WORKSHOP SUMMARY

Marine Black Carbon Emissions:
Testing Protocols and Reporting, Instrumentation, and Emission Factors

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

In collaboration with:
The Netherlands Organization for Applied Scientific Research and
The Dutch Ministry of Infrastructure and Environment

Sponsored by:
The Climate and Clean Air Coalition

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TNO: Netherlands Organization for Applied Scientific Research
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CLIMATE AND CLEAN AIR COALITION
TO REDUCE SHORT-LIVED CLIMATE POLLUTANTS

THE INTERNATIONAL COUNCIL
ON CLEAN TRANSPORTATION

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Executive Summary

This workshop was the second of three designed to inform and guide a two-year project on marine black carbon funded by the Climate and Clean Air Coalition (CCAC) and implemented by the International Council on Clean Transportation (ICCT). The goals of the project are to develop a refined global marine black carbon (BC) emissions inventory and a technology performance database for BC mitigation strategies. The goal for this workshop was to work collaboratively toward consensus on a standardized BC measurement and reporting approach that can be applied in aligned marine BC emissions testing campaigns.

The workshop was held in Utrecht, Netherlands at the offices of the Netherlands Organization for Applied Scientific Research (TNO). It included 30 in-person participants as well as one remote attendee, representing more than 20 organizations from across the globe. The two-day agenda (Appendix A) included three sessions where a total of nine experts presented on issues ranging from the status of current BC testing efforts, BC sampling and measurement protocols, and BC emission factors. The agenda also included a presentation by the awardees of the ICCT Marine Black Carbon Emissions Testing Project led by Kent Johnson of the University of California-Riverside (UCR). Furthermore, a sizeable portion of the workshop agenda was dedicated to breakout groups to discuss three main issues supporting the aforementioned workshop goal: testing protocols and reporting, instrumentation, and emission factors. The outcomes of these breakout groups were discussed with the full group of participants on the second day of the workshop.

The following report is designed to provide a general synopsis of the two-day workshop and to identify key outcomes, emerging next steps, and opportunities for action. The report is divided into the following sections: Introduction, Summary of Workshop Presentations, Summary of Workshop Discussions, and Next Steps.

Key workshop outcomes included: extensive input from participants to refine UCR's research plan for laboratory and on-board BC testing; collaborative recommendations to enhance the utility of a BC testing reporting protocol developed by the European Association of Internal Combustion Engine Manufacturers (EUROMOT); guidance on the appropriate types, applications, and possible performance criteria for testing instruments; and, identification of data gaps that need to be addressed to create a refined global marine BC inventory and to ensure comparability across instruments and measurement approaches.

Near-term next steps emerging from the workshop included:

1. UCR will consider modifications to the planned test stand arrangement for the approved research proposal, particularly:
    a. Divide instruments into an "A Table" and "B Table", to identify which instruments are crucial for the experiment and which instruments are desired but not imperative, and ensure that high priority research outcomes are achieved without interference.
    b. Consider adding the Continuous Soot-Monitoring System (COSMOS) instrument.
    c. Integrate sample conditioning into the bench testing protocol after a literature survey into the current state of research and scholarship on pretreatment – thermal denuders, catalytic strippers, and varied dilution rates – has occurred. (Note: Following the workshop, ICCT sponsored this literature survey and UCR is incorporating the findings into their emissions testing plan).
    d. Evaluate whether integrating a 415SE filter smoke meter at multiple dilutions may be appropriate for cross comparisons.
    e. Develop a list of important questions related to vessel maintenance history and integrate appropriate elements of vessel maintenance records into research design, testing, and reporting. (Note: Following the workshop, UCR and EUROMOT have started testing out incorporating maintenance information into the reporting protocol for on-board vessel testing).
2. EUROMOT will consider revisions to their draft reporting protocol based on input received during and after the workshop as well as the appropriate means to introduce the refined protocol into the IMO process.
3. ICCT and interested stakeholders will decide whether to hold a side meeting to discuss instrumentation performance criteria for marine BC measurement at the third Pollution Prevention and Response meeting (PPR-3) in London in February 2016.
4. ICCT will consider options to share the outcomes of the workshop via the submission of an information paper (INF) to PPR-3 by CCAC member states engaged at IMO.

Introduction

The International Council on Clean Transportation (ICCT)[1], in coordination with the Dutch Ministry of Infrastructure and Environment and the Netherlands Organization for Applied Scientific Research (TNO), hosted a technical workshop on marine BC emissions. This workshop was the second of three designed to shape a two-year project on marine BC emissions funded by the Climate and Clean Air Coalition (CCAC), an international cooperative partnership of over 40 member nations and more than 50 intergovernmental and non-governmental organizations to promote strategies to reduce emissions of short-lived climate pollutants, including BC. Under that project, the ICCT, working with the United Nations Environment Program (UNEP), will develop a refined global marine BC inventory and a BC control strategy performance database for use by CCAC member states.

The first workshop, held in Ottawa, Canada, in September 2014, focused on building consensus on a definition of BC that would be suitable for research purposes. A key outcome of the first workshop on marine BC emissions was a general agreement on the definition of BC as defined by Bond et al. (2013): BC is a "distinct type of carbonaceous material, formed primarily in flames, is directly emitted to the atmosphere, and has a unique combination of physical properties." Two properties in particular were considered to be useful for measurement purposes:

- BC strongly absorbs visible light with a mass absorption coefficient (MAC) value above 5 $m^2 g^{-1}$ at a wavelength λ = 550 nanometers (nm) for freshly produced particles
- BC is refractory, with a volatilization temperature near 4000 K

This definition was formally accepted by IMO at MEPC 68 in May 2015.

The goal of this second workshop was to work toward consensus on a standardized BC measurement and reporting approach that can be applied in marine BC emissions testing campaigns. To achieve this goal, the workshop convened international experts on BC measurement and reporting protocols, instrumentation, and inventory development. A third workshop, to be held in fall 2016, will focus on ways to control marine BC emissions.

This workshop was divided into distinct sessions with the intent of providing expert overviews and subject matter presentations covering the range of BC topics. Each session included an opportunity for questions and answers to provide the foundation for specialized breakout group discussions. The topics and goals for each session are presented in Table 1 below.

[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. Our 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.

Table 1. Workshop Sessions and Goals

Session	Session Goal
Summary of Previous Workshop and Background	*Provide a general overview of the CCAC/ICCT project, highlight the consensus definition agreed at the first workshop, and outline the current IMO context relative to these issues.*
Current BC Testing Efforts	*Learn about the scope and outcomes of current BC testing and research, including impacts from various engine and vessel types, the geographic implications of the research, instrument selection, and results.*
Sampling and Measurement Protocols	*Learn about existing and proposed sampling and measurement protocols as well as identify existing and proposed reporting parameters.*
Research plan for CCAC-funded emissions testing	*Outline the proposed protocols, engines, vessels, fuel types, and other elements of the University of California-Riverside (UCR) consortium's research plan.*
Breakout Group: Testing Protocols & Reporting	*Identify areas of consensus as well as unresolved questions relative to research set-up, temperature, dilution, pretreatment, etc.*
Breakout Group: Instrumentation	*Identify areas of consensus as well as unresolved questions related to particular instruments, including: photo-acoustics, LII, thermal-optical, filter based methods, and the associated capability to generate useful results to meet the goals of the CCAC project.*
Breakout Group: Emission Factors	*Identify areas of consensus as well as unresolved questions related to BC emission factors (engine type, load, fuel, etc.) needed to refine the global marine BC inventory.*
Summary and Next Steps	*Review the highlights of the workshop discussion and identify next steps.*

The complete agenda is included as Appendix A. A list of attendees is found in Appendix B. The following sections walk through the main agenda topics and summarize major discussion points and outcomes.

