Informal document no. 20
47th Session of Working Group on Strategies and Review

Draft Report of the Ad-Hoc Expert Group on Black Carbon

Introduction

1. This report was prepared by the Co-chairs in collaboration with experts from across the CLRTAP Parties and other invited experts. The Black Carbon Expert Group had representation from Belgium, Canada, Denmark, Estonia, Finland, France, Germany, Ireland, Italy, Netherlands, Norway, Russia, Slovenia, Spain, Sweden, Switzerland and the United States. Additional participants included representatives from the United Nations Economic Commission for Europe, Joint Research Centre - European Commission, European Environmental Bureau, experts from the EMEP Center for Integrated Assessment Modelling, the EMEP Task Force on Measurement and Modelling, the EMEP Task Force on Emission Inventories and Projections, the EMEP Task Force on Hemispheric Transport of Air Pollution, and the Expert Group on Techno-economic Issues.

2. This report has five main objectives: (a) to articulate the rationale for addressing near-term and regional/Arctic climate change impacts of air pollution along with impacts on human health and ecosystems under the Convention; (b) to summarize the current work on black and organic carbon by Parties under the Convention; (c) to assess current black and organic carbon emissions information available for Parties to the Convention, particularly for key sectors; (d) to identify priority black carbon emission reduction opportunities in the UNECE region and the associated costs, implementation feasibility, and potential health, ecosystem, and near-term climate benefits of these measures; and (e) to identify the scientific and technical requirements, as well as non-technical measures, needed for implementing options to reduce black carbon and evaluate progress over time.

3. Black carbon (BC) is a light-absorbing carbonaceous particle produced by incomplete combustion of various fuels. BC contributes significantly to global warming by directly absorbing sunlight and to regional warming by darkening ice and snow. Direct BC warming is large at the global (and regional) scale.[1] [2] Immediate climate benefits of BC mitigation are possible due to its short atmospheric lifetime and offer one of the few pathways for achieving near-term climate impacts.

4. Because BC is emitted in varying amounts with other pollutants (e.g., other aerosols, greenhouse gases, toxic air pollutants) that also may impact climate in different ways as well as public health, BC mitigation measures must be evaluated in a way that recognizes the impacts of these co-emitted pollutants.

5. Many terms are used, often interchangeably, to describe the light absorbing subset of particulate matter. Soot, elemental carbon, refractive carbon, and black carbon are all used to describe these particles, but there remains no universal definition or means of identifying exactly which subset of aerosol particles are of concern when addressing climate change. For the purposes of this report, black carbon is synonymous with elemental carbon. Recent studies suggest that there is likely a larger group of aerosols – sometimes referred to as ‘brown carbon’ or ‘light absorbing carbon’ – that may have an influence on climate and

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[1] V. Ramanathan and G. Carmichael, *Global and regional climate changes due to black carbon*, 1 Nature Geoscience 221-22 (23 March 2008)
[2] Jacobson, M.Z. Strong radiative heating due to the mixing state of black carbon in atmospheric aerosols. *Nature* 409, 695-697 (2001)

public health.[3] **The work to define and establish measurement techniques for the entire suite of light-absorbing aerosols goes beyond the scope of this Expert Group, but should be encouraged or mandated by the Executive Body.**

Rationale

6. Controlling the emissions of black carbon will result in significant health benefits as well as climate benefits, especially in sensitive regions such as the Arctic. While the magnitude of the net effects of black carbon's direct and indirect radiative forcing on the global climate is subject to some uncertainty, there is emerging consensus regarding the regional influence of black carbon on areas of snow and ice. [4] [5] [6] [7] Combined, the regional climate impacts and the known health benefits to reducing particulate matter justify the Executive Body of the CLRTAP considering options to mitigate black carbon as a component of PM when making revisions to the Convention's 1999 Gothenburg Protocol.

7. **Impact on Climate - Direct Radiative Forcing of Black Carbon:** One of the ways BC impacts climate is by directly absorbing incoming solar radiation. Estimates of this effect vary from the IPCC estimate of 0.2 (/- 0.15) [8] W m–2 to a high of 0.9 [9] W m–2 (with a range of 0.4 to 1.2 W m–2). Black carbon, together with tropospheric ozone, and methane, may contribute to Arctic warming to a degree comparable to the impacts of carbon dioxide, though there remains considerable uncertainty regarding the magnitude of their effects.[10] Because of the combination of high absorption, a regional distribution roughly aligned with solar irradiance, and the capacity to form widespread atmospheric brown clouds in a mixture with other aerosols, current estimates suggest BC is the second or third strongest contributor to current global warming.[11] [12]

8. **Impact on Climate – Indirect Radiative Forcing of Black Carbon:**
The success of BC emission control in reducing climate warming globally depends on the combination of the direct and indirect (and also semi-direct) effects and the resulting change in net global radiative forcing. While the BC direct effect is generally thought to be warming, there remains high uncertainty in estimates of indirect effect changes associated with BC control due to the complexity of aerosol-cloud-climate interactions. A general scientific consensus is currently missing on the overall global climate effect of BC emission control strategies. At the time this report was developed, a concurrent effort to more systematically outline what is known and not known regarding the direct, indirect and semi-indirect effects was concurrently underway. The EB should look to this effort, referred to as "Bounding the Role of Black Carbon in Climate" when published. .

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[3] M. O. Andreae and A. Gelencs´er: Black carbon or brown carbon? Atmos. Chem. Phys., 6, 3131–3148, 2006 www.atmos-chem-phys.net/

[4] Qian et al. 2009
[5] Hadley et al. 2010
[6] Xu et al. 2009
[7] Flanner et al. 2009
[8] IPCC, *Changes in Atmospheric Constituents and in Radiative Forcing*, in CLIMATE CHANGE 2007: THE PHYSICAL SCIENCE BASIS, CONTRIBUTION OF WORKING GROUP I TO THE FOURTH ASSESSMENT REPORT OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE
[9] V. Ramanathan and G. Carmichael, *Global and regional climate changes due to black carbon*, 1 NATURE GEOSCIENCE 221-22 (23 March 2008)
[10] AMAP / Quinn et al., 2008. The Impact of Short-Lived Pollutants on Arctic Climate. AMAP Technical Report No. 1 (2008), Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway.
[11] Chen et al. Will black carbon mitigation dampen aerosol indirect forcing? GRL, 37,2010
[12] Bauer et al. A global modeling study on carbonaceous aerosol microphysical chacarcteristics and radiative forcing. ACPD, 10, 2010).

9. **Arctic Effects:** Climate processes unique to the Arctic have significant effects on global and regional climate. The IPCC noted nearly 10 years ago that changes in the Arctic have already taken place. These changes are not modeled future scenarios, but rather real changes happening in real time. They include unusual melting of glaciers, sea ice, and permafrost, and shifts in patterns of rain and snow fall, freshwater runoff, and forest/tundra growth. The consequences include disrupted wildlife migration patterns, altered fish stocks, modified agricultural zones, and increased forest fires.

   a. The Arctic continues to warm more rapidly than any other part of the globe. This rate of Arctic warming is significant, because it means that action must be taken in the very near term to reduce the scale of warming in comparison to other areas of the globe. Though the precise magnitude of regional warming that can be attributed to BC is still very uncertain, some estimates suggest that BC may have contributed as much as 50% of 1.9 C warming in Arctic since 1890.[13]

   b. A recent report to the IMO's Marine Environment Protection Committee suggests that BC emission from shipping in the Arctic may increase by a factor of two to three by 2050. With BC constituting between 5%-15% of shipping particulate emissions,[14] this is a source category that merits more attention.

   c. As a result of these changes, indigenous groups who depend on subsistence hunting and gathering practices are at risk. Risks include declining food security due to decline of marine and land wildlife species, reduced quality of other food sources such as wild berries and fish, disrupted land traffic due to infrastructure damage from melting permafrost and forced relocation due to increased coastal erosion.[15]

10. **Rate of Change is Critical:** While the impacts identified above are significant, it is important to consider them in the context of time. This is climate change that is happening now, literally under the feet of indigenous populations and others who live in the Arctic. What is unique about the current changes is the rate at which these temperature changes – and the other ecosystem changes that follow – are occurring. This rate of change has not been observed over the last few thousand years.[16]

    a. International action to reduce carbon dioxide (CO_2) cannot prevent these dramatic changes to the Arctic in the near term[17], therefore additional complementary short-term strategies must be devised. Because of the dual role of BC in regional Arctic climate - atmospheric warming and its effect of darkening and melting snow and ice - reducing BC offers one pathway toward mitigating these effects. Recent studies suggest that black carbon emitted in and near the Arctic has a stronger influence on Arctic warming and melting than emissions outside this region.[18]

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[13] Shindell, D., and G. Faluvegi, 2009: Climate response to regional radiative forcing during the twentieth century. Nature Geosci., 2, 294-300

[14] Lack, D., et al. (2009) "Particulate emissions from commercial shipping; chemical, physical and optical properties." J. Geophysical Research, 114, D00F04, doi:10.1029/2008JD011300.

