CCAC responses to key questions taken from the 'Scope and Key Themes' document prepared for the upcoming (May 2018) IPCC Expert Meeting on Short-Lived Climate Forcers (SLCF) meeting, Geneva.

Theme 1. Assessment of existing methodological framework, observation of atmospheric concentrations and methods to estimate emissions of SLCF

- ***How accurately can we monitor SLCF sources and emission trends, and link them to atmospheric concentrations?***

At a global level, the GAW-WMO programme offers guidelines for the measurement of ambient concentrations of SLCF gases (methane, ozone) and aerosols, including black carbon (GAW Report No. 153, revised in GAW Report No. 197, 2011). Data quality and submission procedures are closely assessed by GAW. Some stations have long term records and in conjunction with national inventories and modelling provide a way to assess the accuracy of the link.

- ***On what SLCF species do emission quantification methodologies already exist, and at what scale (regional, national, sub-national, etc)?***

Quantification methodologies already exist for estimating emissions of the SLCFs [aerosols (black carbon (BC), organic Carbon (OC), $PM_{2.5}$) and the ozone and aerosol precursors (NOx, CO, NMVOC, SO_2, and NH_3)]. Guidance is provided in the European Monitoring and Evaluation Programme/ European Environment Agency (EMEP/EEA) *Emissions Inventory Guidebook* (EMEP/EEA, 2016) to which the IPCC (2006) Guidelines refer those wanting to compile inventories of non-GHGs. Recent interest in BC as a significant positive climate forcer led to the inclusion of voluntary reporting of BC emissions within the Gothenburg Protocol of the UN Economic Commission for Europe's (UNECE) Convention on Long-Range Transboundary Air Pollution (CLRTAP). In order to allow countries to make BC emission estimates, information was added to the 2013 version of the EMEP/EEA *Emissions Inventory Guidebook*, and updates were made for the 2016 version. The voluntary reporting of BC within the CLRTAP has proved to be successful, with more than 30 countries providing emissions estimates. The Annex to the EEA/EMEP guidance includes also references and comparison of several studies where emission factors for organic carbon (OC) were measured/evaluated; however, it is not complete and there is no final guideline provided to report emissions of OC.

Guidance on developing BC emission inventories has also been developed for the Commission for Environmental Cooperation (CEC) countries of North America (Canada, USA and Mexico) (CEC, 2015). These guidelines follow the format of the IPCC (2006) guidelines and EMEP/EEA guidebook and provide a consistent set of methods to improve comparability and completeness of North American BC emission inventories.

The Climate and Clean Air Coalition (CCAC) has developed an initiative *Supporting National Action and Planning* (SNAP) to reduce SLCPs, which is helping countries to set priorities for action to reduce SLCP-related emissions. Part of this activity is the development of emission inventories and emission scenarios to quantify emissions of BC and co-emitted pollutants (including all the other SLCFs) necessary to quantify benefits of mitigation scenarios from all sectors. A software tool (LEAP-IBC[1]) and associated guidance have been produced to assist countries in this activity. The CCAC SNAP initiative is currently supporting 12 countries to estimate emissions, scenarios and impacts

[1] https://www.energycommunity.org/default.asp?action=IBC

(Bangladesh, Ghana, Mexico, Colombia, Chile, Mexico, Cote d'Ivoire, Togo, Nigeria, Philippines, Morocco, Maldives).

All these methodologies are focused on developing national-scale emissions estimates of SLCFs.

Additionally, there exist few models/tools that have been created to estimate systematically inventories and projections of SLCFs and other pollutants and have also country, region and for some countries also sub-national resolution. Examples include SPEW (Bond et al., 2004, 2007, 2013) and GAINS (Amann et al., 2013; Kupiainen and Klimont 2004, 2007; Hoglund, 2012; Klimont et al., 2017). These tools were used to produce peer reviewed estimates but what makes them different from several other peer reviewed studies (inventories like EDGAR, REAS, etc.) for particular country or region is that they can and are used by other users than the original developers of the studies; in a way similar to LEAP.