Summary of Workshop Presentations

The workshop began with a series of presentations focused on (1) current BC testing efforts; (2) existing and proposed sampling and measurement protocols; and (3) the proposed approach for an upcoming marine BC testing campaign. These presentations can be found on ICCT's website. A summary of the presentations is provided in this section.

Current BC Testing Efforts

The first presentation session focused on current BC testing efforts. The goal was to give workshop participants a common understanding of the efforts already underway to measure BC emissions. Three experts presented: Chiori Takahashi from Japan's National Maritime Research Institute (NMRI); Malte Zeretzke from DNV-GL; and Kent Johnson from UCR's Center for Environmental Research and Technology (CERT).

Ms. Takahashi (NMRI) reviewed current BC testing on marine engines in Japan. She explained that NMRI has recently tested three marine engines for BC emissions using a suite of methods and instruments including Filter Smoke Number (FSN) using a Filter Smoke Meter (FSM), Multi-Angle Absorption Photometry (MAAP), Photoacoustic Spectroscopy (PAS) using a Micro Soot Sensor (MSS), Thermal Optical Analysis (TOA), particulate matter (PM) gravimetric analysis, and Laser Smoke Meter (LSM). Ms. Takahashi explained that different instruments and methods can yield different results when estimating BC emissions. She highlighted external factors that can influence how BC estimates compare, based upon preliminary research. For instance, BC estimates obtained by FSN and MSS correlated well for an engine operating on marine diesel oil (MDO) but did not correlate well for an engine operating on heavy fuel oil (HFO). This implies that fuel type can influence BC estimates and can affect the relationship between BC measurements obtained by different instruments or methods. Estimates can also be influenced by engine operating conditions, sample conditioning, particle properties, particle losses, and other factors. Separately, on-board testing showed good agreement between BC emissions as estimated by FSN and MSS instruments on a bulk carrier operating a low speed two-stroke engine on 2.4% sulfur HFO.

Mr. Zeretzke (DNV-GL) explained the capabilities and limitations of various instruments and methods to measure BC emissions. Like Ms. Takahashi, Mr. Zeretzke presented evidence that under current testing measured BC emissions vary not only by instrument and method but also by fuel type. He described challenges in regulating PM and BC emissions and in conducting on-board testing from a classification society perspective. When certifying marine engines for compliance with emissions regulations (e.g. compliance with the NO_x Technical Code), engines are operated at well-defined load points. Mr. Zertzke showed how deviating slightly from those points can significantly affect the amount of PM (and likely BC) emitted from marine engines. This is a challenge for regulating marine engines and speaks to the difficulty of understanding how much pollution is emitted under real world conditions. On-board engine emissions testing is possible, but there are significant barriers to conducting these tests.

Dr. Johnson (UCR CERT) showed how BC emission factors are influenced by engine type, fuel type, engine load, instrumentation, and methods, including sample dilution ratio, over a variety of engines – ranging from small displacement engines used in road transport to larger aircraft and marine engines. For example, as engine power increases, BC emission factors tend to decrease. Additionally, BC emission factors tend to decrease as fuel quality increases, and BC emission factors tend to decrease as engine load increases. Dr. Johnson echoed Ms. Takahashi and Mr. Zeretzke in explaining how instrumentation and methodology influence measured BC emissions. He suggested that future BC testing campaigns, including the campaign to be led by UCR, ought to identify and quantify possible interferences of measurement methods as fuel, load, and engine type vary. He also suggested comparing BC emission factors across instruments and recommended a sample pretreatment/conditioning protocol to limit the influence of semi-volatile material on BC measurements.

Key messages of the session on current BC testing efforts included:

- Some test-bench and on-board vessel testing for BC emissions is already occurring.
- A variety of testing protocols, instruments, and methods are being used to measure BC.
- BC emission measurements can be influenced by a number of factors, including engine type, fuel type, engine operating conditions, sample conditioning, particle properties, particle losses, instrumentation, methods, and other factors.
- Variability in BC emission measurements and the difficulty of on-board testing may make engine certification and regulatory compliance challenging if BC emissions are regulated.
- Sample pretreatment/conditioning can help improve BC emission estimates by reducing the impact of contaminants (e.g., brown carbon) on results.

Sampling and Measurement Protocols

The second presentation session focused on current BC sampling and measurement protocols. The goal was to inform workshop participants about how BC emissions testing is carried out and how emissions of BC are reported. Four experts presented: Daniel Lack, formerly an advisor to the U.S. National Oceanic and Atmospheric Administration (NOAA); Torsten Mundt from DNV-GL; Ralf Oldenburg from MAN Diesel; and Bas Henzing from TNO.

Dr. Lack (fmr. NOAA) described the commercial measurement options for measuring BC light absorption, discussed the potential biases of these measurement options, explained why removing semi-volatile material is important, and made the case for measuring BC light absorption. Dr. Lack explained that some instruments are more accurate than others when measuring BC, ranging from approximately 5% to 40% accuracy; instruments can be biased by light scattering, particle coatings, particle size, filter type, particle loading, organics, semi-volatiles, and other factors. Dr. Lack explained that biases can be reduced by removing semi-volatiles under a sample pretreatment/conditioning protocol (e.g., heating the sample to between 150 and 300° C). He noted that some methods, including some FSN methods, measure BC using a unitless number that cannot currently be compared to other measurements based upon standardized conversion factors. Thus, he made the case for measuring BC light absorption because absorption can be converted to mass using a single conversion factor. Knowing the mass of BC is useful for regulations and for climate and health modeling. Dr. Lack emphasized that a common pretreatment and measurement protocol is needed for researchers, industry, and regulators to work collaboratively on marine BC emissions.

Mr. Mundt (DNV-GL) reviewed BC properties and BC measurement methods. He noted that BC is defined by four distinct properties (light absorption, thermal stability, insolubility, and morphology), and that at this time, there is no one instrument or system that can measure these properties simultaneously. Each measurement tool or approach has biases that must be addressed during the testing process. Overall, the measurement result depends on the measurement technique, measurement protocol and calibration method used. Mr. Mundt explained that the measurement system should be chosen based on the intended use, desired outcome, and location of measurement. He stressed that there are obstacles to comparing BC emissions estimates from one measurement technique to another. Mr. Mundt advocated for a standard measurement technique, protocol, and calibration material to enable future policymaking.

Mr. Mundt also made the distinction between *emissions* and *imissions* as defined in German/European regulations. *Emissions* are defined as “any air pollution…originating from an installation” (e.g., emissions directly from a stack); *imissions* are defined as “any air pollution…which affect human beings, animals and plants, soil, water, the atmosphere as well as cultural objects and other material goods.” Imissions focus on the portion of emissions that have negative impacts. Regulators aim to limit imissions; typically this is achieved by policies to control emissions.

Mr. Oldenburg presented a draft BC reporting protocol developed within EUROMOT. Following recent decisions at IMO, including the adoption of measurement method-neutral definition of BC based on Bond et al. (2013), EUROMOT developed a harmonized reporting protocol for use in BC testing campaigns. The protocol aims to be detailed, measurement method-neutral, and consistent with the existing NO_x Technical Code, and can be used during test-bench or on-board testing. In particular, EUROMOT identified several general parameters that are currently included in the protocol and that should be accounted for in future reporting:

- Engine design parameters, maintenance status and running-in
- Fuel in use during measuring
- Lubrication oil properties and composition during measuring
- Information relevant for the measurement equipment, including the calibration of the particular instruments to be utilized
- Exhaust gas dilution, sample line, and probe conditioning
- Values should be aligned with NTC 2008 and their estimated accuracy
- Measure values at load points under actual engine settings and ambient conditions

Mr. Oldenburg stressed the importance of recording engine maintenance status because BC emissions will vary depending on how long it has been since engine components were last maintained.