[15] ACIA Impacts of a Warming Arctic: Arctic Climate Impact Assessment Cambridge University Press, 2004 http://www.acia.uaf.edu

[16] Polyak et al., History of Sea Ice in the Arctic, Quaterary Science Reviews, 2010

[17] AMAP / Bluestein et al., 2008. Sources and Mitigation Opportunities to Reduce Emissions of Short-term Arctic Climate Forcers. AMAP Technical Report No. 2 (2008), Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway

[18] Quinn, P. K., Bates, T. S., Baum, E., Doubleday, N., Fiore, A. M., Flanner, M., Fridlind, A., Garrett, T. J., Koch, D., Menon, S., Shindell, D., Stohl, A., and Warren, S. G.: Short-lived pollutants in the Arctic: their climate impact and possible mitigation strategies, Atmos. Chem. Phys., 8, 1723-1735, doi:10.5194/acp-8-1723-2008, 2008

b. As the EB considers taking action, it is critical to think in terms of the time scale in which these impacts are occurring, the rate at which change is expected to occur in the future, and the near immediate effect BC reductions will have. Mitigation of long-lived greenhouse gases is critical, but the benefits accrue over a much longer timescale. In the long term, reducing greenhouse gas emissions will be necessary because even if BC is eliminated, Arctic warming would still occur, at a rate significantly greater than the global mean, due to ongoing emissions of other greenhouse gases.[19]

11. Sea ice extent and volume have been declining steadily over the past decades at a rate not seen in thousands of years. As a result, the Arctic may be free of summer sea ice as soon as 2040.[20] While single events cannot be directly attributable to climate change, or in this case black carbon, it is important to note the 2010 rate of decline from April to mid-June was the fastest ever recorded in the satellite record, and for six weeks in May-June was the lowest ever recorded for that period, below the record 2007 measurements. The 2010 minimum sea ice extent, reached on September XX, was [PLACEHOLDER FOR UPDATE][21]

12. **Other Climate Impacts:** The climate impacts of aerosols (including but not limited to BC) more generally are not limited to temperature impacts, but also include contributing to changes in rainfall patterns, contributing to rainfall suppression, reducing surface water evaporation, changing the properties of clouds and even creating a positive feedback loop that worsens air pollution episodes. The way black carbon acts by absorbing incoming solar radiation at the top of the atmosphere (TOA) also has the effect of limiting the amount of solar radiation that reaches the earth's surface (sometimes called surface dimming). The effect of this TOA heating and surface dimming is to stabilize the boundary layer, making air pollution episodes worse, and perhaps affecting rainfall. Surface dimming may also negatively impact agriculture.[22]

13. **Human Health Impacts:** While no single constituent of particulate matter has been linked to specific health outcomes, there is significant scientific consensus that fine particles are associated with a range of significant adverse health effects. Many scientific studies have linked levels of $PM_{2.5}$ to a series of significant health problems, including: premature death in adults with heart and lung disease; heart attacks; low birthweight; childhood pneumonia; chronic respiratory disease (e.g. bronchitis); aggravated asthma and other respiratory symptoms (e.g., coughing, wheezing). BC, a primary pollutant, has been associated with respiratory[23] and cardiovascular[24] health effects. Nevertheless, as no single component of $PM_{2.5}$ is known to be *primarily* responsible for health effects, neither can any component be eliminated from consideration. Because BC is never emitted in isolation, but rather as a component of PM, mitigation strategies to reduce the emissions of primary PM will often, but not always, have some co-benefit of reducing BC. This is because not all reductions in PM reduce BC to the same extent.

    a. The most recent report of the CLRTAP Joint Task Force on the Health Aspects of Air Pollution observed that many epidemiological studies confirm that chronic exposure increases mortality and morbidity (heart disease, stroke, respiratory diseases) in the general population. This research confirmed and strengthened the conclusions of the WHO Air Quality Guidelines — Global Update 2005.[25]

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[19] Holland, M.M. and C.M. Bitz, 2003: Polar amplification of climate change in coupled models. Clim. Dynam., 21, 221-232.
[20] Polyak et al., History of Sea Ice in the Arctic, Quaterary Science Reviews, 2010
[21] June 8 Update from the US National Snow and Ice Data Center http://nsidc.org/arcticseaicenews/index.html
[22] V. Ramanathan & G. Carmichael, Nature Geoscience 1, 221 - 227 (2008)
[23] N. Kulkarni et al., N Engl J Med 355, 21-30 (2006).
[24] A. Peters et al., Epidemiology, 1, 11–17 (2000)
[25] Advance copy Effects of Air Pollution on Health Report by the Joint Task Force on the Health Aspects of Air Pollution http://www.unece.org/env/documents/2010/eb/wge/ece.eb.air.wg.1.2010.11.pdf

b. The 2009 Integrated Science Assessment by the USEPA concluded that the relation of mortality and cardiovascular effects with short- and long-term exposure to $PM_{2.5}$ is causal. [26]
c. A recent USEPA analysis demonstrated that, because primary $PM_{2.5}$ tends to affect populations living in close proximity to these sources, emission control strategies that reduce primary particles will produce the greatest health benefits on a per ton basis as compared to strategies that reduce $PM_{2.5}$ precursors.[27]

14. **Effect of Current Air Quality Strategies**: Much of the global air quality community has focused attention on the emissions of sulphates because of the importance of this pollutant for public health and ecosystem protection. Because sulphates reflect incoming solar radiation, it produces a mostly cooling effect. This cooling has been hiding (or masking) the real levels of anthropogenic climate change. It is imperative that the global community continue the important work of improving public health by cleaning the air, but do so now in a way that is also beneficial for climate. **This means that health driven reductions in "climate cooling" pollutants (e.g., sulphates) need to be matched by health driven reductions in "climate warming" pollutants (e.g., black and brown carbon) to mitigate current effects of air pollution efforts inadvertently unmasking hidden man-made warming.**[28] [29] [30]

15. **Importance of the Emission Mixture:** BC is co-emitted with a range of other pollutants during combustion of fossil fuel and biomass burning. Depending on the emission source, BC may be a smaller or larger fraction of the total PM directly emitted. Co-emitted pollutants also include CO, NMVOC, methane and ozone precursors that affect climate forcing and have relatively short lifetime. Current emission inventories do not appropriately characterize the BC fraction of the PM inventory, especially its spatial and temporal heterogeneity. When understanding the overall climate impacts of any control measure, it is important to understand the location and type of the source and the characteristics of all the co-emitted pollutants. For example, BC's warming effect can be offset to varying degrees by cooling from reflective pollutants emitted by the same source, especially organic carbon (OC). BC warms much more than OC cools, per ton [31] [32] and in an internal mixture is expected to exert an increased warming effect.[33] The ratio of OC to BC and emissions of other climate forcers varies greatly by source sector.

16. It is important to note that organic carbon is also a larger component of $PM_{2.5}$ than BC, and as such is associated with significant adverse health effects. Additionally, some OC components, such as PAHs, have been indicated as potentially toxic. It is also noteworthy that over highly reflective surfaces such as ice and snow, even OC and sulphates are "warming" because they are less reflective than the surface below. As a result, some sources and aerosol mixtures that might be cooling in other regions result in warming over the Arctic and Alpine regions.

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[26] U.S. EPA. Integrated Science Assessment for Particulate Matter (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-08/139F, 2009.
[27] Fann et al., *Air Quality, Atmosphere & Health*, Volume 2, Number 3 / September, 2009
[28] M.V. Ramana et al., Warming influenced by the ration of black carbon to sulphate and the black carbon source, *Nature* Geoscience, Published online 25 July 2010.
[29] Kloster et al, A GCM study of future climate response to aerosol pollution reductions Climate Dynamics, 34, 2010
[30] Raes and Seinfeld New Directions: Climate change and air pollution abatement: A bumpy road. Atmospheric Environment, 43 (32). pp. 5132-5133. ISSN 1352-2310
[31] Saathoff, H., K. -H Naumann, M. Schnaiter, W. Schöck, O. Möhler, U. Schurath, E. Weingartner, M. Gysel, and U. Baltensperger. 2003. Coating of soot and (NH4)2SO4 particles by ozonolysis products of α-pinene. Journal of Aerosol Science 34, (10): 1297-1321.
[32] Lesins, G., P. Chylek, and U. Lohmann. 2002. A study of internal and external mixing scenarios and its effect on aerosol optical properties and direct radiative forcing. Journal of Geophysical Research D: Atmospheres 107, (9-10): 5-1
[33] Chung, S. H., and J. H. Seinfeld (2002), Global distribution and climate forcing of carbonaceous aerosols, *J. Geophys. Res.*, 107(D19), 4407, doi:10.1029/2001JD001397

17. A recent study[34] suggests that in addition to the importance of the BC/OC ratio, control strategies should also consider the black carbon to sulphate ratio. This is because black carbon absorption is offset by the strongly reflecting sulphate. This is also shown in their observations where solar absorption efficiency increased with an increasing BC to sulphate ratio. However, the BC absorption may be amplified if it mixes over time in the atmosphere with sulphates.[35] The Ramana et al. study also concluded that fossil-fuel-dominated black-carbon plumes were approximately 100% more efficient warming agents than biomass-burning-dominated plumes.

18. Many constituents of primary PM and precursors of secondary PM impact the climate. Even after it is emitted, BC mixes with other pollutants and ages in the air. Understanding this complex chemistry and how it impacts global and regional climate is one of the largest areas of uncertainty associated with BC mitigation and climate change. The limitations in our understanding about the mixtures and their influence point to the need for better measurement data and needed investments in emission characterization activities. ***There is general consensus that mitigation of BC will lead to positive regional impacts via reduction of BC deposition on snow and ice, though uncertainties remain in the understanding of global impacts. These limitations do not, however, minimize the need for mitigation activities in the near term.***

19. **Short Atmospheric Residence Time – Known Controls:** The fact that BC stays in the atmosphere for a few days to a few weeks makes it an ideal candidate for fast climate mitigation strategies. Such strategies do not supplant the need for ambitious reductions in carbon dioxide and other greenhouse gases. Rather, fast mitigation strategies offer the only real opportunity to reduce the near-term climate effects being felt in sensitive regions of the global right now. The short atmospheric residence time combined with the suite of known, and often cost-effective, control measures offers a viable path forward for climate that will also reap significant health benefits in the regions investing in mitigation measures.

20. **A Note About Metrics:** There is a strong desire to put the effects of black carbon into a framework to compare and contrast with the effects and influence of CO_2. ***To do so, detracts from the science and policy case that can be made for taking action to reduce black carbon in its own right.*** At this time, there are several efforts to develop new metrics that will capture the unique aspects and regional dimension of short-lived climate forcers. None of these metrics has evolved to the point of widespread acceptance. This report will reference existing metrics that were developed to describe the climate impacts of long-lived greenhouse gases, recognizing that they are ill-suited to the task of describing the impacts of a short-lived forcer such as black carbon.

21. **Role of the Gothenburg Protocol:** ***There are clear environmental benefits to reducing emissions of BC. Given this fact and that no other international forum shares the stature and success of CLRTAP in negotiating and achieving real emission reductions in air pollutants, the Executive Body should engage in active consideration of the options for action presented in this report.***

Summary of Current Activity

22. Current work on black and organic carbon by Parties under the Convention: Activities related to black carbon are taking place in several countries across the CLRTAP Region. The level of activity varies, but includes increased monitoring, country-specific research on emission characterization and inventories, and consideration of black carbon specific control strategies. There will be some overlap between all these

[34] M.V. Ramana et al., Warming influenced by the ration of black carbon to sulphate and the black carbon source, *Nature* Geoscience, Published online 25 July 2010.
[35] Jacobson, M.Z. Strong radiative heating due to the mixing state of black carbon in atmospheric aerosols. *Nature* 409, 695-697 (2001)

efforts, but each may contribute more refined information on various aspects of black carbon's role in climate change. At this time, however, it is not anticipated that the outcome of any of these reports would fundamentally change the direction of the recommendations of this Expert Group. (consider attachment with more detailed summary of assessments to capture similarities and differences – see example sent as separate Excel Spreadsheet)

a. *LRTAP Task Force on Hemispheric Transport of Air Pollution 2010*: The Task Force, co-chaired by the European Commission and the US, is developing an assessment report to be completed in 2010. The assessment report will describe the current state of knowledge with regard to the intercontinental transport of aerosols (including black carbon) and their precursors, ozone and its precursors, mercury, and persistent organic pollutants across the Northern Hemisphere. The assessment will discuss the human health, environmental damage, and radiative forcing impacts of these pollutants.
b. *EUSAAR (European Supersites for Atmospheric Aerosol Research):* the EUSAAR FP7 project pursues the integration –through validation and harmonization– of measurements of atmospheric aerosol properties, including organic carbon, elemental carbon, and light absorption, in a network of 20 high quality ground-based stations distributed across Europe. This integration contributes to a sustainable and reliable operational service in support of policy issues on air quality, long-range transport of pollutants and climate change.
c. *EMEP (European Monitoring and Evaluation Program) Monitoring Strategy for 2010-2019:* Adopted in 2009 (ECE/EB.AIR/GE.1/2009/15), the strategy outlines monitoring obligations for EMEP Parties following a level approach where a basic programme is required at about 100-150 sites across the EMEP domain (level 1 monitoring) and where a subset of sites undertake a more comprehensive programme addressing various topics (level 2 monitoring). Measurement requirements at Level 2 for aerosols include determination of elemental and organic carbon in PM10, aerosol absorption, aerosol scattering, aerosol size distribution, aerosol optical depth and mineral dust. It should be noted the Directive 2008/50/EC also requires monitoring of EC/OC in PM2,5 at rural sites, and that Parties may implement these requirements at EMEP monitoring sites to ensure synergies.
d. *USEPA Report to Congress*: This report is due in April 2011 and will address terminology and measurement aspects of black carbon and other light absorbing carbonaceous aerosols (LACs), inventory major sources of black carbon, assess the impacts of black carbon on global and regional climate, assess potential metrics and approaches for quantifying the climatic effects of black carbon emissions (including its regional radiative forcing and warming effects) and comparing those effects to the effects of carbon dioxide and other greenhouse gases, identify most cost-effective approaches to reduce black carbon emissions and analyze the climatic effects and other environmental and public health benefits of those approaches.
e. *United Nations Framework Convention on Climate Change (UNFCCC):* Black carbon has so far not been part of the work under the UNFCCC. The Federated States of Micronesia made a submission to the Ad Hoc Working Group on Long-term Cooperative Action under the UNFCCC. That submission included a proposal to develop a work programme on black carbon reductions as well as other possibilities for rapid climate mitigation to complement long-term climate mitigation (http://unfccc.int/resource/docs/2009/awglca6/eng/misc04p02.pdf). The proposal has not received much attention in the negotiations to date, but elements of it are still on the table in the negotiating process.

23. Current work by external bodies

a. *Arctic Council Task Force on Short Lived Forcers Report on Black Carbon*: This task force, co-chaired by US and Norway, is charged with recommending key BC mitigation strategies for the Arctic Council Ministers to consider at their next high-level meeting in April 2011. The task force will leverage scientific information to inform how different mitigation strategies may benefit the

Arctic. The primary focus will be on those emission sources within the 8 Arctic Council countries. However, the task force may consider recommendations regarding significant emissions sources that appear to be entering the Arctic from non-Arctic regions. It is expected that there will be new analysis coming from this effort that is expected to better refine what is known about sources, emissions and Arctic impacts.

b. *UNEP Assessment of Black Carbon and Tropospheric Ozone*: This assessment, staffed by the Stockholm Environment Institute, will address the climate change, public health, and ecosystem impacts of measures to decrease global concentrations of black carbon and tropospheric ozone. A final report to the UNEP Governing Council is anticipated in early 2011 following several working meetings. The report is expected to summarize the state of the science related to climate and public health impacts of these pollutants, and to identify a clear suite of technical and non-technical options for different regions of the world, including mechanisms for international action.

c. *International Maritime Organization Issue Paper:* In January 2010, Norway, Sweden and the United States submitted for consideration by the IMO Marine Environment Protection Committee (MEPC) a document that outlined several potential initial proposals for action to reduce BC emissions from shipping that impact the Arctic. General options suggested include various approaches to reduce fuel consumption, alternate power technologies, diesel particulate filters, and other technologies. The proposal will be considered at the MEPC meeting 27 September – 1 October.