The Global Emissions InitiAtive (GEIA http://www.geiacenter.org/) is an international community effort dedicated to emissions information exchange and competence building. It was created in 1990 under the International Geosphere-Biosphere Programme in response to the need for high quality global emissions data. GEIA is now a joint activity of the International Global Atmospheric Chemistry Project (IGAC) and the Integrated Land Ecosystem-Atmosphere Processes Study (iLEAPS). GEIA has maintained an extensive global network of emissions experts, builds emissions data access and analysis platforms, and communicates with the emissions community through online resources and in-person meetings. GEIA is currently supporting the analysis of emission data in four different targeted working groups. Through its China Working Group, GEIA gives exposure to the proliferation of emissions research in China, facilitating the use of new Chinese emissions understanding by the global community. Through its Latin America/Caribbean (LAC) Working Group, GEIA is providing a venue for Latin American emissions experts to work together, and has helped to initiate the development of the first locally-produced emissions inventory for South America. Through its Non-Methane Volatile Organic Compound (NMVOC) Working Group, GEIA has made progress in understanding the sources and variability of NMVOC emissions in the world's urban areas. Through its Urban Working Group, GEIA began efforts to build competence to face urban emissions compilation challenges, carry out activities to benchmark urban emissions following FAIRMODE, and to provide a forum for exchanging experiences and best practices in urban emissions understanding. GEIA is currently investigating the possibility of convening regional Working Groups for Africa and South-East Asia. GEIA host international databases for emission data and information through the ECCAD: Emissions of atmospheric Compounds and Compilation of Ancillary Data datacenter. ECCAD is the single most relevant emission data center on a global basis and includes among other the emission information compiled under LRTAP Task force on Hemispheric Transport of Air pollution, the Chemistry Climate Modeling Initiative (CCMI), emissions under the Copernicus Atmosphere Monitoring Service (CAMS) and emissions developed in support of the IPCC AR6 assessment report (CEDS). The ECCAD portal provides access to global and regional inventories in a consistent format and to ancillary information used to produce these data sets, along with easy-to-use visualization and analysis tools. (see http://eccad.aeris-data.fr/). The GEIA data are usually expert estimates, and only few officially reported data are currently available, such as the ones collected by EMEP. Still, some of the inventories are based on official reports and have been modified after expert analyses. The ECCAD database provides tools to plot the totals provided by each inventory for the full period over which datasets are available, i.e. 1850-2100.

- ***Are they accessible, comprehensive, globally applicable, up-to-date?***

The above guidance documents and methodologies are easily accessible and reasonably up-to-date. The CEC guidance only applies to BC emissions estimation, but both the EMEP/EEA Guidebook and LEAP-IBC tool cover all SLCF-relevant emissions. However, the current version (2016) of the EMEP/EEA Guidebook does not include a complete set of emission factors for OC, although some of the sectoral chapters contain information on carbon speciation as an annex. The global and regional emission models like SPEW and GAINS use documented methodologies and continue to be updated, assimilating peer review and measurement campaign data, at more frequent intervals than any of the official guidebooks which are typically bound by an official process associated with such update.

In terms of applicability, the EMEP/EEA Emissions Inventory Guidebook has been compiled to meet the needs of Parties to the CLRTAP, and consequently there is a focus on sources commonly found in industrialized countries. Therefore, the methodologies within the Guidebook have important limitations when being used for compiling inventories for developing countries - where technologies and practices may differ radically from those used in industrialized countries. Sources that are common in developing countries that are either not well characterised or not included in the Guidebook include:

- Domestic biomass combustion (especially in traditional cookstoves)
- Open-burning of municipal solid waste
- Traditional brick kilns
- Traditional coke ovens
- Charcoal making

The next two sources refer to open burning of biomass. While the guidelines for these sources exist there are important differences between global regions and large uncertainties in activity data. In several European countries as well as Northern America reporting and monitoring of open burning fires have been more rigid/advanced, including efficient enforcement (at least in some of the countries) of ban on open burning of stubble; While the open fires still occur, and most likely current methods underestimate their extent, the developing countries face a much larger challenge. Key would be to work on analysis of remote sensing and ground data to improve the activity data (as well as emission factors to reflect regional crops).

- Crop residue open-burning in the field
- Forest fires and savannah burning

None of the guidelines includes validated and up to date information for Flaring from oil gas production as there are very few measurements representing selected areas or just particular production wells. These are not yet representative of operations and practices in different regions, both in developed and developing countries. Only recently, new data has been made available that could help to create a more representative set of emission factors.