Dr. Henzing (TNO) described the conflict between how PM is measured in ambient air compared with how PM is measured during engine emissions testing. He noted that in the European Union (EU), regulations on PM were originally based on the blackness of exhaust smoke. Blackness of exhaust smoke was measured using Filter-Type Smokemeters for steady-state diesel engines, Opacimeters for internal combustion engines, and Black Smoke Index for ambient air. Dr. Henzing emphasized that these Black Smoke methods do not measure the mass concentration of particles directly. Black Smoke Index and mass were used to regulate engine emissions, but with the introduction of diesel particulate filters, the limit of detection for these Black Smoke instruments was reached. This prompted a shift toward regulating based on particle number.

Dr. Henzing explained that the particle number standard for emission regulations does not match with the standard for ambient monitoring that is currently under development. The main differences are that the emissions regulation standard tests for solid particles that are greater than 23 nanometers (nm) in aerodynamic diameter. This avoids issues with new particle formation and reduces sampling and measurement artifacts during engine testing. On the other hand, many ambient air particles are smaller than 23 nm and there are many non-solid particles that are suspected of adverse health effects. Thus, the standard being developed for ambient air monitoring tests is for particles larger than 7 nm. This means that techniques that reduce larger particles (i.e., > 23 nm) to achieve emissions compliance may not necessarily reduce all ambient particle concentrations. This potentially hampers the ability to evaluate emission reduction strategies.

Dr. Henzing stressed that the absorption properties of marine BC determine its climate impact. Thus, it is important to assess the relationship between absorption (defined as extinction minus scattering in the EU) and BC mass. There has been some work in Europe to investigate the relationship between elemental carbon (EC) and light absorption capacity (equivalent BC) using filter-based and in-situ methods. Dr. Henzing noted that it is likely that climate impact studies will require BC emission factors based on absorption; whereas, health effects studies and regulations will require BC emission factors based on concentration or mass. He highlighted the need to develop BC emission factors that are suitable for both research and regulatory purposes.

Key messages of the session on sampling and measurement protocols included:

- BC is defined by four distinct properties (light absorption, thermal stability, insolubility and morphology) but no one instrument can measure these properties simultaneously.
- Testing protocols and instruments used to measure BC based on one of these properties exist.
- Significant variability in BC emission estimates is seen across different instruments/protocols, with smaller variability existing even using a single instrument/protocol.
- There is a need for a standard measurement technique, protocol, and calibration material if BC regulations are to be realized in the future.
- Air pollution *imissions* that affect human health and the environment can be controlled by reducing *emissions* from pollution sources, including marine engines.
- There may be a conflict between how marine BC is measured for climate impact studies (e.g. absorption) and how BC might be regulated (e.g., mass)
- Given that regulations will likely seek to limit emissions of BC mass, BC emission factors intended to inform policymaking ought to be reported in g/kWh or g/kg fuel
- A standardized sampling, measurement, and reporting protocol is needed for the entire community concerned with marine BC emissions
    - EUROMOT offered a draft BC reporting protocol for possible use
        - Engine maintenance status is an important factor that may influence BC emissions and is included in this draft reporting protocol

Research Plan for CCAC-funded Emissions Testing

The ICCT and the U.S. Department of Transportation's Maritime Administration (MARAD) are administering a CCAC-funded BC emissions testing campaign. The results of this testing campaign will be used to refine the global marine BC emissions inventory and to develop a database that compares the effectiveness of BC control technologies and strategies. The testing campaign will be carried out by a UCR-led research consortium. Dr. Kent Johnson from UCR and Dr. Kevin Thomson from the National Research Council-Canada (NRC-Canada) presented the current test plan to workshop participants.

Dr. Johnson explained that BC emission factors vary based on engine type, fuel type, engine load, and measurement methods. A lack of understanding of how BC emission factors vary, and how they can be refined, is stalling efforts to mitigate BC emissions. Thus, one of the focuses of this testing campaign will be to measure BC emission factors using a variety of instruments under various conditions.

Dr. Johnson laid out his team's research approach for laboratory engine bench testing and on-board engine testing. During laboratory testing, the UCR team will evaluate numerous BC instruments and methods, vary engine load and fuel, vary test sample pretreatment/conditioning approaches, and identify recommended practices for future BC testing, including the on-board portion of this testing campaign. For the laboratory testing, the team plans on testing a Detroit Diesel 6-71 N two-stroke, 210 horsepower, 2,100 rpm engine, which is used extensively in smaller marine applications. The team plans on testing three fuel types: marine gas oil (MGO) with <0.1% S; high-sulfur HFO; and low-sulfur HFO (<0.1% S). These are the fuel types that most vessels will use during normal operations (high-sulfur HFO) or while operating in Emission

Control Areas (<0.1% S MDO or HFO). In all cases, emissions will be measured as the engine is operated on the ISO 8178 E-3 test cycle, which is currently used to certify marine engines under the NO_x Technical Code. The E-3 test cycle varies engine load and engine speed to evaluate how emissions change under various operating conditions. In addition, the UCR team will measure BC emissions under very low engine load conditions (10% load), to simulate conditions where a marine vessel might be operating near port in a vessel speed reduction (VSR) zone. The team plans to measure BC emissions using approximately 19 different instruments/methods under three dilution ratios – 1:1, 10:1, and 300:1 to 1000:1. Certain instruments or filters require no dilution (e.g., quartz and Teflon filters and smoke meters). Others require a 10:1 dilution ratio (e.g., MSS, LII, PAX). Some require a much higher dilution ratio of 300:1 to 1000:1 (e.g., MAAP, SP2, Aethalometer). A schematic of the proposed engine test stand arrangement is included as Figure 1.

