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BLACK CARBON

Report from the Ad-Hoc Expert Group on Black Carbon
Prepared by the Co-chairs of the Expert Group

EXECUTIVE SUMMARY AND KEY RECOMMENDATIONS

1. The Ad-hoc Expert Group on Black Carbon (EGBC), co-chaired by the United States of America and Norway and with participation of Parties and observers to the Convention on Long-range Transboundary Air Pollution (the Convention), has assessed available information on black carbon (BC) to, inter alia, 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. Nothing in this report should be interpreted as negating the need for ambitious and concurrent reductions in long-lived greenhouse gases.

2. There are clear environmental benefits to reducing emissions of BC, based on available information. Given this fact and the success of the Convention in negotiating and achieving real emission reductions in air pollutants, the Executive Body (EB) should actively consider the options for action presented in this report. Combined, the regional climate impacts and the known health benefits that would accrue to the UNECE Region by reducing particulate matter (PM) justify the EB considering options to mitigate BC as a component of PM when making revisions to the Convention's 1999 Gothenburg Protocol to Abate Acidification, Eutrophication and Ground-level Ozone (Gothenburg Protocol).

3. Black carbon is a strongly light-absorbing carbonaceous aerosol produced by incomplete combustion of various fuels. There is general consensus that mitigation of BC will lead to positive regional impacts by reducing BC deposition in areas with snow and ice. There is also general consensus that reducing primary PM will benefit public health. Less certain are the direction and magnitude of the global radiative forcing associated with BC. This is due in large part to poorly understood mechanisms by which BC interacts with clouds.

4. The Arctic, as well as alpine regions, may benefit more than other regions from reducing emissions of BC, which both warms the atmosphere and when deposited increases the melting of snow and ice. BC contributes to the snow-albedo feedback, which may be altering the global radiative balance. Climate processes unique to the Arctic have significant effects that extend globally. The IPCC noted nearly 10 years ago that changes, which include melting of glaciers, sea ice, and permafrost, have already taken place. As a result, action must be taken in the very near term to reduce the rate of warming.

5. The Executive Body should consider the advantages of integrated air quality and climate policies. Climate and air quality are inextricably linked, and strategies devised for one will likely impact the other. For example, air quality management strategies that reduced emissions of secondary PM precursors (such as sulphur and nitrogen oxides) for public health and ecosystem protection resulted in a mainly warming effect. Because sulphate aerosols have a mainly cooling effect, reducing these emissions has unmasked underlying anthropogenic climate change that would have occurred in the absence of these emissions. It is imperative that the important work of improving public health by cleaning the air continue, but going forward in a way that is also beneficial for climate.

6. While it is clear that BC emission reductions would be expected to provide important health and climate benefits, there is substantial room for improving the knowledge base with respect to emissions and impacts. One of the greatest sources of scientific uncertainties arises from the lack of emission data. At this time, no country has a comprehensive program to measure and report the emissions and ambient concentrations of BC (and other carbonaceous aerosols). To enable formulation of effective strategies and policies, technical work on BC under the Convention should be strengthened. The EB should therefore consider tasking specific existing Convention bodies to recommend the most constructive path forward for gathering and sharing data. This may include collaboration with groups working on BC outside the auspices of the Convention.

7. BC emissions in the UNECE region are expected to decline between 2000 and 2020 by about one third as a result of current emission control legislation primarily in the transport sector. These reductions are dependent on full implementation of existing legislation, which is not necessarily guaranteed. While overall BC emissions are expected to decrease, emissions from certain sectors may substantially increase. Currently available measures could reduce BC emissions by another 40% by 2020.

8. Several possible options for including BC in a revised Gothenburg Protocol are included in the report, ranging from establishing relevant environmental objectives to taking action to reduce emissions. For emission reduction commitments, a range of options are identified, such as national emission ceilings and source specific emission limit values. Important sectors with mitigation potential remaining after current legislation is implemented are residential combustion, non-road mobile machinery, road transport, and open burning. Further elaboration of the type of emission reduction commitments may involve many existing Convention Task Forces, EMEP Centres, and Expert Groups.

9. The recommendations here are a subset of the recommendations found in the report, with further detail available therein. In addition to including black carbon in the revisions of the Gothenburg Protocol, the Executive Body should consider the following recommendations for implementation in its 2011 draft workplan:
    a. Improving emission inventories will enable the Parties to select optimal control policies and identify sources that may be under-reported or missing from known inventories. Careful evaluation of emission data is needed as differences for specific sectors can be very large because of different emission factors or varying methodological approaches. The Task Force on Emission Inventories and Projections should give priority to work on guidelines for BC inventories with a focus on BC reductions achievable from existing PM control measures or techniques.
    b. The EB should support the initiative by EMEP to identify the relevant characteristics of BC to be monitored and reported and should consider the swiftest possible implementation of EMEP's monitoring strategy for 2010-2019.
    c. If the EB determines to include BC in the revisions to the Gothenburg Protocol, it may wish to consider charging the EGBC or some other Convention body to:
        i. Develop in greater detail the potential options for using both mandatory and/or voluntary provisions for BC in a revised Gothenburg Protocol;
        ii. Develop more information on existing and emerging control technologies for BC;
        iii. Develop additional options for mechanisms by which Parties that have not yet ratified a revised Protocol might make progress toward a stated environmental objective.
    d. BC emission from shipping in the Arctic may increase by a factor of two to three by 2050. This may have a significant impact on the Arctic environment. This issue is presently under

consideration in the IMO. Although emissions from international shipping are not included in the work under the Convention, the Executive Body could consider informing the IMO about its concern about the effects of black carbon on the Arctic.

10. The EB should also consider the following recommendations for *longer-term* implementation:
    a. Institute mandatory monitoring and reporting requirements for BC and OC emissions.
    b. Consider how to ensure implementation of any agreed upon requirements, including consideration of needed resources.
    c. Because the knowledge of BC is rapidly developing, the EB should consider setting a timeframe for incremental review of work and possible commitments on BC.
    d. Also suggested are possible outreach activities (e.g. capacity building and cooperation on monitoring, developing emission inventories, and mitigation measures) to non-ECE countries, countries with economies in transition, and countries preparing to ratify the Gothenburg Protocol.

INTRODUCTION

11. The Ad-hoc Expert Group on Black Carbon was established by the Executive Body of the Convention on Long Range Transboundary Air Pollution in December 2009. The mandate of the EGBC is to provide options for whether, and if so how, the EB might consider addressing emissions of black carbon to benefit public health and reduce climate impacts, particularly impacts in areas of snow and ice. The EGBC was specifically requested to identify options for potential revisions to the Gothenburg Protocol that would enable the Parties to mitigate black carbon as a component of PM.

