 2018 that FSN, PAS, and LII were the most appropriate BC measurement methods for data collection from international shipping.

The final step for IMO's PPR subcommittee is to identify appropriate BC control measures, which was the focus of this workshop. After considering presentations from BC researchers, scientists, government officials, and shipbuilders, and after intensive discussions, workshop participants identified more than a dozen appropriate BC control measures (technologies and operational practices), including liquefied

[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.

natural gas (LNG) or distillate fuels, diesel particulate filters (DPFs), and zero emission technologies such as batteries and fuel cells. A full summary of the workshop is provided in this document.

Summary of Workshop Presentations and Key Themes

Ten speakers took the floor on the first day of the workshop:[2]

- **Dan Rutherford** and **Bryan Comer** from the ICCT reviewed the workshop goals and explained the progress to date on defining, measuring, and controlling BC from ships. They explained that PPR's remaining task is to identify appropriate BC control measures for international shipping.
- **Alissa Boardley** from Transport Canada gave a high-level update on the status of ongoing IMO BC correspondence group (CG) discussions. She explained that the CG had identified 41 potential BC control measures and that members had provided views on each of these in relation to the four corresponding criteria prescribed in the group's Terms of Reference (later incorporated as "considerations" for appropriate BC control measures for this workshop). She also requested that participants consider how this list could be used to inform discussions on appropriate control measures heading into PPR 6 and beyond.
- **Stéphanie Gagné** from National Research Council (NRC) Canada presented the results of a research campaign to measure BC emissions from a ship with a dual fuel LNG/diesel engine. She explained that LNG is very effective at reducing BC and CO_2. She also presented a case study where methane emissions were reduced by up to about 70% from the base (worst case) scenario using available strategies. She concluded that LNG could be a good option for reducing BC emissions from Arctic shipping even without addressing methane slip, and a good option globally if methane slip can be reduced.
- **Chiori Takahashi** from National Maritime Research Institute (NMRI), Japan, presented the results of several BC control measures studies carried out by her institute. She explained that fuel sulfur content has little direct effect on BC emissions – even for the 2020 compliant fuels, there is the case the BC emission is not reduced especially at low engine load. She also showed that DPFs could reduce BC by 99% or more for a 4-stroke engine operating on heavy fuel oil (HFO) and she explained that electrostatic precipitators (ESPs) have potential promise as a BC control measure. However, she also called attention to the fact that these exhaust gas treatment measures would require substantial space, energy consumption to operate, and, in the case of ESP, disposal of the removed BC.
- **Päivi Aakko-Saksa** from VTT, Finland, summarized the effectiveness of several BC control measures. She showed that LNG and methanol have low BC emissions; oxygenated biofuels reduce BC compared to residual fuels; DPFs greatly reduce particulate matter (PM) because PM is extremely low after DPF, and BC is lower than PM but DPFs require high quality distillate or renewable fuels; SO_x scrubbers do not significantly reduce BC in most cases; engine tuning can reduce BC at cost of elevated NO_x if not combined with e.g. SCR, but quantification of that reduction is difficult; and zero emission vessels (ZEVs) – e.g., hydrogen fuel cells, fully electric – eliminate BC emissions from the ship.
- **John Storey** from Oak Ridge National Laboratory (ORNL), USA, presented on the BC reduction potential of bio-oils. Bio-oils are made by pyrolysis of plant materials and typically contain 30-40% oxygen. ORNL plans to test bio-oils and to measure their BC emissions. They hypothesize that bio-oils may emit substantially less BC than traditional marine fuels.
- **Sunho Park** from Dankook University, Republic of Korea, presented new research on the BC reduction potential of DPFs and wet ESPs. He showed evidence that DPFs can reduce BC by 96% in a 400 kilowatt (kW) engine operating on ultra-low sulfur diesel (<10 ppm S) with less than 1% fuel consumption increases or power losses. He also showed that wet ESPs can reduce BC

[2] Full presentation materials are available on the ICCT's website at https://www.theicct.org/events/5th-workshop-marine-black-carbon-emissions

by 91% in a 3 megawatt (MW) engine operating on marine distillate fuel (Bunker A; 0.29% S m/m).