Additionally, the guidebooks do not include guideline on how to deal with so called high emitting vehicles, issue highlighted in a number of peer reviewed studies, e.g., Smit et al., 2011, and many more. The impact on overall emissions have been highlighted in some regional and global studies (Yan et al., 2014; Bond et al., 2004; Klimont et al., 2017; Evans et al 2017). The SPEW and

GAINS models do include a systematic treatment of high emitting vehicles that can represent a large share of emissions in some regions.

The LEAP-IBC methodology includes many Tier 1 default emission factors from the EMEP/EEA Guidebook but, for the above sectors, also includes default emission factors appropriate for developing countries taken from the literature. The CEC methodology also includes BC emission factors taken from the literature that are relevant to several of the above sectors in Mexico – thus of possible relevance to developing countries elsewhere. However, a comprehensive methodology with a database of default SLCF emission factors for these sectors, that has global coverage, with regional differentiation where appropriate, is currently lacking. The global/regional models (SPEW/GAINS) offer a rather comprehensive set of emission factors which are mostly Tier2/3 type but are data demanding. However, the information and experience included in the models could be used to support development (extension of existing) database where several region-specific source-characteristics could be included.

- ***Are new emission measurements by sources and species available?***

Research in this area is very active and many papers have been published over the last few years focussing on SLCF emissions estimation, especially PM, BC and OC, for the above sectors. These include:

  - Traditional brick kilns (Christian et al., 2010; Weyant et al., 2014; Ortínez-Alvarez, et al., 2018),
  - Open and domestic biomass burning (Johnson et al., 2008, Venkatarman et al., 2005, Akagi et al., 2011; Garland et al., 2017),
  - Kerosene wick lamps (Lam et al., 2012),
  - Gas flaring (Schwarz et al., 2015; Pederstad et al., 2015; Weyant et al., 2016; Evans et al., 2017; Conrad and Johnson, 2017)

- ***What are the most significant knowledge gaps and uncertainties?***

There are uncertainties in emission inventories for all pollutants. Uncertainties in emissions factors tend to be greater for primary PM (including BC and OC) compared with other pollutants, and the characterisation of emissions from sources typical in developing countries of Asia, Latin America and Africa is not widespread, leading to higher uncertainty of emissions from these sources.

While emission factors are indeed an important source of uncertainty, an overlooked problem is lack or only poor activity data (for example use of biomass for cooking and heating, even in the OECD countries) and information about the actual technology used. The latter is very important for several sectors where a wide array of techniques exist at the same time and their emission characteristic vary significantly, e.g., activity data split by types of heating stoves or boilers or for transport engines complying with particular standard (for example EURO standards). While such information might exist in several OECD countries for road transport, non-road machinery data is much more difficult to obtain.

- ***Is it necessary to develop new/improved guidance?***

Yes. Data and limited guidance are currently available to allow initial emission estimates to be determined. However, globally, there is a need for an authoritative and systematic appraisal of emission and activity data to give the best advice to countries, regions, cities and sectors that wish to develop quantitative assessments of BC and co-emitted pollutants, particularly if the emissions inventory is to be used to underpin policy development and implementation.

- ***Is the current knowledge on emissions mature enough to support the development of new/improved guidance?***

Yes. Knowledge concerning relevant emissions has grown considerably over the last 15 years or so. Global research initiatives have now produced national-scale emissions estimates for the whole world for SLCF-relevant pollutants including BC and OC. The International Institute for Applied Systems Analysis (IIASA) has used the Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS) model to develop global emissions of BC and all co-emitted air pollutants. The current emission inventory version is ECLIPSE V5a (Klimont et al, 2017), which estimates emissions for 172 countries. Another global database is EDGAR (Emission Database for Global Atmospheric Research) developed by the Joint Research Centre of the European Commission and Netherlands Environmental Assessment Agency. The most recent EDGAR v4.3.2 dataset covers, in addition to GHGs, emissions of all gaseous and particulate air pollutants, including BC and OC, over the period 1970–2012 (Crippa et al., In review, 2018). The Peking University (PKU) inventory is another example – it is a global, bottom-up emissions inventory covering 11 pollutants including BC, OC, and most other SLCFs other than CH4, from 1960-2014 and spans 64 individual source categories including great detail in the residential sector (http://inventory.pku.edu.cn/download/download.html).

Furthermore, a number of sector specific studies exist which would support further development of guidelines, especially allow to include some locally relevant sources, e.g. wick lamps (Lam et al., 2012), gas flaring (Conrad and Johnson, 2017). Several new studies focused on regions where solid information about activity data and emission factors is missing and their results could help improving guidelines too, e.g., Kholod et al (2016) and several recent studies for China and India.

- ***What new knowledge is expected to emerge in the coming years?***

The recently published study for BC emissions from gas flaring (Conrad and Johnson, 2017) originates from a larger program of measurements and in the near future more data will be made available characterizing emissions with varying gas properties.

The European Union is funding a new activity 'BC Action' lead and coordinated by AMAP (Arctic Monitoring and Assessment Program) of which one of the main goals is identification of knowledge gaps. The project includes several institutions working within LRTAP, modelling, field work in oil and gas sector, residential stoves measurements, etc. The project is running from 2018 through 2021 and is also linked to the development of the next AMAP Assessment report in 2021. Notably, the Arctic Council agreed to reduce emissions of BC, there is a target set for 2030 at the level of 8 Arctic nations, linked also to sharing BC emissions, projections and background reports. The suggested methodology links to the LRTAP EMEP/EEA guidebook but not all countries are using it.

Recently published work on ethane and propane sources (Dalsoren et al., 2018) and methane inventories from oil and gas sector (Hoglund, 2017) will stimulate further discussion on accuracy of estimates of methane loss from oil and gas production.

Theme 3: Suitability for IPCC to develop inventory methodology for SLCF

- ***Which species of SLCF (and which sources) should be prioritised in the future work to develop inventory methodologies?***

Sources of particular relevance to BC emissions should be prioritised to help inform BC mitigation policies although all co-emitted substances from these sources should be covered to enable net climate and atmospheric forcing to be modelled. The sources where the greatest uncertainties exist (in both emission factors and activity data) should be focussed on, many being of particular relevance to developing countries. These include open-burning (vegetation, crop residues, solid municipal waste), residential cookstoves/heatstoves/lighting, charcoal making, traditional brick kilns, traditional coke ovens and flaring from oil and gas production.

- ***Building on findings from themes 1 and 2: Is the IPCC the right organisation to develop the inventory methodologies?***

Yes. Authoritative guidance on SLCFs is necessary to improve integration and the internal consistency between GHGs emission inventories and non-GHGs emission inventories, within and across the various assessments and mitigation strategies at global to local levels, and across sectors. Such guidance would also improve comparability in terms of the emissions inputs into the various models used to inform policies, which already include the SLCFs but emissions need to be generated by the modelling teams since they are not provided alongside GHGs. The EMEP/EEA guidance is mainly of relevance to industrialized countries, their official remit being limited to the UN Economic Commission for Europe (UNECE) region. Globally-relevant guidance on preparing SLCF-related emission inventories is needed with the growing desire of many countries to tackle BC and other SLFCs (in addition to LLGHGs of course) in order to address warming in the near-term that many argue is crucial if the Paris agreement's global temperature targets are to be met and in order to address the impact of aerosols on regional weather patterns.

- ***How will these methodologies on SLCF relate to the existing inventory methodologies on GHG (What kind of elements in the existing GHG inventory methodology can or cannot be applied to SLCF?)***

Regionally differentiated data/factors, as currently offered in the IPCC guidelines for solid waste, wastewater, manure management, enteric fermentation etc., would also be appropriate for many SLCFs.

References:

Akagi, S. K., Yokelson, R. J., Wiedinmyer, C., Alvarado, M. J., Reid, J. S., Karl, T., Crounse, J. D., and Wennberg, P. O. (2011) Emission factors for open and domestic biomass burning for use in atmospheric models, Atmos. Chem. Phys., 11, 4039-4072, doi:10.5194/acp-11-4039-2011.

Amann, M., Klimont, Z., and Wagner, F.: Regional and Global Emissions of Air Pollutants: Recent Trends and Future Scenarios, Annu. Rev. Env. Resour., 38, 31–55, https://doi.org/10.1146/annurev-environ-052912-173303, 2013.