12. 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, European Union (EU), Finland, France, Germany, Ireland, Italy, Netherlands, Norway, Russia, Slovenia, Spain, Sweden, Switzerland, the United Kingdom, and the United States. Additional participants included representatives from the United Nations Economic Commission for Europe, European Environmental Bureau, experts from European Monitoring and Evaluation Programme (EMEP) four programme centers (the Chemical Coordinating Centre, the Meteorological Synthesizing Centre-West, the Meteorological Synthesizing Centre-East and the Centre for Integrated Assessment Modelling), the EMEP Task Force on Measurement and Modelling, the EMEP Task Force on Emission Inventories and Projections, the Task Force on Hemispheric Transport of Air Pollution, and the Expert Group on Techno-economic Issues (EGTEI); and observers from several non-governmental organizations.

13. 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.

14. Black carbon and organic carbon (OC) are produced by incomplete combustion of various fuels. BC is a strongly light-absorbing carbonaceous aerosol and warms much more than OC cools, per ton. [1 2] Because of its light absorbing properties, BC contributes significantly to global warming by directly absorbing sunlight and to regional warming by darkening ice and snow. Direct BC warming is considerable at the global scale, however the limited understanding of other climate impacts (e.g., BC-cloud interactions) make the net global climate impact uncertain.[3 4] Due to the fine size and chemical composition of BC, its negative health effects are also widely recognized.

15. Immediate climate benefits of BC mitigation are possible because it has a short atmospheric lifetime and it is strongly absorbing. There is general consensus that mitigation of BC will lead to beneficial 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.

16. Particulate matter originates through two distinct processes. It can be directly emitted and referred to as primary PM; and it can be formed in the atmosphere from precursor emissions (e.g., such as sulphur oxides and nitrogen oxides) and referred to as secondary PM. BC is a constituent of primary PM emissions. Because BC is emitted in varying amounts with other pollutants that also impact climate and public health, (e.g., other aerosols such as organic carbon, PM and ozone precursors, greenhouse gases, and toxic air pollutants) BC mitigation measures must be evaluated in a way that recognizes the full range of impacts of these co-emitted pollutants. Mitigation measures focused on reducing secondary PM may or may not reduce BC.

17. Many terms are used, often interchangeably, to describe the strongly light absorbing subset of particulates. Soot, elemental carbon, refractive carbon, and black carbon are all in use, 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 influence climate and public health.[5] The work to define and establish measurement techniques for the entire suite of light-absorbing aerosols goes beyond the scope of this EGBC, but should be encouraged or mandated by the EB.

RATIONALE

18. Controlling emissions of BC will result in health benefits, and climate benefits especially in sensitive regions such as the Arctic. The magnitude of the net effects of BC’s direct and indirect radiative forcing on the global climate is subject to some uncertainty, nevertheless there is emerging consensus regarding

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[1] 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 $(NH_4)_2SO_4$ particles by ozonolysis products of α-pinene. Journal of Aerosol Science 34, (10): 1297-1321.
[2] 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
[3] V. Ramanathan and G. Carmichael, *Global and regional climate changes due to black carbon*, 1 Nature Geoscience 221-22 (23 March 2008)
[4] Jacobson, M.Z. Strong radiative heating due to the mixing state of black carbon in atmospheric aerosols. *Nature* 409, 695-697 (2001)
[5] M. O. Andreae and A. Gelencser: Black carbon or brown carbon? Atmos. Chem. Phys., 6, 3131–3148, 2006 www.atmos-chem-phys.net/

the regional influence of BC on areas of snow and ice. [6] [7] [8] [9] Combined, the regional climate impacts and the known health benefits that would accrue to the UNECE Region by reducing PM justify the EB considering options to mitigate BC as a component of PM when making revisions to the Gothenburg Protocol. While it is clear that BC emission reductions would be expected to provide important health and climate benefits, there is substantial room for improving the knowledge base with respect to emissions and impacts.

19. **Impacts on Global Climate:** There is no scientific consensus on the overall global climate effect of BC. At the time this report was developed, concurrent efforts were underway to more systematically outline what is known and not known regarding the full range of effects. The EB's decisions should be guided by these efforts: the "Bounding the Role of Black Carbon in Climate" by the International Global Atmospheric Chemistry – Atmospheric Chemistry and Climate Initiative; and "Black Carbon and Tropospheric Ozone - Opportunities for limiting near-term climate change" by the United Nations Environment Program (UNEP).

    a. **Direct Radiative Forcing of Black Carbon:** One of the ways BC impacts climate is by directly absorbing incoming solar radiation causing an imbalance in the Earth's radiation budget. Estimates of this effect, known as radiative forcing, vary. According to the Intergovernmental Panel on Climate Change 4th Assessment Report (IPCC AR4)[10], the global direct radiative forcing (RF) by fossil fuel BC is 0.2 (+/- 0.15) Wm^{-2}, and that of biomass burning BC 0.03 (+/-0.12) Wm^{-2}. Such estimates are based on emission inventories of BC and subsequent model calculations. A recent expert judgment within the UNEP assessment, proposes a most likely range of 0.2 – 0.6 Wm^{-2} for the total direct RF of anthropogenic BC, not excluding the possibility of higher values.

    b. **Indirect Radiative Forcing of Black Carbon:** Aerosols have other effects on radiative forcing, through their impact on clouds. These were not quantified by the IPCC AR4. The indirect effect relates to cloud cover and lifetime. The semi-direct effect relates to the fact that BC particles heat up the surrounding air mass and prevent the formation of clouds. Finally there is the deposition of BC on ice and snow fields which reduce the surface albedo. The expert judgment within the UNEP assessment proposes a range of -0.4 to +0.4 Wm^{-2}, not excluding the possibility that the three effects mentioned above might cancel out at a global scale.

20. **Arctic Effects:** The Intergovernmental Panel on Climate Change (IPCC) noted nearly 10 years ago that changes in the Arctic have already taken place and continue to occur. They include 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.

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[6] Qian, Y., et al. (2009), Effects of soot-induced snow albedo change on snowpack and hydrological cycle in western United States based on Weather Research and Forecasting chemistry and regional climate simulations, J. Geophys. Res., 114.
[7] Hadley et al. (2010), Measured black carbon deposition on the Sierra Nevada snow pack and implication for snow pack retreat Atmos. Chem. Phys., 10, 7505–7513.
[8] Xu, Baiqing et al. (2009), Black Soot and the Survival of Tibetan Glacier, Proc. Natl. Acad. Sci. Early Edition (2009).
[9] Flanner, M.G., et al., (2009), Springtime warming and reduced snow cover from carbonaceous particles, Atmos. Chem. Phys., 9, 2481.
[10] 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, pp 132.