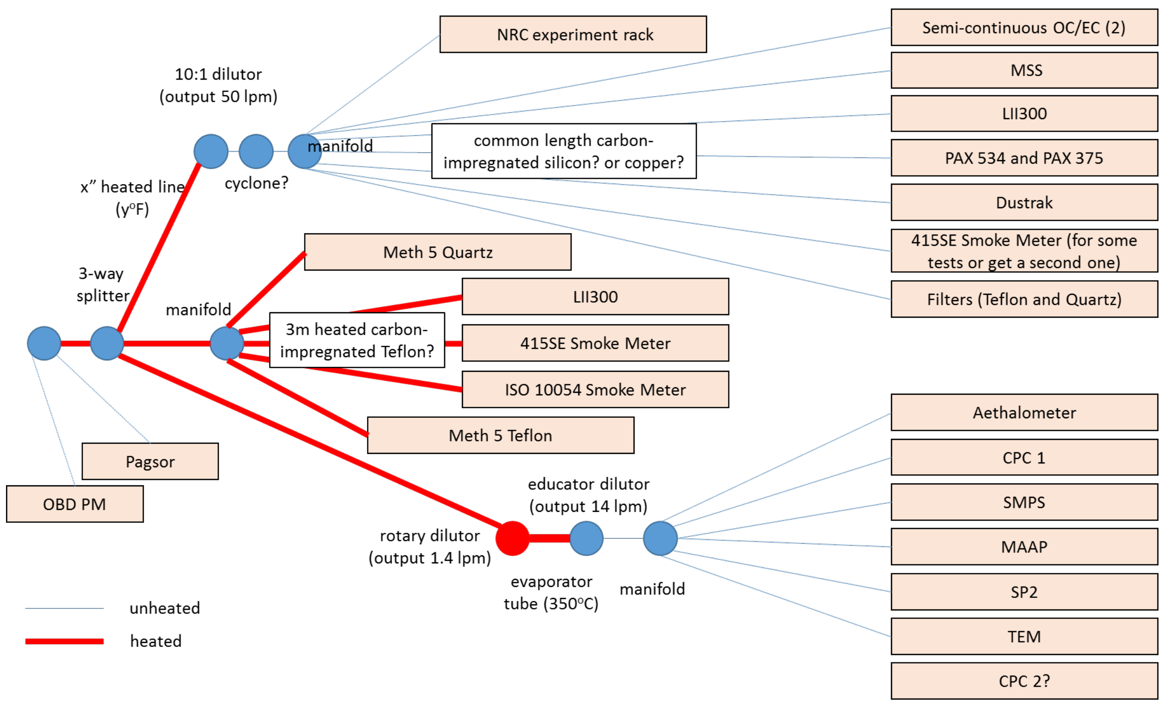

Figure 1. Proposed engine test stand arrangement.

Dr. Thomson explained that NRC-Canada and Environment Canada will also contribute to the laboratory phase of the testing campaign. Transport Canada hopes to support the efforts of NRC-Canada for this project in the future. NRC-Canada will help the UCR team calibrate instruments and compare results across instruments. The goal is to help understand how marine BC emissions do, or do not, change as operating conditions, including fuel and load, change. Additionally, NRC-Canada will help UCR evaluate sample pretreatment/conditioning to help improve the accuracy and precision of results.

After laboratory bench testing, the team will conduct on-board vessel testing. The on-board testing approach may change depending on what is learned from the laboratory testing. For instance, a suitable sample pretreatment/conditioning protocol may be identified in bench testing and then incorporated into the on-board vessel testing. The team plans to measure BC emissions from up to five vessels. The first vessel is a roll-on/roll-off (RORO vessel) with a MAN B&W 21 megawatt (MW) Tier 0 main engine and a 1 MW auxiliary engine. The *Turago* is outfitted with a scrubber that treats exhaust from both the main engine and auxiliary engine. The second vessel is yet to be identified but the preference will be for a newer Tier 1 or better engine to be evaluated. The third, fourth, and fifth vessels are Carnival cruise ships with multiple Wartsila and MAK 8-12 MW engines. They are all outfitted with scrubbers and PM filters. It is not clear how many of these cruise vessels on which the team will be able to measure BC emissions. ICCT and UCR are developing a plan to test as many of the cruise vessels as possible.

The team will measure on-board BC emissions under various fuel types (HFO and MDO), engine loads, and operating conditions. Importantly, they will measure BC emissions before and after exhaust gas treatment technologies (the scrubbers and filters). This will shed light on the BC removal efficiencies of these technologies.

Summary of Workshop Discussions

The second part of the workshop consisted of breakout group and full-group discussions focused on three areas related to marine BC emissions: testing and reporting protocols, instrumentation, and emission factors.

Testing and Reporting Protocols

The goal of the breakout group and full-group discussions on this topic was to work toward consensus on a standardized BC testing and reporting protocol. Workshop attendees with relevant expertise and interest in marine BC testing and reporting protocols participated in a facilitated breakout group to discuss existing and proposed testing and reporting protocols including recent work from Andreas Petzold and colleagues, as well as a BC reporting protocol outlined by EUROMOT (see Appendix C).

The breakout group was asked to identify the key factors necessary for robust and standardized BC testing and reporting protocols. Although there was extensive discussion pertaining to the earlier presentations by experts, the group spent the majority of the session discussing the EUROMOT reporting protocol and there was consensus that the protocol was useful and comprehensive, although group members identified opportunities for refinement. For example, a dedicated section on sample conditioning or pretreatment could be added. However, it was unclear what might be included in such a section, given the apparent dearth of commercially available pretreatment instruments and concerns over the appropriateness of existing ISO protocols (e.g., ISO-8178) as a BC sampling protocol.

One component of the EUROMOT reporting protocol that breakout group participants highlighted as particularly valuable was a place to note engine maintenance status. The group concluded that many researchers may not currently have the means to determine the maintenance state of engines prior to and during on-board testing efforts. As an example of this particular challenge, and the problems it may cause, testing that is done immediately following heavy maintenance may impact the quality of the data collected, as will testing on “outlier vessels” that are kept in prime condition rather than pursuing testing on vessels that are more indicative of the condition of the broader transportation fleet.

The breakout group produced the following **recommendations** and identified a few open questions:

- **Conduct sample conditioning/pretreatment.**
    - Participants agreed that sampling conditioning or pretreatment can help compare BC measurement results across instruments.
    - **Questions:** What initial data can UCR bring forward to inform discussions at PPR-3 pertaining to effective sampling pretreatment?
- **Use a consistent reporting protocol.**
    - Participants agreed that the draft EUROMOT protocol should be identified as a standardized reporting protocol rather than as a standardized measurement protocol.
    - **Questions:** Which factors within the protocol should be prioritized to move toward a standardized measurement approach? Should the prioritization begin with factors that introduce the greatest variability or is another prioritization scheme more appropriate?

On Day 2, the full group was invited to discuss testing and reporting protocols. Participants seemed to agree that the EUROMOT reporting protocol was a good starting point for clarifying how researchers conduct BC emissions testing. However, it became clear that putting forth a standardized BC *testing protocol* was premature. Instead, participants agreed that a *sample pretreatment protocol* should be explored as a means to increase the comparability of different measurement approaches as a first step toward developing a sampling protocol.

The following are the **outcomes** from the full group discussion on BC testing and reporting protocols:

- **The applicability of existing emission measurement protocols should be considered for BC.**
    - The group discussed using existing measurement protocols for particulate matter as a starting point for BC characterization, including ISO 8178. It was clarified that ISO 8178 is only verified for fuels with a sulfur content up to 0.8%, compared to a maximum of 3.5% for marine fuels, and does not specify the key condition of dilution ratios. Several groups are conducting testing using ISO 8178 as a starting point, with modifications (e.g. UCR using a dilution ratio of 10:1 and a reduced transfer line length to limit losses).
- **Sample pretreatment/conditioning is desirable.**
    - Sample pretreatment and conditioning can include dilution and heating. Heating can help remove semi-volatiles that can complicate the precision and comparability of BC testing using different instruments. There are ways to condition the sample using heated inlets, thermal denuders, and catalytic strippers. It was agreed that a literature survey on existing sample conditioning methods was needed and that the results of the survey could help inform the UCR-led BC testing campaign.[2]
- **Accuracy and Precision: Their relative importance varies depending on the goal of the BC testing.**
    - If the goal of the BC testing is engine certification, then *precision* is the priority. However, if the goal of the BC testing is to inform climate or health impact studies, then *accuracy* is the priority.

[2] After the workshop, ICCT contracted Dr. Daniel A. Lack to review the extant literature on sample conditioning methods. Dr. Lack found that either a heated inlet or a catalytic stripper is a good choice for obtaining a consistent sample free of most semi-volatiles. Dr. Kent Johnson of UCR is working to incorporate the findings into the BC testing approach.