- **Joseph Pratt** from Golden Gate Zero Emission Marine, USA, explained that hydrogen fuel cell powered ships emit no air pollution, including BC. Regarding safety, Joseph Pratt stated that hydrogen can be handled and stored in a similar way to LNG and hydrogen is non-toxic and dissipates quickly if there is a leak or spill. He also explained that small hydrogen powered ships exist today, and he showed how hydrogen fuel cells could be scaled up for use on ocean-going vessels.
- **Wayne Miller** from University of California Riverside (UCR), USA, explained that scrubbers that are installed on ships are designed to remove gases and they are not specifically designed to remove solid particles, such as BC. He said that scrubbers could be designed to remove gases and solid particles, but the design would be more complex. He also explained that the BC reduction co-benefits of scrubbers can vary from non-existent to moderate, depending on the scrubber design and operating conditions.

The following key themes were distilled from the presentations:

- General
    - Many BC control measures are available, some in the short term and, therefore, available within 5 years. Further prioritization is needed.
    - Not all PM reduction measures reduce BC.
    - The climate impact of BC is complex – science is moving away from simplified metrics like Global Warming Potential (GWP) in favor of more holistic metrics such as Global Temperature Potential (GTP).
    - There's unlikely to be a "one-size fits all" control technology for marine engines.
    - Policy action is needed beyond just IMO; for example, BC control policies targeting smaller domestic vessels could be pursued.
    - Some BC control technologies are already mature in land transportation and could be applicable to the marine sector in the near future.
- Control measures
    - LNG is very effective at reducing BC but methane slip needs to be considered.
    - Fuel sulfur content has little direct effect on BC emissions; other fuel properties have a larger influence.
    - Oxygenated biofuels can reduce BC compared with residual fuels.
    - Scrubbers do not significantly reduce BC in most cases.
    - DPFs have reduced BC by >90% for smaller (< 1 MW) marine engines when paired with distillate fuels.
    - ESPs can reduce BC >90% but few ship installations exist at the moment.
    - Engine tuning can reduce BC, but quantification of that reduction is difficult.
    - ZEVs are zero emissions and emit no BC or any other air pollutant at the source.
- Other
    - Control measures should be evaluated based on a common metric.
    - A common baseline is needed to quantify the BC reduction effectiveness of control measures.
    - Interactions between control measures may need to be considered (e.g. distillate fuels and DPFs).
    - Criteria pollutant and GHG tradeoffs should be considered when identifying appropriate BC control measures
    - A BC measurement protocol will be needed before regulations are finalized.

Summary of Workshop Discussions

After the presentations, the remainder of the workshop was dedicated to agreeing to a definition of "control measure" for the purposes of the workshop, criteria (considerations) for appropriate control measures, comparing potential measures against each consideration, and finally identifying appropriate BC control measures.

Definition of "control measure" for the purposes of the workshop

Participants agreed that a consistent definition of "control measure" would be needed to make progress at the workshop. While the IMO Black Carbon Correspondence Group (BC CG) considered a broad range of possible control measures including control polices, the workshop participants agreed to the following definition of BC control measure for the purposes of the workshop:

Control measure means a technology or operational practice that reduces BC from the source (i.e. the ship engine) – emissions caused by producing marine fuels and energy sources were not considered at this workshop. Examples of control measures include use of distillate fuel, exhaust gas aftertreatment technologies such as scrubbers or DPFs, and slow steaming. This definition excludes what the IMO BC CG called "regulatory measures" in order to focus on technologies and operational practices rather than the policies meant to support them.

Considerations for evaluating and identifying appropriate control measures

The workshop participants discussed and agreed to a list of criteria to evaluate appropriate control measures. After discussion, the participants agreed that these were not strictly quantitative "criteria" *per se* but, rather, qualitative or semi-quantitative "considerations" for identifying appropriate control measures. The group noted that the IMO BC CG had been asked to consider the effectiveness, feasibility, availability, and safety of potential control measures. Participants agreed that all of these, especially safety, were important considerations; however, they agreed that safety was a key element of feasibility and, therefore, safety was incorporated into the definition of feasibility. Participants debated several additional considerations. In the end, the participants agreed to the set of considerations for evaluating and identifying appropriate control measures shown in Table 1.