21. BC, 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.[11] 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. While this section highlights impacts on the Arctic, similar impacts are being experienced in alpine regions across the UNECE region and beyond.

    a. Changing albedo: BC deposition decreases the reflectivity of Arctic snow and ice. The Arctic albedo also changes when highly reflective sea ice melts and is replaced by dark ocean water, which in turn absorbs more incoming solar energy and exacerbates warming. BC contributes to this process, known as the snow-albedo feedback, and may be altering the global radiative balance. BC effects are particularly important during spring.

    b. Rate of Warming: The Arctic continues to warm more rapidly than almost all 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 rate of warming in comparison to other areas of the globe. As the EB deliberates, it is critical to consider the timescale 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 likely have. Mitigation of long-lived greenhouse gases (LLGHGs) is critical, but the benefits accrue over a much longer timescale. In the long term, reducing LLGHGs 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 these gases.[12]

    c. Sea Ice Extent: Sea ice extent and volume have been declining steadily over the past decades at a rate not seen in thousands of years. [13] If this decline continues, the Arctic may be free of summer sea ice as soon as 2040.[14] Such a change has consequences for the snow-albedo effect, but also implications for increased shipping and other activities, which in turn may increase emissions in the region.

    d. Changes Extend Beyond the Arctic: Climate processes unique to the Arctic have significant effects on global climate, with changes underway extending beyond the Arctic Region. Examples of these global impacts include sea level rise from melting Arctic glaciers and increased global warming as a result of increased absorption of solar energy in the Arctic.

    e. Indigenous Groups: As a result of these changes, indigenous groups who depend on subsistence hunting and gathering practices are at risk. Risks include food insecurity due to decline of marine and land wildlife species, reduced quality of other food sources such as wild berries and fish,

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[11] 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.
[12] Holland, M.M. and C.M. Bitz, 2003: Polar amplification of climate change in coupled models. Clim. Dynam., 21, 221-232.
[13] Polyak et al., History of Sea Ice in the Arctic, Quaterary Science Reviews, 2010
[14] Holland M.M., Bitz C.M. & Tremblay B., "Future abrupt reductions in the summer Arctic sea ice" *Geophys. Res. Lett.*, 33 . L23503 (2006).

disrupted land traffic due to infrastructure damage from melting permafrost and forced relocation due to increased coastal erosion.[15]

f. Arctic Emissions: International action to reduce LLGHGs cannot prevent these dramatic changes to the Arctic in the near term[16], therefore additional complementary near-term strategies should be devised.
   i. Recent studies suggest that BC emitted in and near the Arctic has a stronger influence on Arctic warming and melting than emissions outside this region.[17] [18]
   ii. Over highly reflective surfaces such as ice and snow, even a small amount of BC mixed in with OC and sulphate-containing aerosols can be "warming" because the resulting mix is 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.[19]
   iii. A recent report to the IMO's Marine Environment Protection Committee suggests that BC and ozone emissions 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,[20] this is a source category that merits more attention.

22. **Other Climate Impacts:** The climate impacts of aerosols (including but not limited to BC) are not limited to temperature impacts but also include: contributing to changes in rainfall patterns and rainfall suppression; reducing surface water evaporation; changing clouds properties; and creating a positive feedback loop that worsens air pollution episodes. This latter effect occurs when BC heats the lower atmosphere, limiting the amount of solar radiation that reaches the earth's surface (sometimes called surface dimming). The effect of this lower atmosphere 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.[21]

23. **Human Health Impacts:** In the same way that co-emitted pollutants must be considered to understand the full suite of climate impacts, so must these emissions be accounted for when considering public health. There is broad scientific consensus that fine particles are associated with significant adverse health effects. Many scientific studies have linked levels of $PM_{2.5}$ and PM_{10} to a wide range of serious health effects, including increased morbidity and mortality from cardiovascular and respiratory conditions and lung cancer. Current knowledge does not allow precise quantification or definitive ranking of the health effects

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

[16] 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

[17] 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, 2008.

[18] Hirdman, D., Sodemann, H., Eckhardt, S., Burkhart, J.F., Jefferson, A.., Mefford, T., Sharma, S., Strom, J., and Stohl, A. (2010a) Source identification of short-lived air pollutants in the Arctic using statistical analysis of measurement data and particle dispersion model output. *Atmos. Chem. Phys., 10. 669-693.*

[19] Flanner et.al, "Springtime warming and reduced snow cover from carbonaceous particles", Atmos. Chem. Phys., 9, 2481–2497, 2009, www.atmos-chem-phys.net/9/2481/2009/ .

[20] Lack, D., et al. (2009) "Particulate emissions from commercial shipping; chemical, physical and optical properties." J. Geophysical Research, 114, D00F04.

[21] V. Ramanathan & G. Carmichael, Nature Geoscience 1, 221 - 227 (2008)

of PM emissions from different sources or of individual PM components. Available studies do not attribute the observed health effects to a particular characteristic of PM (other than mass). While it is difficult to link a single constituent of particulate matter to a specific health outcome, a WHO workshop acknowledged that the available evidence on the hazardous nature of combustion related PM (from both mobile and stationary sources) is more consistent than from PM from other sources.[22] It is known, for example, that polycyclic aromatic hydrocarbons, a variety of persistent organic pollutants and other toxics are inevitable products of incomplete carbonaceous fuel combustion. BC, a primary pollutant and a good indicator of combustion related PM, has been associated with respiratory[23] and cardiovascular[24] health effects.

24. Available human evidence shows that diesel soot – composed in large part of BC - represents a lung cancer hazard at occupational exposures. It is reasonable to presume the hazard extends to environmental exposure levels. The U.S. Environmental Protection Agency (USEPA) concludes the overall evidence for a potential cancer hazard to humans resulting from chronic inhalation exposure to diesel soot is persuasive, even though assumptions and uncertainties are involved[25] and that diesel soot is "likely to be carcinogenic to humans by inhalation." Additionally:
    a. The most recent report of the Convention's Joint Task Force on the Health Aspects of Air Pollution observed that many epidemiological studies confirm that chronic exposure to PM 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.[26]
    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. [27]
    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 PM will produce the greatest health benefits on a per ton basis as compared to strategies that reduce $PM_{2.5}$ precursors.[28]

25. **Effect of Current Air Quality and Climate Strategies**: Climate and air quality are inextricably linked, and strategies devised for one will very likely impact the other. For example, air quality strategies that have focused on reducing emissions of sulphate precursors because of the importance of this pollutant for public health and ecosystem protection, have produced a mostly warming effect. Because sulphate aerosols have a mainly cooling effect, reducing these emissions has unmasked underlying anthropogenic climate change that would have occurred in the absence of these emissions. Similarly, the use of biomass is growing in some countries due in part to a desire to decrease CO_2 emissions from fossil fuel use. This

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[22] Health relevance of particulate matter from various sources. Report on a WHO workshop Bonn, Germany 26-27 march 2007. WHO Regional Office for Europe 2007
[23] N. Kulkarni et al., N Engl J Med 355, 21-30 (2006).
[24] A. Peters et al., Epidemiology, 1, 11–17 (2000)
[25] U.S. EPA Health Assessment Document for Diesel Engine Exhaust. U.S Environmental Protection Agency, Office of Research and Development, National Center for Environmental Assessment, Washington Office, Washington DC EPA/600/8-90/057F, 2002
[26] 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
[27] U.S. EPA. Integrated Science Assessment for Particulate Matter (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-08/139F, 2009.
[28] Fann et al., "The influence of location, source, and emission type in estimates of human health benefits of reducing a ton of air pollution," *Air Quality, Atmosphere & Health*, Volume 2, Number 3 / September, 2009

may result in the increase of local and regional levels of BC. It is imperative for the global community to 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 in the near term. The EB should consider the advantages of integrated air quality and climate policies. Specifically, the EB should continue to seek health driven reductions in "climate cooling" pollutants (e.g., sulphates) while also pursuing reductions in "climate warming" pollutants (e.g., black carbon).[29] [30] [31]

26. 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 investments in emission characterization activities. There is general consensus that mitigating BC will lead to positive regional impacts by reducing BC deposition on snow and ice, though uncertainties remain in the understanding of global impacts. These limitations do not, however, minimize the need for action in the near term.