  - The upcoming UCR-led BC testing campaign can explore how sample pretreatment/conditioning may influence accuracy and precision.
- **Sampling protocol is the first step toward a standardized testing protocol**.
  - A sampling protocol that is measurement method-neutral could be put forth for discussion at PPR-3 in February 2016. Sample pretreatment/conditioning helps remove of semi-volatiles that affect BC testing results, regardless of the instrument used to measure BC. A sampling protocol could be a first step toward developing a standardized BC testing protocol; however, pretreatment will also increase system losses. The uncertainty introduced by those losses should be characterized.
  - The structure of the testing protocol will be influenced by the purpose of the BC testing (e.g., engine certification, climate effects modeling, health effects modeling, etc.). Further discussion of this topic may be warranted.

Instrumentation

The main goal for this session was to work toward consensus on instruments to be included and evaluated in the upcoming marine BC emissions testing campaign led by UCR. Although there are numerous existing instruments that can be used to measure marine BC – both in terms of light absorption properties as well as their refractory properties – the workshop discussion focused on the following:

<u>Measures Light Absorption of BC</u>

- Aethalometer
- Continuous Soot Monitoring System (COSMOS)
- Filter Smoke Number (FSN)[3]
- Micro Soot Sensor (MSS)
- Multi-Angle Absorption Photometer (MAAP)
- Particle Soot Absorption Photometer (PSAP)

<u>Measures Refractory Properties of BC</u>

- Laser Induced Incandescence (LII)
- Single-particle Soot Photometer (SP2)
- Soot Particle Aerosol Mass Spectrometer (SP-AMS)

The breakout group focused on the following discussion topics:

- Instruments that may be included and evaluated in the upcoming marine BC emissions testing campaign led by UCR.
- Research needed to enable cross-comparison of results obtained by different instruments.

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[3] Smoke number is a general term encompassing a variety of different measurement instruments, some of which measure light extinction rather than absorption. A workshop participant clarified that AVL's Filter Smoke Meter measures absorption by recording back-scattered light from the filter paper and a diffuse reflector behind the filter paper. The participant also noted conditions under which the uncertainties introduced by particle coatings on filter-based absorption methods can be minimized, and concluded that while the FSN method does not directly measure BC mass concentration, it remains relevant for BC measurements as a proxy for equivalent Black Carbon (eBC).

- Performance criteria for instruments suitable for aligned future research on marine BC emissions.

The breakout group produced the following **recommendations** and identified a few open questions:

- **Start with IMO-identified BC testing methods.**
    - Participants agreed that the four methods that are currently identified by IMO should be included in the UCR test approach: Laser Induced Incandescence (LII), FSN, Photoacoustic Spectroscopy (PAS), and Multiangle Absorption Photometer (MAAP). Participants specifically identified the AVL Filter Smoke Meter and the Micro Soot Sensor (MSS) as instruments that should be included.
    - **Questions:** What, if any, additional instruments could be used by UCR for on-board testing? How should the instruments be organized and prioritized?
- **Prioritize test-bench instruments.**
    - Participants recommended prioritizing instruments that will be included in UCR's engine testing into an "A Table" and a "B Table." Instruments on the "A Table" will be prioritized.
- **Limit the number of instruments brought on-board the vessel.**
    - Participants suggested that the researchers should collect Transmission Electron Microsopy (TEM) grids, filters, or any other item that can be analyzed off-board and test them in the lab rather than brining additional instruments on-board. This provides an opportunity to conduct additional research while not overloading the test set-up.
    - **Question:** To avoid overloading the testing area while on board the vessel, are there other data that could be collected on-board that could be subsequently tested offsite?
- **Limit variability in external variables that affect results.**
    - Participants noted that it is often difficult to keep engine conditions constant during on-board testing but that it is imperative to maintain constant conditions throughout any one test. Variability in test conditions can be minimized through open dialogue with the vessel operators to ensure that particular research conditions are maintained throughout testing points – which can include, for example, dedicating one engine to a constant load or avoiding variable ruddering that can impact engine load.
- **Be transparent.**
    - Participants highlighted the importance of transparency throughout the research campaign. Transparency can be ensured by thoroughly documenting assumptions, data processing techniques, algorithms, etc. used from start-to-finish.
- **Focus on identifying instrument performance criteria rather than selecting particular instruments for BC testing.**
    - Participants recommended that researchers select the instruments that they use to measure BC based on their ability to generate precise and/or accurate results rather than selecting instruments *ex ante*. A standardized pretreatment protocol was identified as a promising way to improve comparability across instruments.
    - **Questions:** How should the development of instrument performance criteria be initiated? When? By whom? What is the appropriate venue?

On Day 2, the full group was invited to discuss instrumentation. The following are the **outcomes** from the full group discussion on BC instrumentation:

- **The recommendations of the breakout group ought to be implemented.**

  - The full group agreed with the recommendations of the breakout group outlined above.
- **Setting performance criteria for instruments remains elusive.**
  - Establishing instrument performance criteria remains a "chicken and egg problem." Instruments should be selected based on how the data will be used (e.g. engine certification, climate modeling, health effects modeling, etc.). This is related to the *precision* versus *accuracy* discussion. Possible performance criteria for selecting instruments could include accuracy, sensitivity, dynamic range/allowable dilution range, calibration to a reference material, maintenance requirements, cost, etc. Participants suggested that a separate discussion on performance criteria was warranted but it remains unclear when and where such a discussion ought to occur.
  - If agreement on such performance criteria cannot be reached, an alternative approach could be taken under which researchers work to establish sampling and measurement protocols to ensure that results from various instruments are comparable.

Emission Factors

The main goal for this session was to work toward consensus on the types of marine BC emission factors that are most needed to develop a refined marine BC emissions inventory and to evaluate the effectiveness of BC emissions reduction technologies and strategies. There are large discrepancies in marine BC emission factors used in existing global and Arctic marine BC emissions inventories. Uncertainty about total marine BC emissions has potentially serious policy implications and BC emission factors have a substantial impact on total estimates of marine BC emissions. Emission factors can vary based on a number of factors, including:

- Testing protocol
- Instrumentation
- Vessel type
- Engine type (2-stroke vs. 4-stroke, certification Tier level)
- Engine speed
- Engine load
- Fuel type
- Exhaust gas after treatment system

The breakout group produced the following **recommendations** and identified a few open questions:

- **Recognize and explain that BC emission factors are uncertain.**
  - Group participants spent a substantial portion of the session discussing the availability and reliability of the data relevant for refining the global marine BC emissions inventory. Emission factors have a range of sensitivities to take into account, including low/high load of the engine, low/high torque conditions, propulsion types/systems, weather patterns and currents, exhaust after-treatment installation and usage, and, the age of the engine and maintenance history of the engine.
- **Use (or develop) emission factors that align with the overall purpose of the research.**
  - Participants suggested that the emission factors that are used or developed depend on the overall purpose of the research. Again, this is related to the

accuracy versus *precision* discussion. One overall goal of the research is to produce a refined global marine emission inventory. An *accurate* emission factor is needed for if the inventory is to be used for climate and health effects modeling. Another goal of the research is to support the development of a database that compares the effectiveness of BC control technologies and strategies. This requires a *precise* BC emission factor.
- **Questions:** How does one prioritize the emission factor to be developed? How does one evaluate if the emission factor is accurate and/or precise? How can it be guaranteed that the collection of emission factor data is useful for both developing a realistic emission inventory and for evaluating the effectiveness of BC emission reduction strategies?