Table 1. Considerations for evaluating and identifying appropriate black carbon control measures for international shipping

Considerations	Definition
Effectiveness	Magnitude of potential BC emission reductions that can be demonstrated consistently
Feasibility	Can be applied to a new or existing ship without unduly impacting operational performance, cost, or safety
Availability	Can be used in the maritime shipping sector in the short- or mid-term[1]
Applicability[2]	The set of engine types, technologies, fuels, and duty cycles where the measure can be used
Co-emitted pollutants[2]	Impacts on other air, liquid, and solid waste pollution from the ship
Other[2]	Other considerations, including but not limited to enforceability, scalability, supply, infrastructure, space constraints, and enabling conditions.

[1] Short-term could mean before 2023, and mid-term could mean from 2023 to 2030, consistent with the *Initial IMO Strategy on Reduction of GHG Emissions from Ships* (Resolution MEPC.304(72)).
[2] Indicates new considerations developed at the workshop that were not considered under the IMO BC CG Terms of Reference.

Control measures evaluated against considerations

Participants then considered the full list of control measures produced by the IMO BC CG. From that list, participants agreed to consider those that CG participants identified as available within the next five years as well as the measures for which workshop participants had experience.
Participants agreed not to consider "ship design measures," which reduce BC indirectly by improving technical efficiency, or "regulatory measures," which support the implementation of control measures, because these categories were beyond the scope of "control measure" as defined by the workshop participants. That is not to say that these types of measures should not be considered when IMO discusses potential BC control measures.

Participants considered control measures in the following categories: fuel type, fuel treatment, exhaust gas treatment, engine and propulsion system design, operation measures, and other measures.

Fuel type includes switching to or using fuels that emit less or no BC. As Chiori Takahashi presented, fuel properties can have a large influence on BC emissions. At the 4th ICCT BC workshop,[3] Dan Lack explained that switching from residual fuels to distillate fuels reduces BC by 33%, according to a review of the literature to date. At this workshop, Stéphanie Gagné and Päivi Aakko-Saksa showed that using LNG with diesel as pilot fuel emitted nearly no BC. Päivi Aakko-Saksa also explained that methanol (55% to 75% reductions depending on the pilot fuel) and oxygenated biofuels (76% reductions) have low BC emissions. John Storey presented that oxygenated bio-oils may emit substantially less BC than traditional marine fuels. Päivi Aakko-Saksa and Joseph Pratt concluded that hydrogen fuel cells are zero emissions and emit no BC. Other zero emission technologies, including fully battery electric, emit no BC.

[3] All 4th workshop presentations are available at https://www.theicct.org/events/4th-workshop-marine-black-carbon-emissions. The updated report on appropriate BC control measures (abatement technologies) prepared by Dan Lack was submitted as PPR 5/INF.7.

Fuel treatment includes Water in Fuel Emulsions (WiFE) and colloidal catalysts. At the 4th workshop, Dan Lack concluded that WiFE is expected to reduce BC by 70% but based upon only a few studies. Participants commented that WiFE (with emulsifier additive, or direct injection of water) was developed for vehicles to reduce NO_x, not BC. No information on colloidal catalysts was presented at any workshop. Päivi Aakko-Saksa commented that fuel-borne metals ("colloidal catalysts"), such as vanadium in HFO, may catalyze BC combustion, but many heavy metals are toxic causing harmful health and environmental effects, and thus not desirable in fuel.

Exhaust gas treatment includes DPFs, ESPs, scrubbers, exhaust gas recirculation (EGR), selective catalytic reduction (SCR), diesel oxidation catalysts (DOCs), and various combinations of these technologies. Chiori Takahashi, Päivi Aakko-Saksa, and Sunho Park's presentations concluded that DPFs greatly reduce BC (>96%). Chiori Takahashi and Sunho Park also showed that ESPs can substantially reduce BC, more than 91% according to Sunho Park's research. Wayne Miller explained that most scrubbers tend to do a poor job of removing BC because they are designed to remove gases (SO_2) rather than solid particles. Päivi Aakko-Saksa showed that SO_x scrubbers do not significantly reduce BC in most cases. EGR and SCR are designed to remove NO_x emissions, as explained by several participants; however, they could be used in combination with engine tuning or other after treatment technologies (e.g. DPFs or ESPs) to reduce BC emissions. DOCs do not reduce BC, the participants agreed.