27. **Short Atmospheric Residence Time:** The fact that BC stays in the atmosphere for a few days to a few weeks means atmospheric concentration of BC can be reduced quickly, unlike long-lived gases. BC reductions do not supplant the need for ambitious reductions in carbon dioxide and other greenhouse gases. Rather, BC, methane and ozone reductions offer the best opportunity to reduce the near-term climate effects that are critical for sensitive regions of the globe. Known control measures for these substances offer an opportunity to reduce near-term climate damage and reap significant health benefits in the regions investing in mitigation measures.

28. **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 LLGHGs. To do so detracts from the science and policy case that can be made for taking action to reduce BC 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.

29. **Role of the Gothenburg Protocol:** There are clear environmental benefits to reducing emissions of BC. Reductions will benefit the Arctic and alpine regions, benefit public health, and likely is a no-regrets strategy for reducing global radiative forcing. Given the Convention's stature and success in negotiating and achieving real emission reductions in air pollutants, the EB should actively consider the options for action presented in this report.

30. **Summary of Current Activity:** Parties under the Convention and other external bodies are actively involved in assessing BC and its climate and public health impacts. A short description of these activities is available as Annex I to the report. The level of activity within individual countries varies, but includes increased monitoring, country-specific research on emission characterization and inventories, and consideration of BC specific control strategies. There will be some overlap between all these efforts, but each may contribute more refined information on various aspects of BC's role in climate change. At this

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[29] M.V. Ramana et al., Warming influenced by the ratio of black carbon to sulphate and the black carbon source, *Nature* Geoscience, Published online 25 July 2010.
[30] Kloster et al, A GCM study of future climate response to aerosol pollution reductions Climate Dynamics, 34, 2010
[31] Raes and Seinfeld New Directions: Climate change and air pollution abatement: A bumpy road. Atmospheric Environment, 43 (32). pp. 5132-5133. ISSN 1352-2310

time, however, it is not anticipated that the outcome of any of these reports would fundamentally change the recommendations of this Expert Group.

EMISSION INVENTORIES

31. Understanding the emissions of BC is needed for well-designed mitigation strategies capable of achieving both climate and public health benefits. Several global emission inventories are widely used and referenced in addition to a number of national level data sets. These different inventories vary in both total amount of black and organic carbon emissions and the relative contributions of the emitting sectors. BC and OC inventories have an estimated uncertainty up to a factor of two (higher for open burning).[32] The disparity between existing inventories derives from large uncertainties in the magnitude of emissions, lack of information regarding the physical distribution of sources, and gaps in knowledge regarding the emissions from specific source categories. Information is lacking for several potentially important sectors such as flaring, shipping, and agriculture and forest burning. Not only is information lacking or deficient for BC, but also for the emissions of the co-emitted pollutants. Improving emission inventories will enable the Parties to both identify optimal control measures and identify sources that may be under-reported or missing from known inventories.

32. The Parties to the Convention do not have an obligation to report BC emissions, so this report relies on the emission inventory data available from the International Institute for Applied Systems Analysis (IIASA).
    a. In July 2010, IIASA provided to each Party to the Convention the information within the GAINS model for that country. The information included the principal emission outputs from the GAINS model documenting the current state of BC/OC and $PM_{2.5}$ implementation in the model, and the principal inputs 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. The Parties may also choose to use that data as they develop their own national BC estimates.
    b. Because the GAINS model is under development and discussions with national experts were initiated only recently, this report does not attempt to compare existing national estimates with the data in GAINS. Discussions to date do demonstrate the need for careful evaluation as differences for specific sectors might be very large.

33. IIASA has updated activity data, control strategies, emission factors, and other model parameters during the work on the revision of the Gothenburg Protocol. The 2005 UNECE emissions of BC and OC as constituents of $PM_{2.5}$ by SNAP sectors are presented in Figure 1.

[32] 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

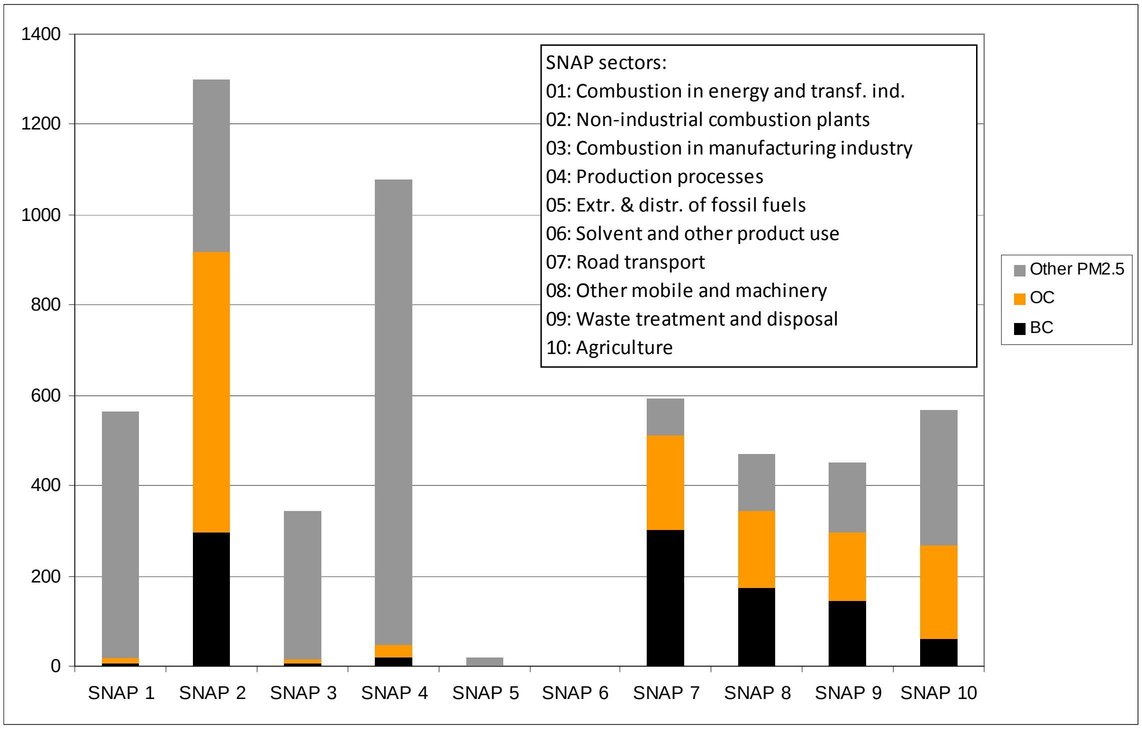

Figure 1. Emissions of BC, OC, and $PM_{2,5}$ in the UNECE (incl. US/CA) for 2005 by SNAP sector *Source:* GAINS model