On Day 2, the full group was invited to discuss emission factors. The following are the **outcomes** from the full group discussion on BC emission factors:

- **The recommendations of the breakout group ought to be implemented.**
  - The full group agreed with the recommendations of the breakout group outlined above, especially the goal to develop emission factors that are useful for a refined global marine BC emissions inventory (requiring an accurate emission factor). An accurate BC emission factor is an important first step toward understanding the contribution of marine shipping activity to the global BC inventory. An accurate BC emission factor can also be incorporated into geospatial modeling to better understand the potential impacts on human health and sensitive environmental regions (e.g. the Arctic). If BC emissions from marine engines are to be controlled, a precise emission factor will be required to certify the engine and to demonstrate compliance.
- **The UCR team has an opportunity to evaluate what factors influence BC emission factors.**
  - There is uncertainty surrounding how BC emission factors change under various conditions. The UCR team should document how emission factors change as engine load, fuel characteristics (including the Calculated Carbon Aromaticity Index), engine maintenance, etc. changes. Ideally, data could be collected using the EUROMOT reporting protocol.

Next Steps

To ensure the relevance of the workshop outcomes, and to build on the momentum created from the workshop, the hosts and participants identified the following **next steps**:

1. The UCR consortium will integrate feedback from the workshop into their testing protocol in an appropriate manner and welcome additional feedback on the proposed approach.

The UCR consortium will consider modifications to the planned test stand arrangement for the approved research proposal, including:

- Dividing the proposed instruments into an “A Table” and “B Table” to identify which instruments are crucial for the experiment and which instruments are desired but not imperative, ensuring that the high priority research outcomes are achieved.
- Investigating the availability and appropriateness of integrating the COSMOS instrument.

- Determining how to integrate sample conditioning into the bench testing and on-board testing protocols.
- Evaluating whether integrating a 415SE filter smoke meter at multiple dilutions may be appropriate for cross comparisons of BC emission factors.
- Develop a list of important questions related to vessel maintenance history and integrate appropriate elements of vessel maintenance records into research design, testing, and reporting (Note: EUROMOT and the UCR team have already begun collaborating to implement this next step).

2. EUROMOT will continue to consider revisions to their draft reporting protocol based on input received during the workshop.

EUROMOT will also identify how to introduce the refined protocol into the IMO process. Additional feedback on the EUROMOT reporting protocol was welcomed.

3. ICCT, CCAC, and other interested stakeholders will consider conducting a side meeting on instrumentation performance criteria at PPR-3.

Questions remain whether PPR-3 is the appropriate venue for such discussions. Also, February 2016 may be too soon for such discussions to occur.

4. ICCT will consider options to share the outcomes of the workshop with IMO.

It may be appropriate for a CCAC member state to submit an informational paper (INF) to PPR-3.

5. ICCT will post this workshop summary, the final agenda, and speaker presentations on its website.

This information can be found on ICCT's website.

6. ICCT will coordinate and schedule the third and final workshop in the ICCT/CCAC series of BC workshops.

The third workshop will be focused on marine BC control strategies.

Appendix A: Final Workshop Agenda

Agenda

Day 1

Time	Activity	Details
8:30 am	**Shuttle from Hotel Mitland to TNO**	Meet in hotel lobby
9:00-9:30 am	**Registration and Coffee**	
9:30-9:45 am	**Welcome Remarks and Review of Agenda** Leo Kusters, Managing Director of Urbanization, TNO Brigit Gijsbers, Director of Maritime Affairs, IenM Dan Rutherford, ICCT	
9:45-10:00 am	**Summary of Previous Workshop and Background** Dan Rutherford, ICCT	- CCAC project background - Definition of BC - IMO Context
10:00-11:15 am	**Session 1: Current Testing Efforts** Malte Zeretzke, DNV-GL Chiori Takahashi, NMRI Kent Johnson, UC Riverside	- Engine/Vessel Types - Geography - Instruments - Results
11:15-11:30 am	**Break**	
11:30-12:45 pm	**Session 2: Sampling and Measurement Protocols** Ralf Oldenburg, MAN Diesel Torsten Mundt, DNV-GL Dan Lack, fmr. NOAA Bas Henzing, TNO	- Protocols (existing and proposed - Reporting parameters (existing and proposed)
12:45-1:30 pm	**Lunch**	Boxed lunch with options to eat in the botanical gardens
1:30-2:15 pm	**Presentation by ICCT Marine Black Carbon Emissions Testing Project Awardees** Kent Johnson, UC Riverside Kevin Thomson, NRC-Canada	- Proposed protocols - Proposed engines/vessels - Proposed fuel types

2:15-3:45 pm	**Breakout Groups** (concurrent)	Goal: Identify areas of consensus as well as open questions for the larger group to discuss on Day 2
	1) Testing Protocols & Reporting	Set up, temp, dilution, probe, pretreatment, etc.
	2) Instrumentation	Photo-acoustics, LII, Thermal-optical, filter-based including FSN, etc. and their ability to generate useful results to meet CCAC project goals
	3) Emission Factors	BC EFs vary based on a number of factors (engine type, load, fuel, etc.) What engine-, fuel-, etc.-specific EFs are needed for a refined global marine BC inventory?
3:45-4:00 pm	**Break**	
4:00-5:00 pm	**Groups Report Out**	Report out to include larger questions or issues needing more input
5:15 pm	**Shuttle from TNO to Hotel Mitland**	
7:00-10:00 pm	**Group Dinner** Stadskateel Oudaen Oudegracht 99 3511 AE Utrecht	Networking Transportation provided to/from hotel (**shuttle departs hotel at 6:30 pm**)

Day 2

Time	Activity	Details
8:30 am	**Shuttle from Hotel Mitland to TNO**	Meet in hotel lobby
9:00-9:15 am	**Coffee**	
9:15-9:30 am	**Recap of Day 1** Gary Decker, Meridian Institute, Facilitator	Brief review of consensus points and open questions from Day 1
9:30-10:30 am	**Testing Protocols & Reporting Discussion** Gary Decker, Meridian Institute, Facilitator	Outcome: Agreement on protocol to measure BC and report the results for the CCAC project
10:30-10:45 am	**Break**	
10:45-11:45 am	**Instrumentation Discussion** Gary Decker, Meridian Institute, Facilitator	Outcome: Agreement on (types of) instruments that should be used to measure BC for the CCAC project
11:45-12:30 pm	**Lunch**	
12:30-1:30 pm	**Emission Factors Discussion** Gary Decker, Meridian Institute, Facilitator	Outcome: Agree on prioritized EF measurements (speed load, fuel, etc.) to inform an updated marine BC global inventory for the CCAC project
1:30-1:45 pm	**Break**	
1:45-2:30 pm	**BC Emissions Testing Process Start-to-Finish Discussion** Gary Decker, Meridian Institute, Facilitator	Outcome: Agree on a complete BC emissions testing process based on the three discussion sessions
2:30-2:45 pm	**Discussion of Next Steps** Dan Rutherford, ICCT	

2:45-3:00 pm	**Summary and Closing Remarks** Dan Rutherford, ICCT	
3:00 pm	**Adjourn**	
3:15 pm	**Shuttle from TNO to Hotel Mitland**	