Engine and propulsion system design includes engine characteristics (e.g., engine size, stroke type, engine rating), engine control technologies (injection system, engine tuning), hydrogen fuel cells, fully battery electric vessels (BEV), and hybrid/energy storage. While engine and propulsion system design affect BC emissions, participants agreed that they were not a control measure *per se* because no manufacturer or ship owner is likely to change these fundamental design parameters (e.g. stroke type) solely to reduce BC. Engine control technologies are common in modern engines and can improve combustion efficiency and reduce BC. Hydrogen fuel cells and fully BEVs eliminate emissions from the ship. Hybrid/energy storage can be used to provide supplemental electrical power to the ship for auxiliary equipment or propulsion, especially when the ship would be operating at low main engine loads, which can reduce BC emissions when the ship is maneuvering or slow steaming.

Operational measures include slow steaming, engine load, voyage optimization, training and crew awareness, trim optimization, and adoptive engine/condition-based maintenance. Here, participants agreed to evaluate only slow steaming because other measures are already common practice or would be difficult to enforce. Slow steaming may increase BC emissions per unit of energy (e.g., grams per kilowatt-hour), but generally reduce BC per unit of time or unit of distance.[4] At the 4th workshop, Dan Lack explained that slow steaming with engine derating could yield 15% BC reductions. However, the effectiveness of slow steaming depends on a number of factors, including fuel type, engine technology, and the ships' duty cycle.

Other measures include promoting ship recycling and promoting shore power. Participants agreed that promoting ship recycling was outside the scope of the workshop definition of control measure. Shore power eliminates BC emissions from the ship while it is at berth.

After considering these BC control measures, participants evaluated 18 BC control measures against six considerations (Table 1) as a step to identify appropriate control measures. The results are shown in Table 2.

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[4] Johnson et al. (2017). Black carbon measurement methods and emission factors from ships. Prepared for the International Council on Clean Transportation. Available at https://www.theicct.org/publications/black-carbon-measurement-methods-and-emission-factors-ships

Table 2. Black carbon control measures evaluated against six considerations (across 4 pages).

Measure[1]	Effectiveness[2]	Feasibility[3]	Availability[4]	Applicability	Co-pollutants	Other
Liquefied Natural Gas (LNG)	High	High (New, N) Low (Existing, E)	Short-term	Gas or Dual-fuel engines	↓ CO_2, NOx, SOx, and PM (magnitude depends on design) ↑ CH_4 , (magnitude depends on design and duty cycle), potentially formaldehyde	Limited bunkering infrastructure
Distillate	Low to Medium	High (N&E)	Short-term	All	↓ SOx & PM (magnitude depends on S content)	
Biodiesel	Medium	High (N&E)	Short-term	All	↓ SOx & PM ↑ NOx (magnitude varies)	Limited supply and regulatory uncertainty (MARPOL reg. 18)
Water in Fuel Emulsions (WiFE)	Insufficient Evidence[5]	Insufficient Evidence	Short-term	Insufficient Evidence	↓ NOx, PM (?)	Needs more research but some ships are using WiFE
Methanol	Medium based on information presented at the workshop; chemistry suggests could be High	High (N) Medium (E)	Short-term	Diesel-cycle, dual-fuel	↓ NOx, SOx, & PM ↑ Formaldehyde (potential)	Limited supply and bunkering infrastructure; International Code for Ships using Gases or other Low-flashpoint Fuels (IGF) code for methanol needs to be completed