34. The BC/OC ratio may be a relevant metric for identifying priority sources in many parts of the world, though it may not be as relevant for snow and ice covered regions. Figure 2 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 bars represent the low and high boundaries of the ratios calculated and show the dramatic difference between countries due to the importance of different sectors and their different emission characteristics.
    a. For example, while total residential sector emissions (SNAP 2 in Figure 1) are dominated by biomass burning characterized by a higher share of OC and BC in $PM_{2.5}$, some UNECE countries still use significant amounts of coal in this sector leading to higher share of the BC in $PM_{2.5}$ (Figure 2) in those countries.
    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 to significant mischaracterization of regional $PM_{2.5}$ 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 characteristics (demonstrated in Figure 2)

such as combustion devices, vehicle types, driving habits, fuels, etc..

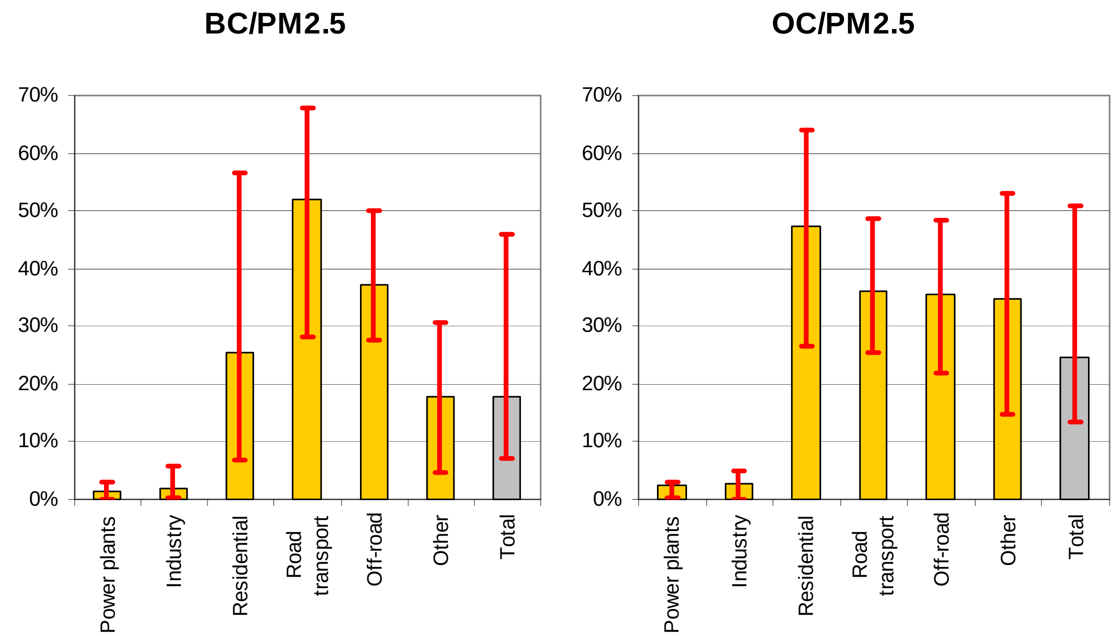

Figure 2. Share of BC and OC emissions in $PM_{2.5}$ (year 2000-05) sectoral total for the whole of the UNECE region and variation between all countries (Red bars indicate low and high).
Source: Preliminary GAINS estimates; 'Industry' equals sum of SNAP 3,4,5,6 and 'Other' the sum of SNAP 9 and 10.

35. 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 emission factor 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 activity levels for various sources) and in a top-down manner (i.e., emissions estimates based on field or satellite measurements and transport modeling).[33] For example, the "Coordinated European Particulate Matter Emission Inventory Program" (CEPMEIP) was initiated within the EMEP working programme and supported by the European Environment Agency (EEA) to develop default methods and emission factors for the use of national experts when submitting primary particulate matter (PM) emission inventories within the CRLTAP/EMEP framework. This type of effort is needed to enable consistent comparisons to be made across national and, to the extent possible, global emission inventories and develop source appropriate mitigation strategies.

36. 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, BC emissions are estimated by matching $PM_{2.5}$ emissions from the national inventory to source-specific elemental carbon speciation information from a database of source category-specific emission speciation profiles. This approach provides information regarding the biggest emitting sources and how much BC mitigation potential remains, but introduces

[33] 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

some uncertainties in the estimates. Similar to the inventories themselves, uncertainties in the emission profiles will vary between countries and sectors. Variability in fuel type, fuel amount, combustion efficiencies, operational practices, and other factors influence the emissions of both BC and co-emitted pollutants.

37. 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. Recent Finnish national measurements have shown that in one of the key sectors, residential combustion, Finnish operational practices and appliances may result in significant differences in the amount and composition of emissions when compared with central Europe and North America.[34] 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.

38. Because major uncertainties in emission inventories stem from a lack of measurement data, ambient and source measurements of BC and its source apportionment should be encouraged. Specifically, the EB should consider the ongoing work of EUSAAR (European Supersites for Atmospheric Aerosol Research). The EUSAAR FP7 project pursues the integration of measurements of atmospheric aerosol properties, including OC, elemental carbon, and light absorption. It is important to note that secondary aerosols are not counted in primary emission inventories, but are a component of ambient measurements.

39. For BC, as with other air pollutants, there is a challenge of identifying sources located far from where impacts are felt. At present, observation-based approaches alone cannot provide the information on source attribution and source-receptor relationships. While there is some confidence in source-receptor relationships within Europe, less is known about inter-continental transport and deposition patterns. Sampling of Arctic snow and ice combined with modeling studies indicate significant amounts of BC are anthropogenic, however at this time, particles in receptor regions cannot be unequivocally attributed to specific sources or source regions.[35] The EB should support the efforts underway to improve the quality of emission inventories, the performance of transport models and the coverage and resolution of observations.