<u>Emission Inventories</u>

24. Understanding the emissions of black carbon is needed for well-designed mitigation strategies capable of achieving both climate and public health benefits. As demonstrated in figure 1, there is some disparity between existing BC inventories. ***Improving emission inventories will enable the Parties to both identify the most efficient path forward and identify sources that may be under-reported or missing from known inventories.***

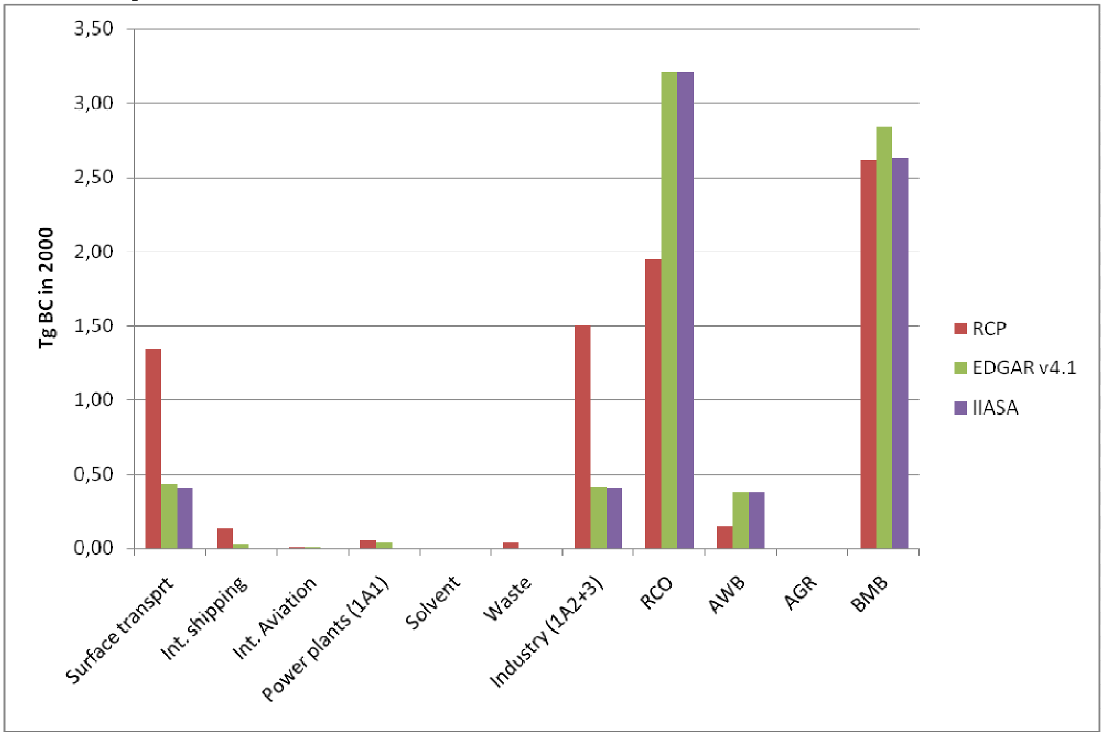

Figure 1. Comparison of global inventory for BC from GAINS, EDGARv4,1, IPCC Reference Concentration Pathways (RCO: Residential ?; AWB: Ag Waste Burning; AGR: Agriculture; BMB: Biomass Burning

Comment [sjt1]: Need Acronyms

25. Mitigating the impact of BC and co-emitted pollutants depends on understanding the emission sources of these pollutants and the effectiveness of any given control strategy on those emissions. To properly understand these impacts, it is imperative for the Parties to have robust emission inventories. The parties to the Convention do not have an obligation to report BC emissions and there are only a few national BC inventories currently available.
   a. The GAINS model (developed at the International Institute for Applied Systems Analysis (IIASA) in Laxenburg, Austria; (http://gains.iiasa.ac./gains)) is being further developed by the EMEP Center for Integrated Assessment Modelling (CIAM), hosted by IIASA, to include estimates of black carbon (and organic carbon).
      i. The research version of the carbonaceous module has been in use since 2004.[36 37] By the end of 2010 it is envisaged that the on-line version of the GAINS model including carbonaceous aerosols will be available and used for estimating the country or region specific emissions and mitigation potential. This first public release will include the results of the ongoing interaction with the national experts within the mandate of the CLRTAP Ad-hoc Expert Group on Black Carbon.
      ii. The GAINS model covers nearly all (51 of 56) of the UNECE member countries.

[36] Kupiainen, K. and Klimont, Z. (2007) Primary emissions of fine carbonaceous particles in Europe. Atmospheric Environment, 41/10, 2156-2170, doi:10.1016/j.atmosenv.2006.10.066.
[37] Kupiainen, K. and Klimont, Z., 2004, Primary Emissions of Carbonaceous Particles in Europe. In: P. Dilara, M. Muntean and E. Angelino (ed.) Proceedings of the PM Emission Inventories Scientific Workshop: 47-52. European Commission, Joint Research Centre, Ispra, Italy.

1. The current activity data for the UNECE countries is based on the work done under the ongoing revision of the Gothenburg Protocol; 16 countries provided updates of the national energy balances and projections so far while for the remaining countries either PRIMES 2008 model scenario or IEA WEO 2009 scenario is used.

b. The EDGAR emission inventory (developed by the Joint Research Center (JRC) in Ispra, Italy in collaboration with the Netherlands Environment Assessment Agency (PBL); (http://edgar.jrc.ec.europa.eu) is also includes emissions of OC, BC and $PM_{2.5}$.

i. By the end of 2010 the EDGAR research version will provide country- and sector-specific emissions estimates of OC, BC and PM2.5. In the meantime, by September 2010 the EDGAR-HTAP emission inventory released a compilation of emission inventories of OC, BC and $PM_{2.5}$.

c. In July 2010, IIASA provided to each Party to the Convention the information within the GAINS model for that country. The files provided contained the principal emission outputs from the GAINS model documenting current state of BC/OC and $PM_{2.5}$ implementation in the model, as well as the principal inputs in the GAINS model used for calculation of BC/OC and $PM_{2.5}$ emissions. Parties were requested to review the data and provide any relevant updates or corrections to IIASA. The Parties may also choose to use that data as they develop their own national BC estimates.

d. Since the GAINS model is under development and a discussion with national experts has been initiated only recently, we are not attempting here a comparison of existing estimates for few countries with the results of the current GAINS implementation. ***Discussions to date point to the need for careful evaluation as differences for specific sectors might be very large owing to different sources of emission factors or varying methodological approaches.***

26. IIASA has updated activity data and control strategies during the ongoing work on the revision of the Gothenburg Protocol as well as updates of emission factors and other model parameters. The 2005 UNECE emissions of BC and OC as constituents of $PM_{2.5}$ by SNAP sectors are presented in Figure 2. Industrial sources (SNAP1, 3-6) have very low shares of carbonaceous particles and therefore are likely to be much less important from the perspective of BC reduction. Residential combustion (SNAP2) and transport sources (SNAP7-8), in turn, have high shares of carbonaceous emissions and therefore are priority source sectors. Transport sources also have a lower OC/BC-ratio compared with residential burning. SNAP9 and 10 include waste flaring and agricultural burning sources which might be of relevance for specific regions. Figure 2 indicates the relative importance of BC and OC in certain $PM_{2.5}$ sectors at the total UNECE emission level.

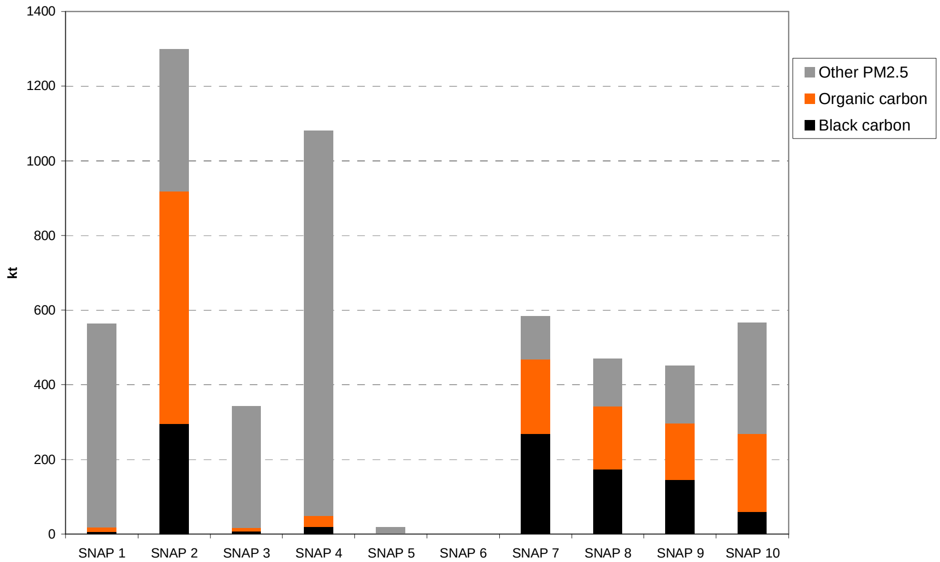

Figure 2. Emissions of BC/OC/$PM_{2,5}$ in the UNECE for 2005 by SNAP sector (see paragraph 26 for descriptions of sectors); *Source:* GAINS model

27. Figure 3 shows the BC/ $PM_{2.5}$ and OC/ $PM_{2.5}$ ratios in the period 2000-2005 as estimated in GAINS by key sectors for all UNECE area as well as the variation between countries. The 'error' bars represent the low and high boundaries of the ratios calculated for the UNECE countries. The wide range of these bars show the dramatic difference between countries due to the importance of different sectors and their different emission characteristics (as demonstrated in Figure 1) as well as differing methodologies among some countries in how these emissions are determined.
    a. For example, while total residential sector emissions are dominated by biomass burning characterized with higher share of OC and BC in $PM_{2.5}$ (Figure 2), some UNECE countries still use significant amounts of coal in this sector leading to higher share of the BC in $PM_{2.5}$ (Figure 3).
    b. Similarly, for road transport the share of BC in $PM_{2.5}$ will strongly depend on the share of diesel fuel and level of control.
    c. Regional differences point to potential problems in using simplified approaches to estimate total $PM_{2.5}$ emissions, e.g., using limited emission factors across diverse countries and sectors. Such an approach might lead regionally to significant mischaracterization of the $PM_{2.5}$ emissions. Using generic BC and OC shares in $PM_{2.5}$ to derive source specific emission factors for individual countries is problematic because of the high variation in country specific emission characteristics owing to specific technology mixes (combustion devices, vehicle types, driving habits, fuels, age,

etc.) as demonstrated in Fig. 2.

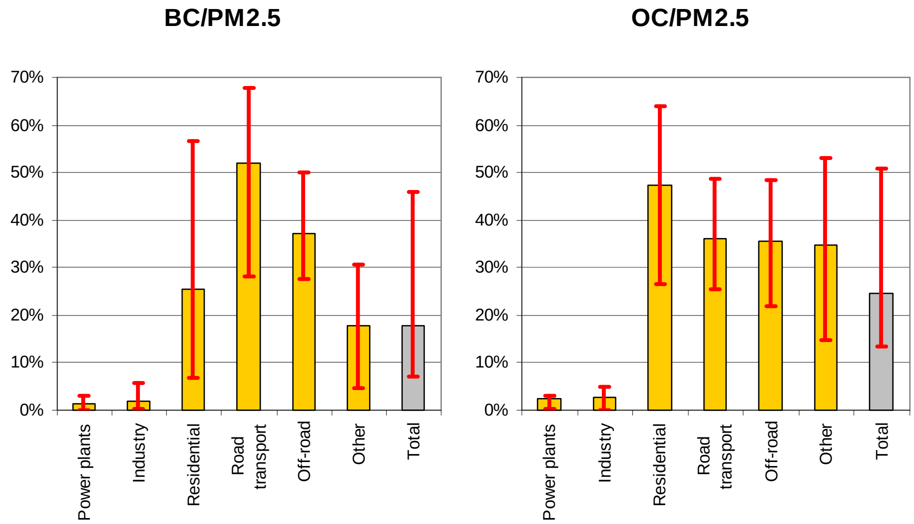

Figure 3. Share of BC and OC emissions in $PM_{2.5}$ (year 2000-05) sectoral total for the whole of the UNECE region and variation between all countries (low-high).
Source: Preliminary GAINS estimates; 'Industry' equals sum of SNAP 3,4,5,6 and 'Other' the sum of SNAP 9 and 10.

28. In addition to IIASA, many researchers are working to improve global and regional estimates of current and future emissions of BC (and co-emitted pollutants), including improved source measurement and estimates for specific sectors and countries. This research is being conducted in both a bottom-up manner (i.e., emissions estimates based on emission factors and activities levels for various sources) and in a top-down manner (i.e., emissions estimates based on field or satellite measurements and transport modeling).[38]

29. The existing bottom-up emission inventories are generally compiled with relatively generic and limited emission factors, source speciation profiles, and activity levels that do not necessarily reflect local conditions or actual sources. In the U.S., for example, black carbon emissions for all sources have traditionally been estimated by matching $PM_{2.5}$ emissions from the national inventory for those sources to source-specific elemental carbon speciation information from a database of source category-specific emission speciation profiles.

30. There is tremendous variability in fuel stock, fuel amount, combustion efficiencies, and other factors that influence the emissions of both black carbon and co-emitted pollutants. Emissions from residential heating and cooking, a sector of concern in many regions, are not well characterized. The estimates of black carbon and organic carbon emissions vary depending on such characteristics as fuel type (different types of wood emit different ratios of black and organic carbon), moisture content of the fuel, efficiency of the burning device etc.

31. A major research effort in Finland highlights the limitations of the current practice of using a very limited number of speciation profiles and emission factors to generate most inventories. Recent Finnish national measurements have shown that in one of the key sectors, the residential combustion, Finnish operational

[38] Chow JC, Watson JG, Lowenthal DH, Chen LW, Motallebi N., . Black and organic carbon emission inventories: review and application to California. J Air Waste Manag Assoc. 2010 Apr;60(4):497-507

practices and appliances may result in significant differences in the amount and composition of emissions when compared with central European and North American situation.[39] More robust inventories will require careful evaluation and review of inputs to the inventory development process. A comparison was made between the Finnish-generated national inventory and three other commonly referenced inventories (Bond et al. 2004 and two GAINS model inventories). The comparison identified the same top-emitting sectors, but demonstrated sometimes significant differences in national emission totals as well as differences within sectors. The primary reasons for the divergences include ─ beyond emission factors ─ differences in energy use, shares and detailed assumptions about the technologies in place.

32. Uncertainties in emission inventories will vary by region, source, pollutant, and inventory year and for many regions are simply not known. Regions with the longest experience in compiling inventories and with well-developed statistical systems (e.g., Western Europe, North America, and Japan) can be expected to have lower inventory uncertainties than other regions, though there are exceptions for certain source categories. The primary reasons for differences in uncertainties between source categories are (i) activity statistics are missing or weak; (ii) emission factors and technologies are known better for some sources than for others; and (iii) emissions depend on natural and variable factors such as temperature and precipitation. Usually, emissions related to the household sector, agriculture, small commercial boilers, and waste disposal are more uncertain than for transportation and large stationary sources. Natural sources and semi-natural sources (e.g., forest fires) are more uncertain than anthropogenic sources.[40]

33. BC and OC inventories have uncertainty ranges from -25 % to a factor of two (higher for open burning).[41] Major uncertainties in emission inventories stem from a lack of measurement data from open biomass burning (forest and grassland fires, agriculture waste burning), biofuel use (for heating and cooking), residential combustion of coal, flaring, and agricultural production systems (including fires). These translate into uncertainties in emissions for the pollutants emitted from these activities, including BC and OC.[42] **Ambient and source measurements of BC and its source apportionment should be encouraged.**

34. For black carbon, as with other common pollutants, there is a challenge of identifying sources originating far from where impacts are felt, such as the Arctic. Sampling of Arctic snow and ice combined with modeling studies indicate significant amounts of BC are anthropogenic, however at this time, the science has not advanced to the point that particles in receptor regions can be unequivocally attributed to specific sources or source regions.[43] This technical work is advancing in several technical forums and certain models are beginning to do source attribution analysis, though uncertainties remain.

Reductions from Current Legislation

35. Because black carbon is a constituent of primary particulate matter, black carbon reductions in most of the UNECE region to date have occurred as a result of particulate matter controls. Data collected across Europe suggest a large fraction of anthropogenic PM - up to 50% - form from emissions of the secondary particulate precursors (SO_2, NOx, NH_3, and NMVOCs).[44] In Europe, reductions of SO_2 that have taken place since 1990 have accounted for 60% of the overall reduction in particle formation, with NOx accounting for a further 30% of the observed reduction. The reduction in emissions of primary particles

[39] Tissari J., Hytönen K., Lyyränen J., Jokiniemi J. 2007. A novel measurement method for determining fine particle and gas emissions from residential wood combustion. Atmospheric Environment 41, 8330-8344.
[40] HTAP 2010 Part A DRAFT 06/07/2010
[41] Bond T C, Streets D G, Yarber K F, Nelson S M, Woo J-H and Klimont Z 2004 A technology-based global inventory of black and organic carbon emissions from combustion J. Geophys. Res. 109 D14203
[42] HTAP 2010 Part A DRAFT 06/07/2010
[43] HTAP 2010 Part A DRAFT 06/07/2010 2-31
[44] Putaud et al. A European aerosol phenomenology - 3: Physical and chemical characteristics of particulate matter from 60 rural, urban, and kerbside sites across Europe, Atmospheric Environment, Vol. 44, Issue 10, March 2010, pages 1308-1320.

has accounted for only 6% of the overall reduction.[45] While the reductions of the secondary particulate precursors have resulted in significant positive impacts on public health and ecosystem protection, the net climate benefits of these reductions are less certain, and may in fact be warming due to reduced cooling resulting from lower concentrations of the secondary precursors.[46]

36. The reductions in total emissions of particulate matter between 1990 and 2007 have been mainly due to the control technologies applied to energy, road transport, and industry sectors as well as control measures, such as fuel switching, in industrial sectors. Emissions of primary PM10 and secondary PM10 precursors are expected to decrease in the future as vehicle technologies are further improved and stationary fuel combustion emissions are controlled through abatement or use of low sulphur fuels such as natural gas. Despite this, it is expected that within many of the urban areas across the EU, PM10 concentrations will still be well above the EU limit values for PM_{10}. Substantial further reductions in emissions will therefore be needed if the air quality limit value set in the EU's Air Quality Directive is to be reached. [47]

   a. The European directive 2008/50/EC sets limit values for daily and annual concentrations for PM10, and annual concentration and exposure for $PM_{2.5}$. Because there is no requirement in the EC Directive to explicitly reduce BC, the $PM_{2.5}$ and PM_{10} limit values could be met without necessarily reducing BC, but rather by reducing only the secondary aerosol precursors or other PM constituents. There is therefore a strong argument for considering a further metric for directly emitted PM, such as BC. This (together with previous) EC Directive has had a positive impact on PM levels. The net climate benefit of the current European legislation is therefore not that certain. If it is the intention to achieve reductions in BC in addition to the other PM species, control technologies and measures will have to be intentionally applied to do so.
   b. In contrast, the Euro 5 standard for vehicles (into force on 1 September 2009 for the approval of vehicles, and applicable from 1 January 2011 for the registration and sale of new types of cars) sets a limit of 5 mg PM / km (80% reduction of emissions in comparison to the Euro 4 standard for Diesel vehicles). This should have a significant impact on EC emissions, traffic (Diesel engines) being expected to be the largest contributor to EC emission (based on source apportionment study by JRC-Ispra).[48]

37. A combination of factors has contributed to the reduction of both primary PM10 and secondary particulate matter emissions in these sectors between 1990 and 2007.[49] These include for primary PM10:
   a. improvements in the performance of particulate abatement equipment at coal-fired power stations;

38. For the secondary particulate matter precursors:
   a. fuel switching from high-sulphur solid (e.g. coal) and liquid (e.g. heavy fuel oil) fuels to low sulphur fuels (such as natural gas) for power and heat production purposes within the 'energy industries', industry and domestic sectors;
   b. the impact of European Community directives relating to the sulphur content of certain liquid fuels;

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[45] Emissions of primary particles and secondary particulate matter precursors (version 2) - Assessment published Jan 2010 - http://www.eea.europa.eu/data-and-maps/indicators/emissions-of-primary-particles-and-1/emissions-of-primary-particles-and-1
[46] Raes and Seinfeld New Directions: Climate change and air pollution abatement: A bumpy road. Atmospheric Environment, 43 (32). pp. 5132-5133.
[47] Emissions of primary particles and secondary particulate matter precursors (version 2) - Assessment published Jan 2010 - http://www.eea.europa.eu/data-and-maps/indicators/emissions-of-primary-particles-and-1/emissions-of-primary-particles-and-1
[48] Gilardoni et al. Better constraints on sources of carbonaceous aerosol using a combined C14-macro tracer analysis in a rural European site, Abstract of the12th Symposium of the International Commission on Atmospheric Chemistry and Global Pollution (iCACGP) and the 11th Science Conference of the International Global Atmosphere Chemistry (IGAC) Project, 2010
[49] Emissions of primary particles and secondary particulate matter precursors (version 2) - Assessment published Jan 2010 - http://www.eea.europa.eu/data-and-maps/indicators/emissions-of-primary-particles-and-1/emissions-of-primary-particles-and-1

c. the introduction of flue-gas abatement techniques (e.g. flue gas desulphurisation, NOx scrubbers and selective (SCR) and selective non-catalytic (SNCR) reduction) and introduction of combustion modification technologies (such as use of low NOx burners);
d. the introduction of three way catalytic converters for petrol-fuelled cars (driven by the legislative 'Euro' standards) coupled with an increased penetration of diesel-fuelled vehicles.

Comment [sjt2]: What can we say about the impact of these on BC?

39. The current (2005) and future (2030) baseline (current legislation - CLE) BC emissions are presented in Figure 3. Total BC and OC emissions of 2005 in the UNECE region are estimated at 1.0 and 1.4 Tg, respectively. The majority of BC emissions originates from the residential (30%) and transport sectors (50%). There are, however, important regional and sectoral variations. For example, in the EU-15 and US the transport emissions are more important, contributing over 60 percent of the total BC.
    a. In Russia major contributions come from oil and gas flaring[50] and open burning of agricultural residues. Lack of activity data and emission factors for these latter categories means these estimates are very uncertain. In fact there are no established BC emission factors for flaring and only recently a research group in Canada undertook an effort to estimate and validate numbers in use, but published data is not yet available.
    b. As reductions occur as a result of current legislation, the relative importance of other source categories may become important. For example, significant reductions are expected in the transport sector, which may increase the relative contribution of the residential and industrial sectors in the out-years.

40. Figure 4 shows expected future development of BC emissions assuming successful implementation of the current legislation (CLE). Although there is no specific legislation targeting carbonaceous aerosols, the existing and proposed PM and SO_2 regulation is expected to bring significant reductions of primary BC and OC.
    a. While residential combustion is and remains in the future a key BC emitting sector, emissions from the transport sector (especially road) are expected to decline by about 70 percent by 2020 provided current policies (DPF technology) will bring expected reductions.
    b. The highest overall reductions are expected in the EU-15, where BC emissions could decline by 49 percent by 2020. This expected reduction is greater than, for example, that expected in the US and Russia (-38 and -25 percent, respectively) through implementation of current legislation. However, current legislation is expected to have less of an impact on emissions from off road transportation (including the marine sector), which will increase this sector's relative importance in the future in terms of mitigation efforts.
    c. On-road measurement studies of vehicle emissions conducted in some countries have revealed that a relatively small fraction of vehicle fleet is responsible for a relatively large share of emissions. These vehicles are referred to as high emitters or super emitters.[51] The potential effect of these vehicles is not included in the emission values in Figure 3. A preliminary estimate with the GAINS model indicates that the high emitting vehicles could increase the transport BC emissions in the UNECE region by about 10 and 15 percent in 2005 and 2030, respectively, in the CLE case. The country specific increments vary due to differences in vehicle age distribution, fuel use and the estimated share of high emitters in the fleet. Targeting high emitting vehicles could provide a separate mitigation opportunity for BC. However, further studies are needed to refine the estimates of their shares in different countries as well as their contribution to emissions.

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[50] 1. The GAINS data for oil and gas flaring has been recently reviewed making use of the NOAA NGDC study (Elvidge et al., 2009). The data has been allocated to GAINS regions according to the spatial information provided at the study website (http://www.ngdc.noaa.gov/dmsp/interest/gas_flares.html).

[51] Ban-Weiss et al. 2009. Measurement of Black Carbon and Particle Number Emission Factors from Individual Heavy-Duty Trucks. Environ. Sci. Technol. 43, 1419-1424.

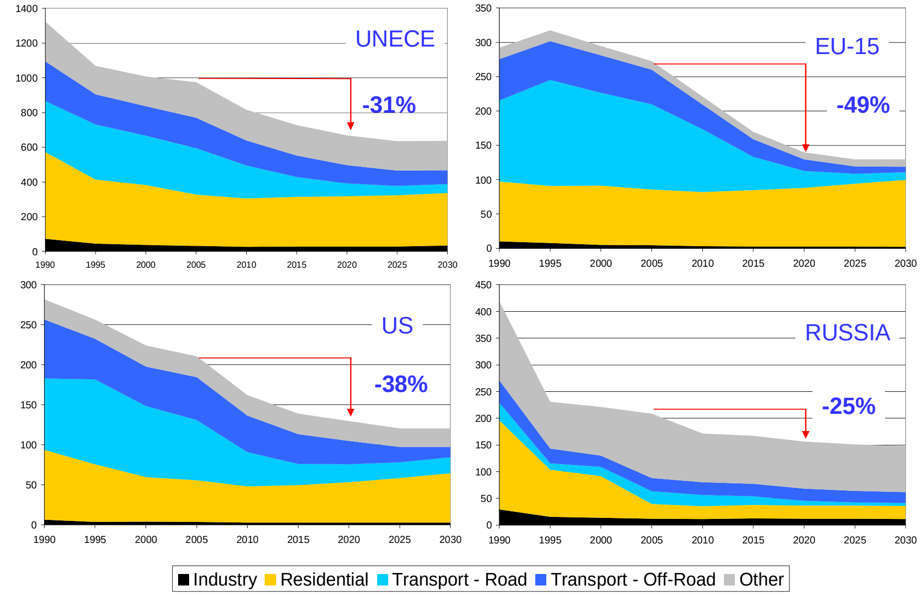


Figure 4. Sectoral structure and development of BC emissions [kt] in selected UNECE regions in the CLE scenario; indicated reductions refer to the change between 2005 and 2020 – *Source:* GAINS model

41. Because these estimates of future emission reductions rely on the assumption of successful full implementation of current legislation, and the economic downturn and other factors may influence the applicability of this assumption, there remains a need to test the validity of the assumptions used in these projections. For example, on 7 July 2010 the European Commission proposed to allow sales of non-road mobile machinery that do not meet the EU emission standards applicable from 2011 to the end of 2013 (Directive 2004/26/EC), noting recent sudden and unexpected falls in sales resulting from the global financial and economic crisis.

42. It is also important for the Executive Body to consider whether the reductions projected under this analysis will happen at an appropriately rapid rate to mitigate the impacts of BC on sensitive regions such as the Arctic. More analysis is needed to determine the rate and rigor of implementation of current legislation, particularly for large transport and off-road vehicles, and the impact of these reductions on sensitive regions.

43. Considering the fact that there is very little information available about key parameters of the off road transport sector, and because the equipment operates often in harsh conditions, and have long lifetimes, careful monitoring of existing legislation and strengthening of policies in this area are worthy of consideration by the Executive Body.

44. [Figure 5 shows the regional distribution of BC emissions in Europe in 2005 and 2030 CLE scenario where significant reductions are visible in most of Europe.

Comment [sjt3]: these maps originate from the UNEP project and JRC did the gridding; they are placeholders (unless permission is received from them to use it) for Svetlana to put the maps from EMEP, maybe only for 2005.

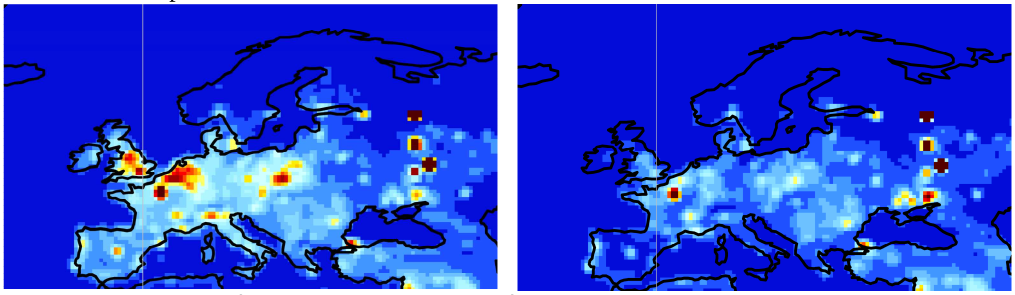
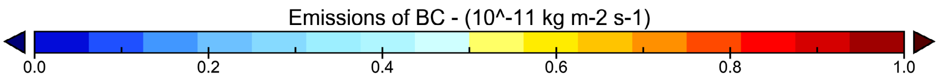


Figure 4. Emissions of black carbon in 2005 (left) and 2030 (right); *Source:* GAINS model calculation for IEA W



, Ispra, Italy).]

Potential Additional Reductions

45. Specific PM control measures already under discussion for potential inclusion in a revised Annex VII (Particulate Matter) to the Gothenburg Protocol may or may not result in significant BC reductions. More testing needs to be conducted to determine the exact efficiency of control measures and technology for BC removal. For example, in general fabric filters and ESPs will reduce BC, while cyclones and scrubbers won't reduce BC to any significant degree, but can reduce the larger particle species.

46. **Because of the public health benefits of reducing black carbon, as well as the location of the countries across the CLRTAP regions in relation to the Arctic, the EB should consider taking additional measures to reduce BC.** Impacts on the Arctic will vary by country, but all countries will benefit from local emission reductions of BC and other co-emitted pollutants.

47. **Given the rate at which the Arctic and other sensitive regions are experiencing impacts, the EB should consider not only specific new measures, but determine whether the existing measures are being implemented with an adequate fidelity and the speed needed to avoid the most catastrophic results, for example sea ice and ice sheet melt.**

48. If the decision is taken to consider additional measures to ensure needed reductions in BC as part of a broader PM strategy under the Gothenburg protocol, current analysis shows there are potential emission reductions available across a range of source categories. The cost and feasibility of these approaches will vary across regions and countries. Additionally, there is limited analysis currently available that can provide definitive estimates of the precise climate benefits, though they are thought to be positive. Health impacts are better understood and estimates do exist for the health benefits of PM reductions, especially those in urban areas where exposures (and therefore benefits of reductions) are concentrated.

49. The table below identifies a range of additional measures, specifically targeted toward reducing BC, that may be implemented in various CLRTAP regions. While uncertainties regarding emissions and transport exist, there is some confidence that there is enough known about the emissions and impacts to merit consideration of these measures.

Comment [sjt4]: Does the BCEG have enough information to fill in this table, or parts of the table?

Measure	Reduction Potential	Implementation Feasibility	Cost (if known)	Benefits (RF/Health)
	Max/Feasible			
Households				

Improved biomass and coal stoves				
Replacement of biomass cooking stoves				
Industry and power generation				
Cyclones				
ESP				
Fabric Filters				
Non-recovery coke ovens with end-of-pipe				
Brick Kiln - VSBK technology				
Brick Kiln - tunnel kilns				
Flaring				
Road transport				
Particle traps (DPF) for heavy and light duty vehicles				
Elimination of super-emitters				
Off-road				
Particle traps (DPF)				
Elimination of super-emitters				
Shipping				
Ships				
Ports				
Open burning				
Ban of open burning of agricultural residues				
Ban of open burning of garbage				

Options for potential revisions to the Gothenburg Protocol

50. **Monitoring and Reporting:** One of the greatest weaknesses in the overall effort to understand and effectively mitigate the impacts of black carbon (and other carbonaceous aerosols) is the paucity of data. At this time, no country has a comprehensive program to measure and report their black carbon emissions. Given the uncertainties of the inventories, inconsistencies in measurements across the CLRTAP region, and the lack of country and source-specific measurements needed to understand the mixtures being emitted, **the EB should consider instituting monitoring and reporting requirements for emissions and air quality specific to black carbon.** This could include specifically listing the constituents of particulate matter, as in the Directive 2008/50/EC, when including the pollutant in the Protocol language.

51. **The EB should also consider tasking specific existing expert groups to recommend the most constructive path forward for gathering and sharing data in the following areas. This may include collaboration with groups working on BC outside the auspices of the CLRTAP.**
    a. Source Measurement

i. Characterize and define various carbonaceous aerosol properties (absorption and scattering coefficients, indices of refraction);
ii. Characterize BC aging properties and atmospheric residence time for various priority source categories;
iii. Identify and characterize missing sources

b. Emission Factors
i. Compile and evaluate all available emissions and activity factors, with guidelines on when they are appropriate to use.
ii. Identify a central location where emissions test data would be collected, quality assured, and disseminated.

c. Emission Inventories
i. In addition to the obligation to establish inventories for other listed pollutants, add the obligation for each Party to establish a BC/OC emission inventory and a procedure for its regular updating and validation.
ii. The Task Force on Emission Inventories should give priority to more work on guidelines for BC inventories with a focus on BC reductions achievable from existing PM control measures/techniques.
iii. Validate BC inventories against ambient concentrations with an appropriate regular measurement program.
iv. Reconcile bottom-up and top-down regional and national inventories
v. Evaluate sources and consequences of uncertainties in emissions inventories

d. Ambient Monitoring and Measurement
i. There is currently no reference method in Europe or North America for elemental carbon or aerosol absorption coefficient measurements. As a result data from different laboratories at varies sites are of unknown accuracy and can be compared only after inter-calibration.
ii. The CEN working group devoted to the definition of the European reference method for Elemental (and organic) carbon is still waiting for a mandate from the European Commission. In the meantime, the EMEP manual should clearly decide for a provisional standard methodology (pending completion of the CEN effort), possibly based on the work performed at the JRC within EUSAAR.[52] This work should also include methods for measuring the light absorbing characteristics of relevant particles.
iii. **The EB should consider the swiftest possible implementation of EMEP's monitoring strategy for 2010-2019.** This strategy already includes measurements of Elemental and Organic Carbon in PM_{10}, and the determination of the aerosol absorption coefficient. Meanwhile, the Directive 2008/50/EC requires the monitoring of Elemental and Organic Carbon at rural background sites (i.e. where EMEP stations are to be located) in PM2.5. It might be seem unreasonable for Parties that are EU member states to implement the monitoring of Elemental and Organic carbon in both PM fractions. Elemental Carbon is very likely sitting mainly in $PM_{2.5}$. A specific EMEP intensive campaign could help to verify this.

e. Exchange of Information and Technology
i. Add BC (and other carbonaceous aerosols) to the list of pollutants under Article 4 of the Gothenburg Protocol.

52. **The EB should support the initiative by EMEP to define black carbon** or more accurately, operationally define each component of particulate matter that is important from a climate perspective. This means reaching agreement on how the Parties will define, measure and use different terminology

[52] Cavalli et al. Toward a standardised thermal-optical protocol for measuring atmospheric organic and elemental carbon: the EUSAAR protocol, AMT, 3, 2010

regarding light absorbing (and scattering) carbonaceous aerosols. This could be then included in the definition article of the Protocol.

53. **Measurement and Reporting Currently Under Consideration:** The monitoring strategy and measurement program of EMEP outlines measurement and reporting requirements for PM10. The EN 12341 ("Air Quality - Field Test Procedure to Demonstrate Reference Equivalence of Sampling Methods for the PM10 fraction of particulate matter") is indicated as the reference method for the sampling and measurement of PM. Average daily PM10 concentrations are to be yearly reported.

54. The directives 1999/30/EC and 2008/50/EC set measurement and reporting requirements for PM10 and PM2.5, respectively. Directives indicate that measurements should be made in a manner consistent with those of EMEP and where appropriate, should be coordinated with the monitoring strategy and measurement program of EMEP. Limit values for 24-hour average and annual average concentrations for PM fractions are set and the corresponding mass concentrations to be reported.

55. **Preambular Language**: A revised Gothenburg Protocol could include rationale language to highlight the urgency of achieving reductions in BC. Similar to the rationale in this report, the preamble might mention impacts on the Arctic and other non-warming effects, public health co-benefits, and ongoing work in other forums.

56. **Environmental Objective**: More broadly the Executive Body should consider whether to include an objective that gives overall priority to measures that achieve, or are explicitly linked, to climate outcomes or targets. A revised Gothenburg Protocol could establish an environmental objective for black carbon that can be used to measure progress and for integrated assessment modelling. Options include both qualitative and quantitative objectives. Examples of qualitative objectives are: slow the melting of sea ice in the Arctic; or contributing to slowing down the enhanced warming of the Arctic. Examples of quantitative objectives are: reduce the radiative forcing due to BC in the Arctic by a total or percentage reduction in W/m2 by a date certain; or reduction by certain percent in the amount of deposited BC on snow.

57. **Country Specific Goals:** The ability to establish these country specific goals will depend on how accurately sources of BC emissions can be identified, and ideally, emitter - receptor relationships established. Some types of country specific goals outlined below may be for consideration in the medium- rather than near-term given the continuing scientific uncertainties and information gaps.
    a. Emission Ceilings are one option for individual countries. Given the variability in priority sectors by country, emission ceilings could be established based on the reduction potential of each CLRTAP country. These may be developed for PM with a focus on sources known to be high emitters of BC. The EB could charge the BC Expert Group or other CLRTAP body to determine whether existing emission ceilings and implementation timelines are adequate to achieve the stated environmental objectives.
    b. Provisional, indicative ceilings could be established if the EB determines that the inventories and modelling do not enable rigor and confidence to establish definitive emission ceilings.
    c. Technical annexes are another approach to commitments developed and adopted under the Gothenburg Protocol. Some are mandatory, while others have a status closer to that of guidance documents. This option would require BAT (Best Available Techniques, e.g. emission limit values) and BAP (Best Available Practices) to be identified and developed for BC emissions.
    d. The EB may wish to consider charging the BC Expert Group, or some other CLRTAP body to develop in greater detail the potential options for using both mandatory and voluntary provisions in a revised Gothenburg Protocol. Mandatory provisions may be more appropriate for actions needed to fill critical information gaps, or for reductions from source categories for which more is known

regarding impacts and control options. Voluntary provisions may be more appropriate for actions where less is known or where technologies may be still developing.

e. The EB may wish to consider charging the BC Expert Group, or some other CLRTAP body to develop additional options for mechanisms by which Parties who do not adopt the revised Protocol might make verifiable and measurable progress toward the stated environmental objective.

58. **Source Category Specific Emission Limit Values:** Alternatively, or to complement country-specific emission ceilings, the EB could consider implementing emission limit values for those source categories known to emit high amounts of black carbon. Examples include a timeline for complete removal of super-emitting vehicles; emission limits for categories of on and off-road vehicles on an accelerated schedule; or emission limit values on industrial boilers for which known and cost effective controls exist.
    a. EGTEI is developing a new chapter for the technical annex VII on emissions of PM from combustion installation < 50 MW including domestic appliances burning wood. This chapter will consider BC.
    b. The EB may consider tasking EGTEI to assess the impacts of other annex technologies (e.g, for TSP and dust) on BC as well as identify for the Draft Technical Annex on Dust those Emission Limit Values that would also result in a reduction of BC.

59. **Review and Amendment Provisions**: The scientific knowledge of BC continues to evolve very quickly. At least four major international assessments or reports are underway that will further shed light on the climate and public health impacts associated with black carbon and other short lived climate forcers. In addition to the work identified above, for example, ongoing analysis from the International Polar Year (IPY) will most likely produce a number of important scientific results pertinent to the impacts and control of emissions of BC. To take advantage of this work, the Gothenburg protocol could include in its mechanisms for revising the protocol to rapidly take action as a result of further scientific synthesis.

60. As individual countries take action unilaterally or under CLRTAP, further analysis is needed to ensure that these actions are having the intended impact. Provisions could be included to facilitate fast-track amendments to the protocol to make adjustments based on scientific and policy advancements.

61. **Non-binding Goals:** The EB should consider whether to make a non-binding statement outlining even more ambitious non-binding environmental objectives. Examples include potential actions outside the CLRTAP region; or an encouragement to the Parties to swiftly and effectively begin implementation of BC emission reductions to a greater extent than might be agreed by Parties to the revised Protocol. Such a statement could include interested Parties or entities, such as those nations that are members and/or observers of the Arctic Council.

62. Actions outside the UNECE region could include:
    a. Capacity development for black carbon emissions monitoring and reporting,
    b. Support for development of institutions and infrastructure for monitoring and reporting,
    c. Transfer of black carbon reduction technology for key emission source sectors.

63. The EB could consider entering into a memoranda of understanding with non-UNECE states that are significant sources of black carbon emissions transported to the UNECE region and/or that are transported to key sensitive regions, such as the Arctic that have been identified as a priority for black carbon reduction in the amended Protocol.

64. The EB could consider developing mechanisms such that certain obligations – e.g., to cooperate in developing black carbon monitoring and reporting capacity, institutions and infrastructure – would be

binding upon select non-UNECE States that had made an explicit declaration to this end. Alternatively, such a provision could be included into the Gothenburg Protocol.

65. The EB may also wish to consider exchange and capacity development on black carbon monitoring, reporting and technology transfer with the nations of the ASEAN Agreement on Transboundary Haze Pollution. Additionally, the EB should urge the IMO to enact requirements to reduce emissions of black carbon from international shipping, especially emissions in those areas that impact Arctic climate.

66. **Evaluating progress:** Given the gravity of the task before the Parties, the EB should give serious consideration to how and in what timeframes it will evaluate progress under a revised Gothenburg Protocol. With the Arctic and other sensitive regions experiencing negative consequences now, it is likely imprudent to wait until 2020 or 2030 to measure progress and adjust the course of progress. A number of metrics exist for consideration, such as measured extent, age and thickness of sea ice; measured BC deposition in sensitive regions; measured ambient concentrations of BC; and/or measured emission reductions of BC. Each of these examples has limitations, including inter-annual variability and limitations on our understanding of the relationship of these measures to climate impacts of concern. The EB could consider tasking EMEP or other CLRTAP body with identifying appropriate measures and timeframes for inclusion in the Gothenburg Protocol.

67. With several major assessments being issued over the course of 2010, the EB could consider charging the BCEG or other CLRTAP body with synthesizing the results of these assessments to determine what new information is available to inform ongoing development of the Gothenburg Protocol.

Summary of Key Recommendations