Measure[1]	Effectiveness[2]	Feasibility[3]	Availability[4]	Applicability	Co-pollutants	Other
Diesel Particulate Filters (DPF)	High	High (N) Medium (E)	Short-term to Mid-term	High-speed diesel (HSD) and medium-speed diesel (MSD) for now and should be paired with marine fuels with low S and ash content (e.g. distillates)	↓ PM ↑ CO_2 & solid waste	Space constraints for retrofits and waste storage; backpressure is a concern; regeneration concerns; scalability to slow-speed diesel (SSD) should be considered
SO_x scrubbers (Exhaust Gas Cleaning Systems, EGCS)	Low but variable with design and fuel	High (N & E)	Short-term	SSD/MSD with heavy fuel oil (HFO)	↓ SOx & PM ↑ CO_2, liquid & solid wastes	Space constraints for retrofits and waste storage
Exhaust gas recirculation (EGR) with Scrubbers	Insufficient Evidence	Insufficient Evidence	Short-term	SSD with HFO	↓ NOx, SOx, & PM ↑ CO_2, liquid & solid wastes	Space constraints for retrofits and waste storage
Electrostatic Precipitators (ESP)	High	High (N), Medium (E) depending on space	Short-term to Mid-term	SSD with HFO	↓ PM (and SOx for wet ESPs) ↑ CO_2, liquid & solid wastes	Space constraints for retrofits and waste storage; needs low exhaust temp.
Diesel Oxidation Catalyst (DOC)	Not effective	High (N & E)	Short-term	HSD with ULSD* although one MSD with HFO has a DOC. *Note: ULSD may not be safe for use in larger marine engines	↓ HC, Polycyclic Aromatic Hydrocarbons (PAH), & CO ↑ CO_2	Space constraints for retrofits; need high exhaust gas temperature

Measure[1]	Effectiveness[2]	Feasibility[3]	Availability[4]	Applicability	Co-pollutants	Other
DPF coated with Selective Catalytic Reduction (SCR) catalyst	High	High (N) Medium (E)	Mid-term	HSD/MSD with distillate fuel for now	↓ NOx, PM, ? CO_2 ↑ solid waste	Available in road transport; space constraints for retrofits and waste storage; backpressure is a concern; regeneration concerns; scalability to slow-speed diesel (SSD) should be considered
Engine tuning with SCR/EGR	Low to Medium	High (N) Medium (E)	Short-term	All	↓ NOx, PM, CO_2, HC, & CO	
Engine Control Technologies	Low to Medium depending on engine type	High (N) Medium (E)	Short-term	All	↓ NOx, PM, & CO_2	e.g. slide valves for SSD engines, common rail injection, electronically controlled engine
Full battery electric	High	High (N) Low (E)	Short-term to Mid-term depending on size	Short range	Zero emissions from the ship	Weight; chemical leakage potential; materials availability for some battery chemistries
Hybrid/Energy Storage	Low to Medium depending on duty cycle	High (N) Medium (E)	Short-term	Best for ships with fluctuating load profile	↓ All	Space constraints; chemical leakage potential; materials availability for some battery chemistries

Measure[1]	Effectiveness[2]	Feasibility[3]	Availability[4]	Applicability	Co-pollutants	Other
Hydrogen fuel cells	High	High (N) Low (E)	Short-term to Mid-term depending on size	Short range (compressed H_2) Longer range (liquid H_2)	Zero emissions from the ship	Limited supply and bunkering infrastructure; potential safety issues (flammability); limited materials availability for certain fuel cell components; regulatory hurdles
Slow steaming	Not effective to Medium depending on the engine technology and existing slow steaming operations	High (N&E)	Short-term	All	↓ in general, but could increase NOx and PM depending on engine and load	Enforceability is a concern; system-wide effects (additional vessel movements or vessels to maintain transport supply); safety with minimum power needs to be addressed
Shore power	High while at berth	High (N) Medium to High (E) depending on the size of the ship	Short-term	All	Zero emissions from the ship at berth	Only mid-term applicability to near-Arctic ports; infrastructure requirements for ships and ports