REDUCTIONS FROM CURRENT LEGISLATION

40. Because BC is a constituent of primary PM, BC reductions in most of the UNECE region to date have occurred as a result of PM controls. Data collected across Europe suggest a large fraction of anthropogenic PM - up to 50% - is formed from emissions of the secondary particulate precursors (SO_2, NOx, NH_3, and NMVOCs).[36] In Europe, reductions of SO_2 since 1990 have accounted for 60% of the overall reduction in particle formation, with NOx accounting for a further 30% of the reduction. The

[34] 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.
[35] Draft 2010 Assessment Report on the Hemispheric Transport of Air Pollution Part A DRAFT 06/07/2010 2-31.
[36] 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.

reduction in emissions of primary particles has accounted for only 6% of the overall reduction.[37] 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.[38]

41. The reductions in total emissions of PM between 1990 and 2007 have been mainly due to the control technologies applied to energy, road transport, and industry sectors as well as non-technical measures, such as fuel switching, in industrial and domestic sectors. Emissions of primary PM_{10} and secondary PM_{10} precursors are expected to decrease in the future as vehicle emission control technologies are further improved and stationary 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, 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 2008/50/EC is to be reached. [39]
    a. The European directive 2008/50/EC sets limit values for daily and annual concentrations for PM_{10}, and annual concentration and exposure targets for $PM_{2.5}$ with the aim of protecting public health from the adverse impacts associated with exposure to particulate matter. The concentration limits and targets are based upon available epidemiological evidence, which does not distinguish between BC and other sources of particles. Compliance with such air quality limits and targets will not necessarily lead to reductions in the concentrations of particular aerosol components such as BC. Moreover, there is no health based metric that could be used at the current time to establish an air quality target for BC alone that would drive emissions reductions of BC.
    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). The upcoming Euro VI standard for heavy duty vehicles (into force in 2013 and 2014 for type-approval and registration respectively) sets a limit of 10 mg PM /kWh (50% reduction of emissions in comparison to the current Euro V standard) as well as a stringent particle number standard (current number under discussion is $6x10^{11\,\#}$/kWh). 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).[40]

42. A combination of factors has contributed to the reduction of both primary PM_{10} and secondary particulate matter emissions between 1990 and 2007.[41] The reductions for primary PM_{10} include:
    a. improvements in the performance of particulate abatement equipment at combustion installations;

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[37] 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
[38] Raes and Seinfeld New Directions: Climate change and air pollution abatement: A bumpy road. Atmospheric Environment, 43 (32). pp. 5132-5133.
[39] 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
[40] Source apportionment of PM10 in ten cities of the Lombardy Region, winter (2006-2007). B. Larsen, Collaborative Research Project for Air Pollution Reduction in Lombardy, Italy (2006-2010). Identification of air pollution origin and Source apportionment.' Fifth progress report. October. 2008. 90 pp.
[41] 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

b. improved, cleaner stoves
c. lower emitting vehicles

43. 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 in 2005 originated from the residential (30%) and transport sectors (50%). There are, however, important regional and sectoral variations.
    a. In the Russian Federation major contributions come from oil and gas flaring[42] and open burning of agricultural residues, and forest fires. Lack of activity data and emission factors for these 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 on-road transport sector, which may increase the relative contribution of the residential, industrial and non-road sectors in the longer term.

44. Figure 3 shows expected future development of BC emissions assuming successful implementation of the current legislation (CLE). Although there is no specific legislation targeting carbonaceous aerosols, existing and proposed PM and SO_2 regulations are expected to bring significant reductions of BC and primary OC.
    a. While residential combustion is and remains in the future a key BC emitting sector, emissions from the transport sector (especially on-road) are expected to decline by about 70 percent by 2020 provided current policies (e.g., diesel particulate filter (DPF) technology) bring expected reductions.
    b. The highest overall reductions are expected in the EU-15, where BC emissions could decline by about 50 percent by 2020. This expected reduction is greater than, for example, that expected in the US and the Russian Federation (-38 and -25 percent, respectively) through implementation of current legislation. However, current legislation is expected to have less of an impact on emissions from stationary diesel engines and non-road mobile machinery (including the marine sector), which will increase these sectors' relative importance for future mitigation efforts.
    c. On-road measurement studies of vehicle emissions conducted in some countries show that a small fraction of the vehicle fleet is responsible for a large share of emissions. These vehicles are referred to as high emitters or super emitters. [43] 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 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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[42] The GAINS data for oil and gas flaring was reviewed using 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).

[43] 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.

d. Non-road mobile machinery may offer some potential for future mitigation. The US has adopted a comprehensive national program to reduce emissions from future non-road diesel engines by integrating engine and fuel controls as a system to gain the greatest emission reductions. Because these reductions apply to newly built engines and controls are not required for the existing fleet, these engines are expected to be a continuing source of BC emissions.

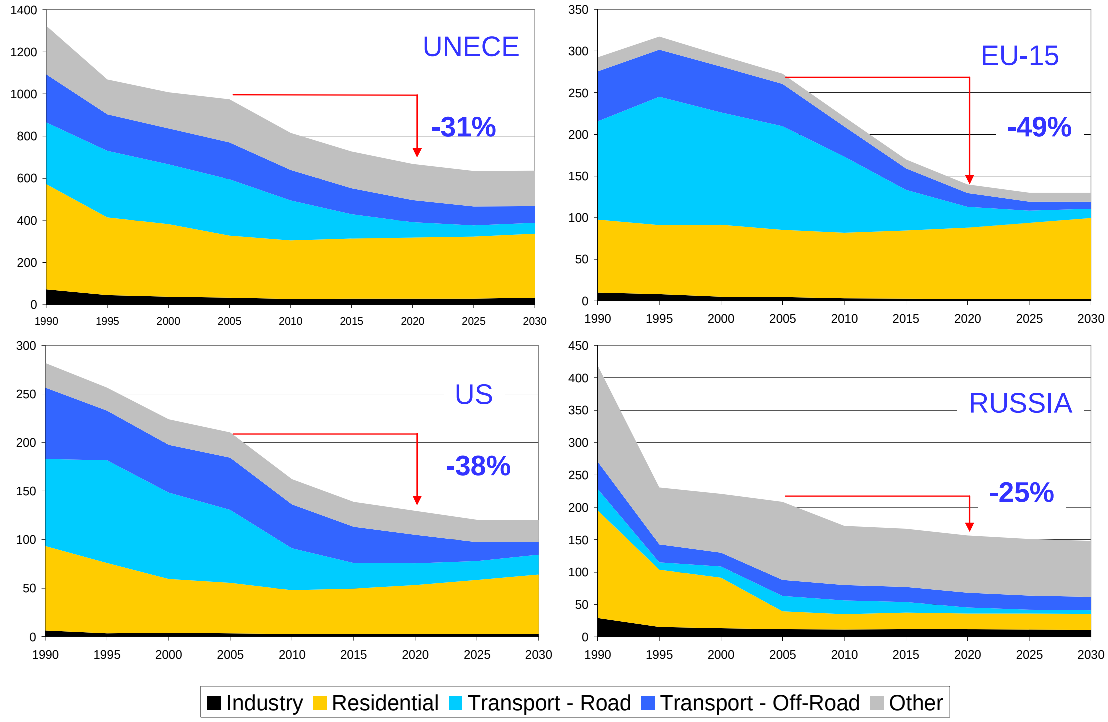

Figure 3. Sectoral structure and development of BC emissions [kt] in selected UNECE regions in the CLE scenario; indicated reductions refer to the change between 2005 and 2030 – *Source:* GAINS model

45. Because 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. For example, on 7 July 2010 the European Commission (the executive branch of the EU) proposed to extend an existing flexibility scheme to allow continued 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. The effect of this action is to postpone the entering into force, and diminish or delay expected reductions.