Appendix B: Attendee List

Workshop Participants

Name	**Email**	**Organization**
Alyson Azzara	Alyson.azzara@cmts.gov	US Department of Transportation, Committee on the Marine Transportation System (CMTS)
Anne-Marie Svoboda	annemarie.svoboda@rws.nl	Dutch Ministry of Infrastructure and Environment
Bas Henzing	bas.henzing@tno.nl	TNO
Brigitte Behrends	Brigitte.Behrends@marenaltd.com	Marena Ltd.
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Chiori Takahashi	chiori@nmri.go.jp	National Maritime Research Institute (Tokyo, Japan)
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Dan Lack	danielalack75@gmail.com	Fmr. NOAA
Dan Rutherford	dan@theicct.org	ICCT
Dan Yuska	Daniel.Yuska@Marad.dot.gov	MARAD
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Kent Johnson	kjohnson@cert.ucr.edu	UC Riverside
Kevin Thomson	Kevin.Thomson@nrc-cnrc.gc.ca	National Research Council Canada
Malte Zeretzke	malte.zeretzke@dnvgl.com	DNV GL
Monica Tutuianu	Monica.Tutuianu@avl.com	AVL/AT
Morten Winther	mwi@envs.au.dk	Aarhus University
Paul Izdebski	Paul.Izdebski@ec.gc.ca	Environment Canada
Peter Lauer	peter.lauer@man.eu	MAN Diesel & Turbo
Peter Stehouwer	Peter.Stehouwer@sgs.com	SGS

Peter van Velthoven	velthove@knmi.nl	Royal Netherlands Meteorological Institute (KNMI)
Ralf Oldenburg	Ralf.Oldenburg@man.eu	MAN Diesel & Turbo
Sarah Lasselle	Sarah.Lasselle@dnvgl.com	DNV GL
Stefanie Wong-Zehnpfennig	Stefanie.Wong-Zehnpfennig@bmub.bund.de	German Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety
Torsten Mundt	torsten.mundt@dnvgl.com	DNV GL
Vladimiro Bonamin	Vladimiro.bonamin@sgs.com	SGS

Appendix C: Draft EUROMOT Marine Black Carbon Emissions Testing Reporting Protocol

IMO measurement protocol for Black Carbon determination

1. Engine design parameters (to be completed before measurement)

1.1 Engine Production year: ____________
Location: □ Testbed
□ Ship

1.2 Engine total runnig hours ____________ [h]

1.3 Regular maintenance interval ____________ [h]

1.4 Hours since last regular maintenance ____________ [h]
Documentation of relevant maintenance to be provided

1.5 Engine category
□ 4-stroke
□ 2-stroke

1.6 Engine fuel system
□ Diesel
□ Gas
□ Dual fuel

1.7 Engine max. rated power ____________ [kW]

1.8 Mean effective pressure at rated power ____________ [bar]

1.9 Engine speed
□ Less than 130 rpm
□ 130 or more but less than 2000 rpm
□ 2000 rpm or more

1.10 Method of air aspiration
□ Naturally aspirated
□ Pressure-charged single stage
□ Pressure-charged multi stage

1.11 Injection system
□ Conventional
□ Common rail

1.12 Applicable emission limit □ IMO Tier I □ IMO Tier II □ IMO Tier III
□ Others: ____________________________

1.13 Applicable test cycle □ C1 □ D2 □ E2 □ E3
□ Others: ____________________________

1.14.1 Specific lubrication oil consumption SLOC: ____________ [g/kWh]

Breaking-in period:
- □ finished
- □ not finished
- □ not applicable

1.14.2 Cylinder liner lubrication
- □ none
- □ yes, active at
  - □ 100% Feed rate: ____________ [g/h]
  - □ 75% Feed rate: ____________ [g/h]
  - □ 50% Feed rate: ____________ [g/h]
  - □ 25% Feed rate: ____________ [g/h]
  - □ 10% Feed rate: ____________ [g/h]

Breaking-in period:
- □ finished
- □ not finished
- □ not applicable

1.14.3 Inlet valve seat lubrication
- □ none
- □ yes, active at
  - □ 100% Feed rate: ____________ [g/h]
  - □ 75% Feed rate: ____________ [g/h]
  - □ 50% Feed rate: ____________ [g/h]
  - □ 25% Feed rate: ____________ [g/h]
  - □ 10% Feed rate: ____________ [g/h]

1.15 Exhaust gas treatment device □ none □ yes
- □ SCR
- □ Scrubber
- □ EGR
- □ Water injection
- □ Others: ____________________

2. Fuel

2.1 Fuel in use

□ ULSD	□ DMX	□ DMA	□ DMZ	□ DMB	
□ RMA	□ RMB	□ RMD	□ RME	□ RMG	□ RMK

□ Natural Gas
□ Other gases acc. IGF: ____________________

□ Liquid to gas fuel ratio as certified at mode point:
- 100%: ____________
- 75%: ____________
- 50%: ____________
- 25%: ____________
- 10%: ____________

Fuel properties and composition (as used for measurement)

2.2 Gas
Please fill in as far as possible

Property	Unit / Standard	Actual value	Remark
Methane number	[-] / DIN EN 16726		
Lower calorific value	[MJ/kg] / ISO 6976		
Higher calorific value	[MJ/kg] / ISO 6976		
Wobbe Indices Ws / Wi	[MJ/m^3] / ISO 6976		
Density	[kg/m^3] / ISO 6976		
Methane	wt.-% [kg/kg] / ISO 6974 or DIN 51894		
Ethane	wt.-% [kg/kg] / ISO 6974 or DIN 51894		
Propane	wt.-% [kg/kg] / DIN 51894		
Isobutane	wt.-% [kg/kg] / DIN 51894		
N-Butane	wt.-% [kg/kg] / DIN 51894		
Pentane	wt.-% [kg/kg] / DIN 51894		
Hexane	wt.-% [kg/kg] / DIN 51894		
Heptane	wt.-% [kg/kg] / DIN 51894		
Nitrogen	wt.-% [kg/kg] / ISO 6974		
Sulfur	wt.-% [kg/kg] / ISO 6326-5		
Hydrogen sulfide	wt.-% [kg/kg] / ISO 8819		
Carbon dioxide	wt.-% [kg/kg] / ISO 6974		
Hydrogen	wt.-% [kg/kg] / DIN 51894		
Others			

2.3 Liquid fuel
Please fill in as far as possible

Property	Unit / Standard	Actual value	Remark
Kind of fuel	Grade / ISO 8217		
Flash point	[°C] / ISO 2719		
Viscosity @ 40/50°C	[mm^2/s] / ISO 3104		
Density @ 15°C	[kg/m^3] / ISO 3675 or 12185		
Net calorific value (Hu)	[J/g] / DIN 51900		
Sulfur content	ppm [mg/kg] / ISO 8754 or 14596		
Ash content	ppm [mg/kg] / ISO 6245		
Water content	ppm [mg/kg] / ISO 3733		
Carbon content	wt.-% [kg/kg] / ASTM D5291		
Hydrogen content	wt.-% [kg/kg] / ASTM D5291		
Nitrogen content	wt.-% [kg/kg] / DIN 51444		
Oxygen content	wt.-% [kg/kg] / DIN 51732		
Cetane index	ISO 4264		
CCAI			
FAME content	wt.-% [kg/kg] / EN 14078		
Mono aromatic compounds	wt.-% [kg/kg] / EN 12916		
Di aromatic compounds	wt.-% [kg/kg] / EN 12916		
Tri aromatic compounds	wt.-% [kg/kg] / EN 12916		
Poly aromatic compounds	wt.-% [kg/kg] / EN 12916		
Inorganic constituents (V)	ppm [mg/kg] / ISO 14597 or 8691		
Inorganic constituents (Ni)	ICP		
Carbon residues	wt.-% [kg/kg] / ASTM D4530		
Others			

3. Lube oil properties and composition (as used for measurement; Producers specification can be used)

3.1 Circulation lubrication oil
Please fill in as far as possible

Property	Unit / Standard	Actual value	Remark
Lube oil	Brand / Type		
Grade	multi / mono		
BN	mg KOH/g / ISO 3771		
Ash content	wt.-% [kg/kg] / ISO 6245		
Viscosity	[mm^2/s] / ASTM D7042		
Sulfur content	wt.-% [kg/kg] / ISO 20884		