[1] Participants agreed not to consider "ship design measures," which reduce BC indirectly by improving technical efficiency, or "regulatory measures," which support the implementation of control measures, because these categories were beyond the scope of "control measure" as defined by the workshop participants. Those measures could be considered when IMO discusses potential BC control measures. A list of measures not evaluated by participants is included in Table 3.
[2] Qualitative scale where the magnitude of potential BC emission reductions that can be demonstrated consistently aligns roughly with the following ranges: High (90% or more); Medium (between 30% and 90%) and Low (less than 30%).
[3] Qualitative scale where High means a measure can be applied without unduly impacting operational performance, cost, or safety; Medium means a measure can be applied with manageable impacts on operational performance, cost, or safety; and Low means that the measure can be applied but with significant impacts on operational performance, cost, or safety.
[4] Short-term could mean before 2023, and mid-term could mean from 2023 to 2030, consistent with the *Initial IMO Strategy on Reduction of GHG Emissions from Ships* (Resolution MEPC.304(72).
[5] Insufficient evidence means that the group felt that it did not have enough information to fill the box.

Categorization of Control Measures

After evaluating the 18 selected BC control measures against each consideration, workshop participants identified 13 appropriate black carbon control measures for international shipping as shown in Table 3. Additionally, the participants identified one control measure that was not appropriate, and participants could not arrive at consensus on four control measures. The measures were categorized in the same way as the IMO BC CG and include fuel type (LNG, distillate, etc.), exhaust gas treatment (DPFs, ESPs, etc.), engine and propulsion system design (hydrogen fuel cells, engine controls, etc.) and other measures (shore power). Participants agreed that DOCs were not appropriate because they are not effective at removing BC. For four measures, the participants could not arrive at consensus either because there was insufficient evidence on their effectiveness (WiFE; EGR with scrubbers) or because their effectiveness is not consistent across design, fuels, and/or duty cycles (SO_x scrubbers; slow steaming). Note that the order the control measures are presented in does not indicate priority.

Table 3. Black carbon control measures for international shipping

Appropriate*	Not appropriate	No consensus	Not evaluated
Fuel Type ○ LNG ○ Distillate ○ Biodiesel ○ Methanol Exhaust Gas Treatment ○ DPF paired with marine fuels with low S and ash content (e.g. distillates) ○ DPF w/ SCR, paired with marine fuels with low S and ash content (e.g. distillates) ○ ESP Engine and Propulsion System Design ○ Engine tuning to low BC (NO_x reduced with EGR/SCR) ○ Engine control technologies ○ Hybrid/energy storage ○ Full BEV ○ Hydrogen fuel cells Other Measures ○ Shore power *These are BC control measures that the group agreed were appropriate for international shipping after evaluating them against the six considerations in Table 2. Order does not imply priority. See Table 2 for further information about each measure, including the set of engine and fuel types for which they may be applicable.	DOC (not effective)	Fuel Treatment ○ WiFE (insufficient evidence) Exhaust Gas Treatment ○ SO_x scrubbers (effectiveness varies) ○ EGR with scrubbers (insufficient evidence) Operation Measures ○ Slow steaming (effectiveness varies)	Fuel Type ○ Nuclear (would be zero BC; not practical for international commercial shipping) Fuel Treatment ○ Colloidal catalysts (limited information) Exhaust Gas Treatment ○ SCR with scrubbers (NO_x, not BC control) ○ EGR or SCR without engine tuning (NO_x, not BC control) Engine and Propulsion System Design ○ Slide valves (already common) ○ Engine stroke type (cannot reasonably change) ○ Engine rating (cannot reasonably change unless it's to be de-rated; no BC CG votes for implementable within 5 years) Ship Design (beyond scope of this workshop) ○ Improving energy efficiency of new ships ○ Improving energy efficiency of existing ships Operation Measures (already common or difficult to enforce) ○ Engine Load ○ Voyage optimization ○ Training and crew awareness ○ Trim optimization ○ Adaptive engine/condition based maintenance Regulatory Measures (beyond scope of this workshop) Other Measures ○ Promote ship recycling (beyond scope of this workshop)

Next Steps

The outcomes of the workshop, including the indicated appropriate BC control measures, will be submitted to IMO's PPR 6 meeting which will be held in February 2019. We anticipate that PPR will consider the information summarized above and agree to a list of "appropriate" BC control measures. As such, the ICCT plans to convene a sixth workshop at a to-be-determined location in Autumn 2019 focused on identifying appropriate BC control policies.