POTENTIAL ADDITIONAL REDUCTIONS

46. 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 electrostatic precipitators will reduce BC, while cyclones and scrubbers will not reduce BC to any significant degree, but can reduce the larger particle species.

47. Because of the public health benefits of reducing BC, as well as the location of the countries across the Convention regions in relation to the Arctic, the EB should consider taking additional (BC specific) measures to reduce BC. Impacts on the Arctic and alpine areas will vary by country, but all countries will benefit from local emission reductions of BC and other co-emitted pollutants. All countries will benefit from preventing the melting of the Arctic ice cap.

48. Similarly, the EB should consider not only specific new measures, but assess whether the existing measures are being implemented with an adequate fidelity and speed needed to avoid the most catastrophic results, for example sea ice and ice sheet melt. It is important for the EB 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 heavy duty transport and non-road vehicles, and the impact of these reductions on sensitive regions. The EB should consider careful monitoring of existing legislation and strengthening policies in this area.

49. 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 measures will vary across regions and countries. 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. As stated earlier in this report, any control measure considered should be assessed in an integrated way for its overall climate and public health impact, including the full range of co-emitted pollutants.

50. **Potential Mitigation Measures:** Overall, BC emissions in the UNECE region are expected to decline between 2000 and 2020 by about one third as a result of ongoing implementation of current emission control legislation in the transport sector (Figure 3). IIASA estimates suggest that additional measures are available to reduce BC emission by another 40% by 2020. These measures are discussed in the paragraphs below.

51. *Residential Combustion:* By 2020, small-scale residential heating will become the dominating source of BC emissions in most countries and cause about half of total emissions. This trend could be even stronger if additional biomass combustion is promoted as a climate policy measure. Thus, effective reduction strategies must address residential combustion as a priority, with an estimated nearly 50% of the remaining mitigation potential in the UNECE region resting in this sector. Implementation will require a combination of technical and non-technical measures. Appropriate technology exists and is available on most markets. However, it is essential to explore implementation barriers and the practical feasibility of implementing specific measures within a given time horizon.

52. Emissions from new residential combustion stoves and boilers could be reduced through product standards and emission limit values that reflect state-of-the-art combustion technology. For example, modern pellet stoves and boilers could significantly reduce BC emissions from biomass combustion. Emissions from existing residential combustion installations can be reduced through retrofit programs and improved operation practices, for which public information and awareness programs will be necessary. Dedicated

programs could provide incentives to replace the oldest boilers and stoves by modern installations and stimulate the exchange or retrofit of old appliances.

53. For effective implementation of all these measures, international harmonization of measurement methods and certification tests that account for fuel savings will be necessary.

54. *Non-road machinery:* As off-road machinery has a long life time and often poor maintenance, this sector offers the second largest technical potential for reduction of BC emissions in the UNECE region. While current legislation should lead to lower emissions in this sector in the future, compliance will be critical. In addition, emissions could be further reduced through accelerated introduction of particle traps (DPF) for new machinery and retrofitting of existing machinery with DPFs. This could be implemented by mandating all non-road diesel engines comply with emission standards similar to heavy duty vehicles, i.e. the upcoming Euro VI standard. Eliminating high emitting vehicles and enforcing Euro-VI standards (where applicable) accounts for nearly 20% of the total reduction potential in the region.

55. *Road Transport:* Current legislation is expected to achieve significant reductions of BC emissions in the next decade in this sector, though it is essential to assure the effectiveness of this policy, e.g., through regular (annual) emission testing programs in all UNECE countries. Additional reductions include elimination of high emitting vehicles (super-emitters) and accelerated introduction of particle traps (DPF) for light duty and heavy duty vehicles, and retrofitting of existing vehicles. Overall, in 2020 these measures account for less than 10% of the total mitigation potential in the UNECE region.

56. *Open burning:* Although open burning of agricultural residues is already banned in several UNECE countries, the enforcement efficiency is largely unknown and remote sensing data shows that burning continues across large areas of the region. Activity and emissions data are more uncertain than for other sectors. It is estimated that an effective ban of open burning could account for about 10% of the total reduction potential for BC emissions. Additionally, agricultural fires often cause forest fires, which are in turn another important source of emissions. However, there are significant implementation barriers in some countries (e.g., jurisdictional issues in North America).

57. *Shipping:* To encourage the use of the best available techniques and accelerate the introduction of cleaner fuels and ships IMO regulations could be complemented by strict national or regional emission standards and/or by economic instruments, such as emission charges. Additional mitigation may be achieved from sources associated with port activities. Examples of mitigation activities include port electrification.

58. *Industry and power generation:* In relation to other sources, there is only a relatively small potential for further reduction of BC emissions in this sector and it is estimated that measures in these sector account for less than 5% of the total potential in the ECE region The most important source in this sector are small (<50 MW_{th}) poorly operated old plants using coal, oil, and biomass. Though little data exists regarding the actual numbers and contribution of these small installations, setting tight emission standards would either force operators to close or install end of pipe controls (e.g., ESPs, fabric filters), and consequently reduce emissions. For example, in Sweden about 19% of small district heating plants (10-30 MW) are not equipped with end-of-pipe controls for particulate matter while in Finland most plants below 20 MW have only cyclones, excluding oil boilers that usually have no PM abatement.

59. *Flaring:* Although anecdotal evidence suggests gas flares can be a significant source of pollution, the overall magnitude of BC emissions is very uncertain. More effective methods to quantify black carbon emissions are currently being developed through a Canadian research effort. Additionally, flare improvements programs are underway (e.g. reducing venting and flaring) in a few countries (e.g., Canada and Norway), but their impact on BC release is unknown. Resources should be made available to better understand activity data and actual BC emissions from this source.

60. *Waste (garbage) burning:* Although open garbage burning has been banned in most countries, the effectiveness is a subject of concern and this source might be locally representing a measurable contribution to BC emissions. Emissions could be reduced by assuring enforcement of this law or introducing such legislation if it is missing.

OPTIONS FOR POTENTIAL REVISIONS TO THE GOTHENBURG PROTOCOL

61. The EGBC recommends the EB to consider options to mitigate BC as a component of PM when making revisions to the Convention's 1999 Gothenburg Protocol. A range of options are outlined below.

62. **Monitoring and Reporting:** One of the greatest challenges in the overall effort to understand and effectively mitigate the impacts of BC (and other carbonaceous aerosols) is lack of data. At this time, no country has a comprehensive program to measure and report BC emissions. Given the uncertainties of the inventories, inconsistencies in measurements, 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 BC. This could include specifically listing the constituents of PM, as in the EU air quality Directive 2008/50/EC, when including the pollutant in the Protocol language.

63. 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, OC and other co-emitted pollutants outside the auspices of the Convention, for example EUSAAR and IMPROVE[44]. The list below offers examples and is not intended to be an exhaustive listing of all possible action, nor should the order presented be interpreted as establishing any priority.
    a. Source Measurement and Emission Factor Development
        i. Characterize and define various carbonaceous aerosol properties (mass, number, size distribution, absorption and scattering coefficients, indices of refraction).
        ii. Identify and characterize missing sources.
        iii. Compile and evaluate all available emissions and activity factors, with guidelines on when they are appropriate to use.
        iv. Identify a central location where emissions test data would be collected, quality assured, and disseminated and establish mechanisms for continuous improvement of emission factors for specific and currently relevant sources.
    b. Emission Inventories

[44] The IMPROVE (Interagency Monitoring of Protected Visual Environments) network monitors aerosols in the United States. http://vista.cira.colostate.edu/improve/

   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 and Projections should give priority to more work on guidelines for BC inventories with a focus on BC/OC 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.

c. 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 for sampling and chemical analysis[45] recommends a provisional standard methodology but is waiting for the completion of the CEN effort[46] to make this recommendation permanent. 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 (EC) and OC in PM_{10}, and the determination of the aerosol absorption coefficient. Meanwhile, the Directive 2008/50/EC requires the monitoring of EC and OC at rural background sites (i.e. where EMEP stations are to be located) in $PM_{2.5}$. It might seem unreasonable for Parties that are EU member states to implement the monitoring of EC and OC in both PM size fractions, when EC is very likely mainly in $PM_{2.5}$. A specific EMEP intensive campaign could help to verify this.

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

e. Control options
   i. 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.
   ii. 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.

f. Cost effectiveness
   i. The EB should request the Task Force on Integrated Assessment Modelling to assess the cost effectiveness of mitigation options.

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[45] (http://tarantula.nilu.no/projects/ccc/manual/index.html)
[46] Cavalli et al. Toward a standardised thermal-optical protocol for measuring atmospheric organic and elemental carbon: the EUSAAR protocol, Atmos. Meas. Tech., 3, 79-89, 2010

64. The EB should support the initiative by EMEP to define BC or more accurately, operationally define each component of PM that is important from a climate perspective. This means reaching agreement on how the Parties will define, measure and use different terminology regarding light absorbing (and scattering) carbonaceous aerosols. This could be then included in the definition article of the Protocol.

65. **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 climate effects, public health co-benefits, and ongoing work in other forums.

66. **Environmental Objective**: The EB 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 BC that can be used to measure progress and for integrated assessment modelling. Options could include either qualitative or quantitative objectives or both. 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 a certain percent the amount of deposited BC on snow. Other examples could include impacts on near term radiative forcing and other appropriate near term climate metrics.

67. **Country Specific Goals:** The ability to establish country specific goals will depend on how accurately sources of BC emissions can be identified, and ideally, source - receptor relationships established. The country specific goals outlined below may be for consideration in the medium- rather than near-term given 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 Convention country. These may be developed for PM with a focus on sources known to be high emitters of BC. The EB could charge the EGBC or other Convention 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 the inventories and modelling are not yet able to be used 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 EGBC or other Convention 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 EGBC, or some other Convention body to develop additional options for mechanisms by which Parties who do not ratify the revised Protocol might make verifiable and measurable progress toward the stated environmental objective.

68. **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 BC. Examples include a timeline for complete removal of super-emitting vehicles; replacement of older residential heating stoves with pellet stoves, emission limits for categories of road and non-road vehicles on an accelerated schedule; or emission limit values on industrial boilers for which known and cost effective controls exist.

69. **Financial Resources:** The efforts suggested to improve the availability of data on black carbon will require significant resources. The EB may wish to consider how to ensure adequate resources are available to implement this work, including potential ways of cooperation to ensure implementation in all Parties.

70. **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 BC and other short lived climate forcers. In addition to the work identified above, for example, ongoing analysis from the International Polar Year 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 mechanisms for revising the protocol to rapidly take action as a result of further scientific synthesis.

71. As individual countries take action unilaterally or under the Convention, further analysis is needed to ensure 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.

72. **Non-binding Goals:** The EB should consider whether to make a statement outlining even more ambitious non-binding environmental objectives. Examples include potential actions outside the Convention 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 nations that are members and/or observers of the Arctic Council. The EB could also encourage existing task forces and expert groups do additional outreach to non-UNECE countries and to be inclusive of BC related research and mitigation activities.

73. While the EB should prioritize work to ensure development within the Convention region, the EB could also encourage actions outside the UNECE region that may include:
    a. Capacity development for BC emissions monitoring and reporting,
    b. Support for development of institutions and infrastructure for monitoring and reporting,
    c. Transfer of BC reduction technology for key emission source sectors.

74. The EB could consider entering into memoranda of understanding with non-UNECE states that are significant sources of BC emissions transported to the UNECE region and key sensitive regions, such as the Arctic, focusing on sources identified as a priority for BC reduction in the amended Protocol.

75. The EB could consider developing mechanisms such that certain obligations – e.g., to cooperate in developing BC monitoring and reporting capacity, institutions and infrastructure – would be binding upon select non-UNECE States that make an explicit declaration to this end. Alternatively, such a provision could be included into the Gothenburg Protocol.

76. The EB may also wish to consider exchange and capacity development on BC monitoring, reporting and technology transfer with interested nations, such as those in the Association of Southeast Asian Nations (ASEAN) Agreement on Transboundary Haze Pollution and the Male Declaration.

77. The EB should urge the IMO to enact requirements to reduce emissions of BC from international shipping, especially emissions in those areas that impact Arctic climate.

78. **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 the understanding of the relationship of these measures to climate impacts of concern. The EB could consider tasking EMEP or other Convention body with identifying appropriate metrics and timeframes for inclusion in the Gothenburg Protocol.

79. With several major assessments being issued over the course of 2010 and 2011, the EB could consider charging the EGBC or other Convention body with synthesizing the results of these assessments to determine what new information is available to inform ongoing development of the Gothenburg Protocol.

Annex I
Summary of Current Activities

Activities related to black carbon are taking place in several countries across the Convention 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 these 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.

a. *LRTAP Task Force on Hemispheric Transport of Air Pollution 2010*: The Task Force, co-chaired by the European Union 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 EU 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.

Additional work is being conducted by organizations related to but outside the auspices of the Convention

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. The co-chairs of the AMAP Expert Group on Short Lived Climate Forcers participate in the task force. The AMAP expert group on SLCFs will provide scientific and technical advice regarding 1) the formulation of mitigation strategies; and 2) the assessment of Arctic climate benefits and other potential related co-benefits of the mitigation strategies developed by the task force.

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.