Bond, T. C., Streets, D. G., Yarber, K. F., Nelson, S. M., Woo, J. H., and Klimont, Z.: A technology-based global inventory of black and organic carbon emissions from combustion, J. Geophys. Res., 109, 1–43, https://doi.org/10.1029/2003JD003697, 2004.

Bond, T. C., Bhardwaj, E., Dong, R., Jogani, R., Jung, S., Roden, C., Streets, D. G., and Trautmann, N. M.: Historical emissions of black and organic carbon aerosol from energy-related combustion, 1850–2000, Global Biogeochem. Cy., 21, 1–16, https://doi.org/10.1029/2006GB002840, 2007.

Bond, T. C., Doherty, S. J., Fahey, D. W., Forster, P. M., Berntsen, T., DeAngelo, B. J., Flanner, M. G., Ghan, S., Kärcher, B., Koch, D., Kinne, S., Kondo, Y., Quinn, P. K., Sarofim, M. C., Schultz, M. G., Schulz, M., Venkataraman, C., Zhang, H., Zhang, S., Bellouin, N., Guttikunda, S. K., Hopke, P. K., Jacobson, M. Z., Kaiser, J. W., Klimont, Z., Lohmann, U., Schwarz, J. P., Shindell, D., Storelvmo, T., Warren, S. G., and Zender, C. S.: Bounding the role of black carbon in the climate system: A scientific assessment, J. Geophys. Res.-Atmos., 118, 5380–5552, https://doi.org/10.1002/jgrd.50171, 2013.

CEC (2015) North American Black Carbon Emissions Estimation Guidelines: Recommended Methods for Estimating Black Carbon Emissions. Montreal, Canada: Commission for Environmental Cooperation. http://www3.cec.org/islandora/en/item/11629-north-american-black-carbon-emissions-recommended-methods-estimating-black-en.pdf

Christian, T. J., Yokelson, R. J., Cárdenas, B., Molina, L. T., Engling, G., & Hsu, S. C. (2010). Trace gas and particle emissions from domestic and industrial biofuel use and garbage burning in central Mexico. Atmospheric Chemistry and Physics, 10(2), 565-584. https://doi.org/10.5194/acpd-9-10101-2009

Conrad and Johnson, 2017. Field Measurements of Black Carbon Yields from Gas Flaring. Environ. Sci. Technol. 51, 1893−1900

Crippa, M., Guizzardi, D., Muntean, M., Schaaf, E., Dentener, F., van Aardenne, J. A., Monni, S., Doering, U., Olivier, J. G. J., Pagliari, V., and Janssens-Maenhout, G.(2018) Gridded Emissions of Air Pollutants for the period 1970–2012 within EDGAR v4.3.2, Earth Syst. Sci. Data Discuss. https://doi.org/10.5194/essd-2018-31, in review, 2018.

Dalsøren SB, Myhre G, Hodnebrog Ø, Myhre CL, Stohl A, Pisso I, Schwietzke S, Höglund-Isaksson L, Helmig D, Reimann S, Sauvage S, Schmidbauer N, Read KA, Carpenter LJ, Lewis AC, Punjabi S, & Wallasch M (2018) Discrepancy between simulated and observed ethane and propane levels explained by underestimated fossil fuel emissions. *Nature Geoscience*

EMEP/EEA (2016) Air pollutant emission inventory guidebook. EEA Technical report No 21/2016. European Environment Agency https://www.eea.europa.eu/publications/emep-eea-guidebook-2016

Evans, M., Kholod, N., Kuklinski, T., Denysenko, A., Smith, S. J., Staniszewski, A., Hao, W. M., Liu, L., and Bond, T. C.: Black carbon emissions in Russia: A critical review, Atmos. Environ., 163, 9–21, https://doi.org/10.1016/j.atmosenv.2017.05.026, 2017

Garland, Charity, et al. (2017) Black carbon cookstove emissions: A field assessment of 19 stove/fuel combinations. Atmospheric Environment 169, 140-149.

GAW Report No 153: ftp://ftp.wmo.int/Documents/PublicWeb/arep/gaw/gaw153.pdf

GAW Report No 197: http://www.wmo.int/pages/prog/arep/gaw/documents/FINAL_GAW_197.pdf

Lena Höglund-Isaksson (2017) Bottom-up simulations of methane and ethane emissions from global oil and gas systems 1980 to 2012. Environmental Research Letters, Volume 12, Number 2

Johnson, M., Edwards, R., Alatorre, F. C., & Masera, O. (2008). In-field greenhouse gas emissions from cookstoves in rural Mexican households. Atmospheric Environment, 42, 6, 1206-1222.

Kholod, N., Evans, M., and Kuklinski, T.: Russia's black carbon emissions: focus on diesel sources, Atmos. Chem. Phys.,16, 11267–11281, https://doi.org/10.5194/acp-16-11267-2016,2016.

Klimont, Z., Kupiainen, K., Heyes, C., Purohit, P., Cofala, J., Rafaj, P., Borken-Kleefeld, J. and Schöpp, W. (2017) Global anthropogenic emissions of particulate matter including black carbon. Atmospheric Chemistry and Physics 17, 8681-8723 https://doi.org/10.5194/acp-17-8681-2017.

Kupiainen, K. and Klimont, Z.: Primary Emissions of Submicron and Carbonaceous Particles in Europe and the Potential for their Control, International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria, 2004.

Kupiainen, K. and Klimont, Z.: Primary emissions of fine carbonaceous particles in Europe, Atmos. Environ., 41, 2156–2170, https://doi.org/10.1016/j.atmosenv.2006.10.066, 2007.

Lam, N. L. et al. (2012) Household light makes global heat: High black carbon emissions from kerosene wick lamps. Environ. Sci. Technol. 46, 13531−13538.

Ortínez-Alvarez, A, O. Peralta, H. Alvarez-Ospina, A. Martínez-Arroyo, T. Castro, V. H. Páramo, L. G. Ruiz-Suárez, J. Garza, I. Saavedra, M. L. Espinosa, A. De Vizcaya-Ruiz, A. Gavilan, R. Basaldud, J. L. Munguía-Guillén (2018) Concentration profile of elemental and organic carbon and personal exposure to other pollutants from brick kilns in Durango, Mexico. Air Quality, Atmosphere and Health, 11, 285-300. https://doi.org/10.1007/s11869-017-0539-z

Pederstad, A., Smith, J. D., Jackson, R., Saunier, S., and Holm, T.: Assessment of flare strategies, techniques for reduction of flaring and associated emissions, emission factors and methods for determination of emissions to air from flaring, Carbon Limits AS, Trondheim, Norway, available at: www.miljodirektoratet.no, 2015.

Schwarz, J. P., Holloway, J. S., Katich, J. M., Mckeen, S., Kort, E. A., Smith, M. L., … Peischl, J. (2015). Black Carbon Emissions from the Bakken Oil and Gas Development Region. Environmental Science and Technology Letters, 2:281–285. https://doi.org/10.1021/acs.estlett.5b00225

Smit, R. and Bluett, J.: A new method to compare vehicle emissions measured by remote sensing and laboratory testing: High-emitters and potential implications for emission inventories, Sci. Total Environ., 409(13), 2626–2634, https://doi.org/10.1016/j.scitotenv.2011.03.026, 2011

Venkataraman, C., Habib, G., Eiguren-Fernandez, A., Miguel, A. H., & Friedlander, S. K. (2005). Residential Biofuels in South Asia: Carbonaceous Aerosol Emissions and Climate Impacts. Science, 307, 1454-1456.

Weyant, C., Athalye, V., Ragavan, S., Rajarathnam, U., Lalchandani, D., Maithel, S., … Bond, T. C. (2014). Emissions from South Asian brick production. Environmental Science and Technology, 48(11), 6477–6483. http://doi.org/10.1021/es500186g

Weyant, C. L., Shepson, P. B., Subramanian, R., Cambaliza, M. O. L., Heimburger, A., McCabe, D., Baum, E., Stirm, B. H., and Bond, T. C.: Black Carbon Emissions from Associated Natural Gas Flaring, Environ. Sci. Technol., 50, 2075–2081, https://doi.org/10.1021/acs.est.5b04712, 2016.

Yan, F.,Winijkul, E., Streets, D. G., Lu, Z., Bond, T. C., and Zhang, Y.: Global emission projections for the transportation sector using dynamic technology modeling, Atmos. Chem. Phys., 14, 5709–5733, https://doi.org/10.5194/acp-14-5709-2014, 2014.