Appendix A: Workshop Agenda

5th ICCT Workshop on Marine Black Carbon Emissions

September 19-20, 2018
Energy Foundation Offices, 301 Battery St., Fifth Floor, San Francisco, California, USA 94111

Workshop Goal: Identify appropriate black carbon control measures for international shipping.

Day 1

Time	Activity	Details
9:00-9:30	**Registration, coffee/tea and light breakfast**	
9:30-10:00	**Review of agenda and workshop goals** Dan Rutherford, ICCT	
10:00-10:30	**Taking stock: Where are we on defining, measuring, and controlling BC?** Bryan Comer, ICCT	Brief review of the progress to date
10:30-11:00	**Update on IMO's BC Correspondence Group** Alissa Boardley, Transport Canada	Goal: Learn the status of the IMO BC CG discussions
11:00-11:30	**New research on BC Control, Part 1** Stéphanie Gagné, NRC Canada	BC from dual fuel diesel/LNG engine
11:30–12:00	**New research on BC Control, Part 2** Chiori Takahashi, NMRI Japan	BC after a DPF
12:00-12:15	**Group Photo**	
12:15-13:15	**Lunch** (Provided)	
13:15-13:45	**New research on BC Control, Part 3** Päivi Aakko-Saksa, VTT Finland	BC after diesel oxidation catalysts and scrubbers
13:45-14:15	**New research on BC Control, Part 4** John Storey, Oak Ridge National Laboratory, USA	BC with biofuels
14:15-14:45	**New research on BC Control, Part 5** Sunho Park, Dankook University, Korea	BC after DPFs and electrostatic precipitators
14:45-15:15	**Zero emission vessels (ZEVs)** Joseph Pratt, Golden Gate Zero Emission Marine	New work on building ZEVs
15:15-15:30	**Coffee/tea break**	
15:30-15:45	**Scrubber Design and BC** Wanye Miller, University of California, Riverside	How scrubbers work
15:45-16:45	**Discussion: Criteria for appropriate control measures, Part 1** Bryan Comer and Dan Rutherford, ICCT, Facilitators	Goal: Begin discussion
16:45-17:15	**Day 1 Closing remarks** Dan Rutherford, ICCT	- Closing remarks - Preview of Day 2 agenda - Logistics for dinner
17:15	**Adjourn for the day**	
18:30-21:00	**Group Dinner** (complimentary) E&O Kitchen and Bar, 314 Sutter St., San Francisco, CA	Join your colleagues for dinner.

Day 2

9:00-9:30	**Coffee/tea and light breakfast**	
9:30-10:00	**Recap of Day 1** Dan Rutherford, ICCT	Brief recap of Day 1
10:00-10:45	**Discussion: Criteria for appropriate control measures, Part 2** Bryan Comer and Dan Rutherford, ICCT, Facilitators	Goal: Agree on criteria for "appropriate" BC controls
10:45-12:00	**Discussion: What are appropriate control measures based on the criteria? Part 1** Bryan Comer and Dan Rutherford, ICCT, Facilitators	Goal: Begin discussion
12:00-13:00	**Lunch** (Provided)	
13:00-14:30	**Discussion: What are appropriate control measures based on the criteria? Part 2** Bryan Comer and Dan Rutherford, ICCT, Facilitators	Goal: Continue discussion
14:30-14:45	**Coffee/tea break**	
14:45-15:45	**Discussion: What are appropriate control measures based on the criteria? Part 3** Bryan Comer and Dan Rutherford, ICCT, Facilitators	Goal: Agree on appropriate BC controls
15:45-16:05	**Coffee/tea break**	
16:05-16:45	**Summary of workshop outcomes** Dan Rutherford, ICCT	Goal: Agree on key workshop outcomes, including appropriate control measures
16:45-17:00	**Closing remarks** Dan Rutherford, ICCT	
17:00	**Adjourn**	
17:15+	**Happy Hour** Royal Exchange, 301 Sacramento St., San Francisco, CA	Join us for an informal networking happy hour!

Appendix B: Attendee List

Participants – 5th ICCT workshop on Marine Black Carbon Emissions
19-20 September 2018
Energy Foundation Offices, 301 Battery St., Fifth Floor, San Francisco, California, USA
Updated: 20 September 2018

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