3.2 Cylinder oil
Please fill in as far as possible
Please fill in if applicable

Property	Unit / Standard	Actual value	Remark
Lube oil	Brand / Type		
Grade	multi / mono		
BN	mg KOH/g / ISO 3771		
Ash content	wt.-% [kg/kg] / ISO 6245		
Viscosity	[mm^2/s] / ASTM D7042		
Sulfur content	wt.-% [kg/kg] / ISO 20884		

3.3 Valve seat lubrication oil
Please fill in as far as possible
Please fill in if applicable

Property	Unit / Standard	Actual value	Remark
Lube oil	Brand / Type		
Grade	multi / mono		
BN	mg KOH/g / ISO 3771		
Ash content	wt.-% [kg/kg] / ISO 6245		
Viscosity	[mm^2/s] / ASTM D7042		
Sulfur content	wt.-% [kg/kg] / ISO 20884		

4. Measurement equipment information and parameters (to be completed before measurement)

Measurement instrument

4.1 BC measurement instrument information Type: ______________________
Producer: ______________________

4.2 Measurement principle

□ LII
□ FSN
□ PAS
□ MAAP
□ Others: ______________

4.3 Values reported as

□ EC (thermal) Protocol acc.: ______________
□ rBC
□ eBC
□ FSN
□ Others: ______

4.4 Values reported in unit

□ mg/m_n^3 (wet basis; act. O_2-concentration) H_2O-conc.: ______ [Vol.-% wet]
□ mg/m_n^3 (dry basis; act. O_2-concentration)
□ mg/m_n^3 (dry basis; Ref. O_2-concentration) O_2-conc.: ______ [Vol.-% dry]
□ mg/kWh refer to 5.
□ FSN
□ mg/kg fuel refer to 5.
□ Others: ______________________________

4.5 Reference conditions
(only if 4.4 is referred to Norm-cubic meters [m_n^3])

Norm temperature: ______ [°C]
Norm pressure: ______ [mbar]

4.6 Sampling time / -number

Sampling time of each measurement: ______ [s]
If mean valueas are reported: Number of consecutive measurements at each mode point: ______ [-]

4.7 BC instrument parameter

Temperature inside measuring cell: ______ [°C]
Pressure inside measuring cell: ______ [mbar]
Repeatability of the instrument used ______
Reproducibility of the instrument used ______
Other parameters which could influence the measured values:

Parameter	Unit

4.8 BC Instrument Calibration	Date of last calibration: (dd.mm.yyyy) Calibration procedure acc. manufacturer recommendations: □ yes □ no □ Others: □ Others: ______ Calibration including zero point: □ yes □ no Used medium for zero point calibration: ______ Used calibration standard: □ Synthetic flame soot □ Printex-U □ Graphite spark aerosol generator GfG soot □ Soot with inorganic coatings □ Soot without inorganic coatings □ Reflectance standards □ Others: ______ Remark: ______ Leakage test performed before or after calibration: □ yes □ no □ not applicable
4.9 Exhaust gas dilution	Exhaust gas dilution: □ no □ yes Dilution ratio (1:x) at mode point: ______ [-] ______ [-] ______ [-] ______ [-] ______ [-] Dilution medium: □ Ambiet air □ Exhaust gas □ Others: ______ Filtration of the dilution medium before dilution: □ yes □ no Temperature of the dilution medium: ______ [°C] Temperature of the diluted exhaust gas: ______ [°C]
4.10 Sample flow rate/volume	Sample flow rate of the raw exhaust gas: ______ [l/min] Sample flow rate of the diluted exhaust gas: ______ [l/min] Sample volume of the raw exhaust gas: ______ [l] Sample volume of the diluted exhaust gas: ______ [l] □ subkinetic □ isokinetic □ superkinetic □ not applicable

Sample line and probe

4.11 Sample/transfer line

Use of a sample line: □ no (in situ,…)
□ yes

Length of the sample line: ____________ [m]

Heated sample line: □ no
□ yes Temperature: ___________ [°C]

Sample line material: ____

Inner diameter of the sample line: ____________ [mm]

Isolated or heated connections between sample line, measurement instrument and probe: □ yes □ no

Electrical conductive (sample line material): □ yes □ no
Grounded: □ yes □ no
Earthing method: ____

Backflushing sample line between measurements: □ yes □ no

4.12 Sample probe

Use of sample probe: □ yes □ no (in situ,…)

Material: □ Stainless steel □ Others: ______________________

Type/design:
□ Probe with single hole at the end (pipe)
□ Probe with single hole at the end (45° beveled)
□ Multi-hole
□ L-shaped pipe with single hole, opening shielded with preclassifier (e.g. hat)
□ Others: ____
____

Direction of the probe opening relative to the exhaust gas flow:
□ Against flow
□ With flow
□ Others: ____
____

Effective cross section of sample hole opening(s) ___________ [mm]
Backflushing sample probe between measurements: □ yes □ no

Sampling point/probe location

4.13 Sample probe location

Location:
- □ Engine Outlet
- □ Downstream heat exchanger
- □ Downstream exhaust gas treatment device
- □ Others: ____________________

Distance between engine outlet and sampling point: __________ [m]

Diameter of the exhaust gas pipe: __________ [m]

Type of exhaust gas pipe where the sample probe is located:
- □ straight part of the exhaust gas pipe
- □ bent part of the exhaust gas pipe

Immersion depth of the sample probe: __________ [m]

Position of the exhaust gas pipe where the sample probe is located:
- □ horizontal
- □ vertical
- □ Others: ____________________

Length of straight part of the exhaust gas pipe,
if sample probe is located at straight part of the exhaust gas pipe:
upstream sample probe: __________ [m]
downstream sample probe: __________ [m]

Exhaust gas pulsation at the sampling point during measurement:
□ no □ yes __________ [mbar]

5. Determination of engine load, exhaust gas flow, fuel mass flow, exhaust water content, CO_2 and O_2 (if applicable)

5.1 Determination of values, instrument performance and calibration have to be in accordance with the requirements of NTC 2008 and its applicable appendices

5.2 Estimated accuracy of engine load determination: __________ [+/-%]

5.3 Estimated accuracy of exhaust gas flow determination: __________ [+/-%]

5.4 Estimated accuracy of exhaust gas water content determination: __________ [+/-%]

6. Measured values for BC determination (to be completed during measurement; measured values)

Date of measurement (dd.mm.yyyy)						

Engine parameters

Measurement at mode points:						[%]
	↓	↓	↓	↓	↓	
6.1 Stabilized mode point						
Actual Speed						[rpm]
Speed variation during measuring						[+/-%]
Actual Load						[kW]
Load variation during measuring						[+/-%]
6.2 Charge air temperature						[°C]
6.3 Charge air pressure						[mbar]
6.4 Exhaust gas temp. at engine outlet						[°C]
6.5 Exh. gas temp. at sampling point						[°C]

(only if there is a significant difference to the exhaust gas temperature at the engine outlet)

6.6 Exhaust gas back pressure						[mbar]
6.7 Exhaust gas mass flow						[kg/h]

Ambient conditions

6.8 Ambient temp. at engine inlet						[°C]
6.9 Ambient pressure at engine inlet						[mbar]
6.10 Absolute humidity of ambient air						[g/kg]

Black Carbon emission						
Estimated accuracy of BC-measurement						[+/-%]

Reported as (see 4.3): ____________

Unit (see 4.4): ____________

Remark: