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# INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE



UNEP

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## **REPORT OF THE IPCC EXPERT MEETING ON EMISSION ESTIMATION OF AEROSOLS RELEVANT TO CLIMATE CHANGE**

(Submitted by the Co-chairs of the Task Force Bureau)



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**Report of the IPCC Expert Meeting on  
Emission Estimation of Aerosols Relevant to Climate Change**

2-4 May 2005

Geneva, Switzerland

This expert meeting was agreed in advance as part of the IPCC work plan, but this does not imply Task Force, Working Group or Panel endorsement or approval of this report or any recommendations or conclusions contained herein. This report is Supporting Material prepared for consideration by the Intergovernmental Panel on Climate Change. The report was compiled by the Technical Support Unit of the IPCC National Greenhouse Gas Inventories Programme (NGGIP) from the individual breakout group reports and notes of the meeting and has been reviewed twice by participants. This material has not been subjected to formal IPCC review processes.

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### **Box 1 Conclusions**

The meeting reached these conclusions (see chapter 4 for more detail):

- Global inventories of emissions of aerosols relevant to climate change contain significant sources of uncertainty. Currently, it is not possible to reliably produce internationally comparable national emission estimates and estimate real differences in emission characteristics between countries. Work is needed to reduce some of the uncertainties identified in this report and particularly on the research priorities identified here.
- To reduce uncertainties in carbonaceous aerosol emission estimates there needs to be consideration of the different measurement methods of each of Black Carbon, Elemental Carbon and Organic Carbon. Both the development of standard methodologies that provide less ambiguous results, and also methods to relate results of different measurement methods to each other, are urgently needed to reduce these uncertainties. The NGGIP could review the implications of these differences on inventory estimates; however a wider consultation is needed to resolve this issue. While the role of the IPCC could be to encourage and facilitate this discussion, the IPCC is not itself the body to take responsibility for carrying out research programmes for setting measurement standards.
- Co-operation within the IPCC between the WG1 scientific work on climate change and the NGGIP global emission inventory work, started at this meeting, and was found to be valuable.
- Future work on aerosol emissions, particularly by the NGGIP, should be focussed on the needs of the relevant research communities. Given the importance of “natural” emissions, the methodological overlap with other anthropogenic sources and the uncertainty of defining anthropogenic and natural emissions the NGGIP should not limit its consideration to anthropogenic sources.
- The meeting concluded that further similar meetings participated by WG1, NGGIP and other aerosol inventory experts should be held. These meetings should focus on some of the specific issues identified during the current meeting. Three main topics for consideration are:
  - ***Needs of speciated aerosols emission data and definitions.***
  - ***Use of existing inventory information*** in particular from air quality studies.
  - ***Sectoral issues*** – improvements of specific key source sectors.

# 1. Background

The IPCC Third Assessment Report (TAR) identified aerosols as potentially significant contributors to climate change with radiative forcing of the same magnitude as methane, nitrous oxide or halocarbons (see Figure 1). The quantification of radiative forcing of aerosols is very difficult. Aerosols differ from the greenhouse gases already in the inventories as they both absorb and scatter sunlight, they have indirect effects on clouds and they have short atmospheric lifetimes. Primary aerosols include carbonaceous aerosols (black and organic carbon), mineral dust, marine aerosols and biogenic material. Secondary aerosols are formed in the atmosphere from the emission of other gases including SO<sub>2</sub>, NO<sub>x</sub>, NH<sub>3</sub> and NMVOC<sup>1</sup>.

The issue of emission estimates for aerosols was first discussed by the IPCC National Greenhouse Gas Inventories Programme<sup>2</sup> (NGGIP) at the September 2003 scoping meeting for the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. IPCC XXI (Nov. 2003) approved the Terms of Reference, draft Table of Contents and the Work Programme for the IPCC 2006 Inventory Guidelines, but decided not to include guidance on estimating emissions of aerosols. Instead, IPCC XXI and XXII (Nov. 2004) endorsed the recommendation of the Inventory Task Force to hold an expert meeting on aerosols. The objectives of this meeting were:

- **To conduct a preliminary assessment of issues related to developing estimates for anthropogenic emissions of aerosols** identified in the IPCC Third Assessment Report (TAR) as having an impact on climate change. In this context, the discussion of aerosols and climate change in the TAR will provide relevant background.
- **To discuss the methodological approaches and related issues for estimating emissions of aerosols.** While the whole range of aerosols will be considered, the primary focus will be on carbonaceous aerosols. (The Scoping Meeting for the 2006 IPCC Guidelines (Sept. 2003) noted, “Methodologies for sulphate aerosols are covered in other agreements and it is not anticipated that additional consideration is needed for them.”)

The expert meeting was organised by the Task Force on Inventories assisted by the IPCC Working Group I. A list of participants is attached as Annex 5.

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<sup>1</sup> In North America the definition of Volatile Organic Hydrocarbons (VOC) differs from the definition of non-methane volatile organic compounds (NMVOC) used in Europe. While this difference can be important, particularly when speculated composition is required, in this review it is not a significant difference and NMVOC can be taken to refer to either.

<sup>2</sup> The IPCC’s NGGIP produces and promotes guidelines for the estimation of National Greenhouse Gas Inventories. These inventories aim to estimate accurately, and without bias as far as can be judged, total annual emissions (or removals) of greenhouse gasses from a country. These guidelines are used for reporting to the UNFCCC national emissions and are the basis for the review of inventories under that convention. Thus they are the fundamental measure by which compliance with international emission reduction or control agreements is judged. They are also used as a basis for other emission estimations e.g. for companies or emission control projects. Given their use, they have to be able to replicate national emission characteristics, to enable emission reduction policies and control measures to be tracked and to accurately represent differences between countries in their emission characteristics (e.g. use of different technologies, national penetration of various control measures, use of different raw materials, specific national policies, and the impacts of climate and land use). They also have to be useable world wide from developed countries with relatively large resources to those with few resources. All anthropogenic sources are included, industry, domestic and transport, as well as agriculture, forestry and other land use and land use change. (See <http://www.ipcc-nggip.iges.or.jp/>)

The meeting was organised in two parts, first key note presentations to inform the meeting of climate specific type and impacts of aerosols, then detailed, sector specific discussions in smaller groups (see agenda, Annex 4). The keynote presentations were in two parts (see summary below and Annex 7).

- Atmospheric sciences and discussions on data, including characterisation of aerosols required for climate change research.
- Aerosol emission estimation, and discussions on extent of current inventories and their applicability to greenhouse gas and climate change issues.

Following the keynote presentations the meeting discussed how to organize the breakout groups. There was some debate whether there needed to be a separate group, in addition to three sectoral groups, to deal general issues such as measurements and aerosol characterization. In the end, however, the meeting agreed to deal with those general issues in each sectoral group, as follows (Annex6 shows the membership of the groups):

- ***Breakout Group 1 – Energy.*** This group covered all fuel combustion (both fossil fuels and biofuels) from all economic sectors (transformation, industry, residential and commercial, and transportation), and incineration.
- ***Breakout Group 2 – Industry and Other Emissions.*** This group covered a wide range of sources including Industrial Process Emissions (e.g. Cement and Iron and Steel), Mining & Quarrying, Entrained Road Dust, Construction, Stock piles and the Transport of bulk products.
- ***Breakout Group 3 – Land Use.*** Dust Emissions from Different Land Uses, Open Burning (e.g. prescribed burning, disposal of agricultural waste and savannah burning), Wild Fires and Biogenic aerosols.

### **Box 2 “Anthropogenic” and “Biogenic”**

Many climate studies use a very different definition of “anthropogenic” to that used in traditional Greenhouse Gas Inventories which is also used in the UNFCCC and in international reporting. Climate studies often split emissions into “anthropogenic” and “biogenic” where biogenic emissions (eg from plants) are not anthropogenic. On the other hand, in traditional Greenhouse Gas Inventories, the NGGIP, and in the UNFCCC much of these “biogenic” emissions in many countries would be considered as “anthropogenic”. This is because the inventories, and UNFCCC emission reporting, aim to estimate the total impact on the atmosphere of all human activities. Thus emissions from managed forests are anthropogenic, so in Western Europe, for example, all of the biogenic emissions would also be considered anthropogenic.

## 2. Keynote Presentations

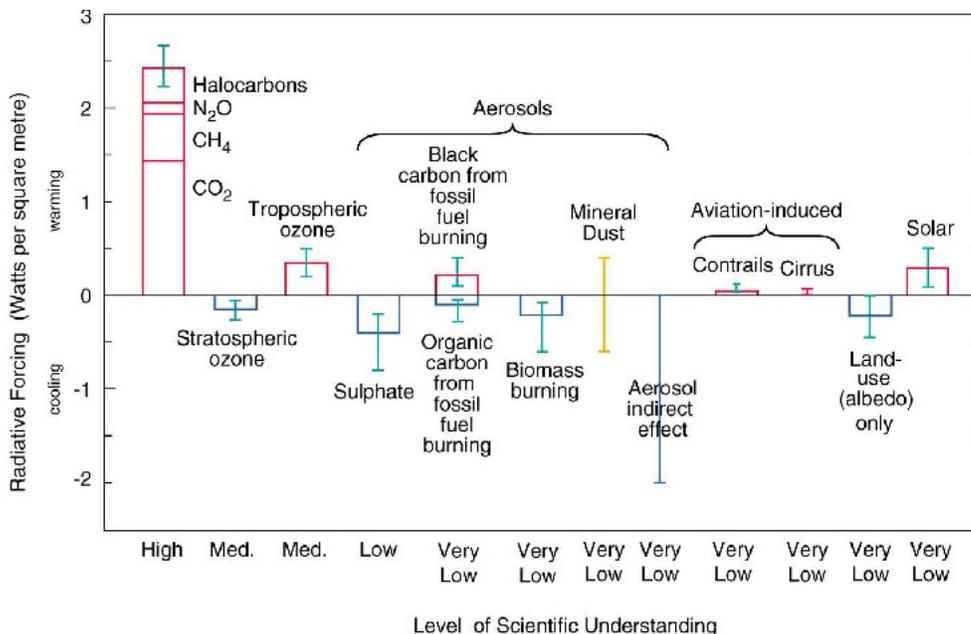
This section briefly summarises the presentations, particularly issues related to emission estimation. The complete presentations are included in Annex 7.

### 2.1. Direct effects of aerosols on climate: What do we know?

*Prof. Joyce Penner, University of Michigan, USA*

The IPCC Third Assessment Report 2001, (TAR), reported the impacts of Sulphate<sup>3</sup>, Black Carbon from Fossil Fuel Combustion, Organic Carbon from Fossil Fuel Combustion, Biomass burning (both black and organic carbon) and Mineral Dust on the climate system (see Figure 1).

In the TAR, about half of the total aerosol load or burden (for particles less than 2  $\mu\text{m}$ ) has anthropogenic sources<sup>4</sup>. These aerosols include fossil fuel sulphate and associated ammonium, organic and black carbon from fossil fuels, smoke from biomass burning, mineral dust and fossil fuel nitrate and associated ammonium. This presentation reviewed the impact of these aerosols on direct radiative forcing. There are major uncertainties in estimates of these emissions and further uncertainties in each step of the modelling process from emissions to radiative forcing. Reducing the uncertainty in estimates of aerosol direct forcing will require improvements in global models, in aerosol sources and their strengths, and processes determining aerosol lifetime and burden, and in secondary aerosol formation. The biggest uncertainties relate to black carbon, organic carbon aerosols and dust.



**Figure 1. The global mean radiative forcing of the climate system for the year 2000, relative to 1750, (IPCC TAR 2001)**

<sup>3</sup> Sulphate aerosol is formed in the atmosphere from emissions of sulphur dioxide. Emission inventories of SO<sub>2</sub> are widespread (for air quality reasons) and guidelines on how to estimate SO<sub>2</sub> emissions have also been produced. The same is true of other aerosol precursors: nitrogen oxides (NO<sub>x</sub>) and to a lesser extent ammonia (NH<sub>3</sub>)

<sup>4</sup> Many climate studies use a very different definition of “anthropogenic” to that used by the NGGIP and the (see Box 2).

## **2.2. Indirect Effects: Aerosol and Cloud Microphysics**

*Prof. Ulrike Lohmann, Institute for Atmospheric and Climate Science, Switzerland*

The indirect effects of aerosols on climate, through impacts on clouds, were reviewed. The net radiative forcing of these effects is negative and very uncertain. The impacts can occur through three mechanisms: increasing the cloud albedo by increasing the number of droplets (increasing cloud condensation nuclei); increasing cloud lifetime (more drops implies smaller sizes and longer life); and black carbon in the cloud (absorption of radiation and increases cloud temperature, thus decreasing cloud lifetime). The impact of these effects varies regionally. All types of particle can act as cloud condensation nuclei, however the chemical composition affects the hygroscopic properties and cloud droplet nucleation in ways that are poorly understood. Thus chemical speciation of aerosols may be important. Work currently underway is examining these issues and is likely to be included in the IPCC Fourth Assessment Report. Climate modelling groups are looking at these issues for the future but they are not included in most current models.

## **2.3. EC/OC Emissions: Current Understanding & Relevant Issues**

*Dr. Zhang Xiaoye, Centre for Atmosphere Watch & Services, China*

The current understanding of elemental carbon and organic carbon emissions in China was reviewed. Emission sources include biomass burning, power plant, transport, residential activities and industry. Coal, oil, wood and other biomass are all important fuels. Provincial fuel used data has been combined with databases of forest and grassland fires and county level agricultural output data to produce country-wide, spatial maps of emissions. While the black carbon estimates are broadly similar to other recent estimates published since the TAR, the latest organic carbon estimates are significantly higher, with increased contributions from rural industry, residential coal combustion and agricultural activities. Moreover, secondary organic carbonaceous aerosol particles appear to be a large fraction of the entire aerosol mass. A wide range of measurements of aerosols and other climate relevant parameters were also reviewed. The existing global estimation of aerosol radiative forcing shows the net total organic aerosol radiative forcing to be negative, this probably under-estimates the negative effect of secondary organic aerosols. All kinds of aerosol species should be considered in the climate change discussion, emphasising climate change and links to other environmental issues.

## **2.4. Aerosol Coupling with Photochemistry of Greenhouse Gases**

*Professor Michael Prather, University of California, USA*

This presentation looked at both the indirect effects of greenhouse gases and secondary organic aerosols. Reactive atmospheric chemistry affects a number of “indirect” greenhouse gases as well as tropospheric ozone, the lifetime of both gases and aerosols and the formation of secondary aerosols. Aerosols affect the global budgets of O<sub>3</sub>, OH and CH<sub>4</sub>. The impacts of all these effects are highly dependent on both the region and the timeframe considered. Most of the secondary organic aerosols are thought to form from biogenic<sup>5</sup> NMVOC emissions. Work done for regional air quality assessments has already provided detailed chemical speciation of many of these NMVOC emissions in Europe and North America. Considerable uncertainties still surround emission estimates – both mass and composition. Temporal variation can be important with significant seasonality. The spatial location of the emissions is important. Current models

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<sup>5</sup> Many climate studies use a very different definition of “anthropogenic” to that used by the NGGIP and the (see Box 2).

use 2-4 degree grid cells with refinement to 1-2 degree cells being developed. For precursor emissions, with relatively fast atmospheric chemistry in the atmosphere, finer resolutions of about 1km are needed, though the development of global models at this scale is unlikely at present.

## **2.5. Definitional Issues for Aerosols**

*Dr. Tami Bond, University of Illinois, USA*

The climatic effects of carbonaceous particles depend on their composition, which varies widely so emissions have been divided into climate relevant classes of particles, e.g. black carbon and organic carbon. However no standard measurement methods uniquely measure these climate relevant particle types. For example, black carbon can be measured using either an optical measurement (light absorption) or a thermal measurement, but these are affected by particle form, non-carbon absorption and measurements protocol (filters and wavelengths etc.). The distinction between black and organic carbon is particularly important for climatic purposes and is defined operationally, i.e. by the particular measurement method. Thus, there are no universally accepted definitions of black carbon, elemental carbon and organic carbon. A significant proportion of the modelled uncertainty in radiative forcing can be traced to the uncertainties in emission estimates, the climate relevant properties and lifetime of the aerosols. Hence standard measurement methods, or improved knowledge of the relationship between different methods, will assist with both emission estimation and comparison with measurements for model assessment. In addition, the link between chemical measurements and optical properties needs to be better understood.

## **2.6. Soil Dust Emissions**

*Dr. Ina Tegen, Institute for Tropospheric Research, Germany*

Soil dust emissions are primary aerosols that do not undergo secondary atmospheric transformations. The TAR estimated a wide range of globally-averaged radiative forcing (both positive and negative) and assumed about half of these emissions was anthropogenic<sup>6</sup>. While there are now some satellite data on dust storms and some station data from more populated areas, this information is not sufficient to understand dust storms and their frequency or how they may be changing. There are some models of dust emissions and these can be combined with land cover (vegetation) to produce emission estimates. Humans can impact these emissions through cultivation (especially in arid regions), soil protection and irrigation, overgrazing, deforestation, unpaved roads, construction and military activities in deserts. Similarly, changes in climate can also cause changes in emissions. Recent estimates suggest agricultural activities may cause up to 10-25% of the soil dust emissions (although in some regions it may be a dominant source e.g. possibly Europe). Emission estimates need to be improved and a better understanding of the size distribution developed.

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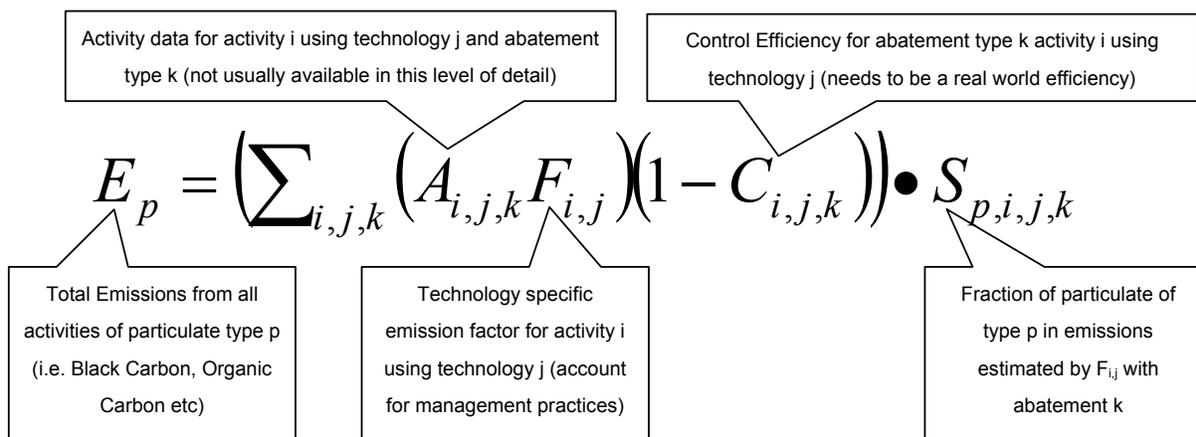
<sup>6</sup> Again it is unclear how the definition of “anthropogenic” used relates to the usual inventory, or political, definition (see Box 2).

## 2.7. Practical Experiences of Aerosol Inventory Preparation - European Perspective

Dr. Kristin Rypdal, CICERO & Mr Zbigniew Klimont, IIASA

Recently in Europe there has been a stronger focus on aerosols, primarily due to their health impacts. Thus they are at the centre of air quality improvement strategies developed in Europe. The main effort at present is in the development of PM<sub>10</sub> and PM<sub>2.5</sub> inventories, with black and organic carbon a secondary priority. The inventory development work is being co-ordinated by the UNECE<sup>7</sup> Convention on the Long Range Transboundary Air Pollution (CLRTAP) with the aim of producing validated inventories by including PM<sub>10</sub> and PM<sub>2.5</sub> in their guidebook<sup>8</sup>.

The general estimation approach is shown in Figure 2. This shows the typical approach; some sectors can have considerably more complex calculations. The activity data needs to be split by activity type, technology and abatement types as these significantly influence emission rates. It is necessary to speciate the emission estimates to derive the quantities of climate interest, e.g. the emission factors available may estimate PM<sub>2.5</sub> while black carbon emissions are needed. It is important that the fuel burnt in different types of sources as well as the fractions of each source that use emission controls are considered.



**Figure 2 Generalised Estimation of Aerosols showing main factors - some sectors will have considerably more complex approaches.**

Currently, European air pollution policy envisages support for the further development and improvements of methods needed to prepare speciated aerosol inventories. There is now a reporting requirement for PM<sub>10</sub> and PM<sub>2.5</sub> in the UNECE. Work undertaken to improve existing guidance on estimating emissions has identified some sources not already included in the inventory guidelines including construction, wood products and handling and storage of bulk products (coal ores etc.). Other sources that are not significant for current greenhouse gas inventories will be significant for aerosols and so need to be better defined. Data is not readily available for biomass use on either total biomass use or its distribution among various small scale combustion installations (e.g., fireplaces, stoves, etc.). In Western Europe the major sources of black carbon were biomass and diesel use while in Central and Eastern Europe coal and “other” sources

<sup>7</sup> United Nations Economic Commission for Europe, which includes European countries east to Russia and the USA and Canada.

<sup>8</sup> EMEP/CORINAIR Emission Inventory Guidebook - 3rd edition September 2004

were significant as well. Diesel emissions in Western Europe and coal emissions in Central and Eastern Europe are projected to show significant declines between 1990 and 2020<sup>9</sup>. Also, there is a need to understand the relationship between measurements and real-world emissions. While the methods are based on existing inventories further methodological development is still needed.

## **2.8. Combustion Aerosol Emission Measurements**

*Ms. Lisa Graham, Environment Canada*

Combustion sources include fossil fuel use (both stationary and mobile) and open burning (grass, agriculture and waste). Mobile sources include both gasoline and diesel fuelled vehicles: in both cases if low sulphur fuel is used the particulate is more than 95% carbon (although with quite different physical properties depending on the original fuel). Other fossil fuel emissions (e.g. from coal fired electric power generation) have lower amounts of carbon. Emission rates and aerosol properties are highly dependent on combustion conditions and control and abatement equipment. For open fires emissions also depend on combustion conditions. Grass fires are mostly flaming and have higher black carbon to organic carbon ratios while the ratio is lower for forest fires where there is also significant smouldering. Combustion sources are also significant emitters of all types of aerosol precursors, and, in many cases, secondary aerosol formation is larger than the primary emissions. Black carbon is a light absorbing, micro crystalline graphitic form and is not the same as either elemental carbon (defined operationally by thermal evolution and oxidation methods or soot (carbonaceous matter formed by combustion)). Organic carbon is also operationally defined. There is a need for standardised protocols for organic and elemental carbon measurement. The understanding of the relationship between optical properties and chemical properties needs to be improved. There is an urgent need for more simultaneous measurements on mass, particle size, optical properties, number density and speciation to enable the use of the literature of chemical and physical emissions characterisation information.

## **2.9. Global Estimates of Carbonaceous Aerosols using Bottom-Up<sup>10</sup>**

### **Methods**

*Dr. Tami Bond, University of Illinois, USA.*

Inventories of carbonaceous aerosols are more difficult to develop than those of other greenhouse gases as they are dependent on processes (rather than the mass balance in CO<sub>2</sub> or SO<sub>2</sub>), harder to validate (due to the lifetimes and transformation in the atmosphere) and the link to optical and chemical properties is more difficult to define. Emissions for a single fuel and source can vary widely due to operation and emission controls. Residential biofuels are a significant source globally both for black carbon and even more so for organic carbon. Major uncertainties arise from many sources. There are significant uncertainties in the amounts burnt (particularly for residential biofuel use and open burning). The relationship between laboratory measurements and real-world combustion is unclear especially for road transport and small combustion sources. For example owners of poorly maintained, highly emitting, vehicles are unlikely to have them measured. Thus the importance of knowledge of operational practices, and their impacts, is

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<sup>9</sup> Kupiainen K. and Klimont Z.: (2004) Primary Emissions of Submicron and Carbonaceous Particles in Europe and the Potential for their Control. Interim Report IR-04-079, International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria

<sup>10</sup> “Bottom-up” here refers to estimating emissions from an understanding of the size and scope of each source.

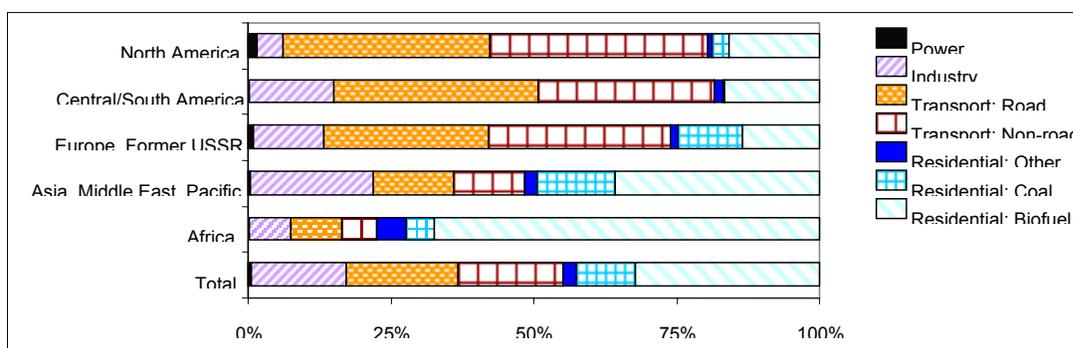
important in making estimates of primary aerosols from combustion. Current global inventories use fuel based PM inventories and multiply by black carbon and organic carbon fractions to derive their emission estimates

The latest estimates of BC are lower than the amount that global models need to explain the measured concentrations and this discrepancy is large enough that it is unlikely to be explicable by the uncertainties in the emission estimates alone.

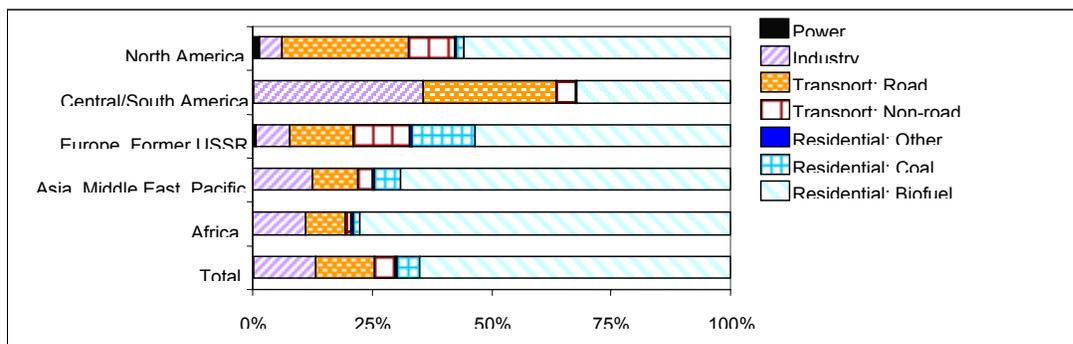
There is also a need to consider the current air quality estimates of aerosol emissions for their utility in estimates of emissions of aerosols relevant to climate change.

**Table 1 Comparison of latest Emission Estimates of Black and Organic Carbon and those in the TAR.**

	Bond et al <sup>11</sup>		TAR	
	Fossil Fuel	Biomass	Fossil Fuel	Biomass
Black Carbon	3.3	5.0	6-8	6-9
Organic Carbon	2.4	31	10-30	45-80



**Figure 3 Global Sources of Black Carbon (Bond et. Al. 2004)**



**Figure 4 Global Sources of Organic Carbon, (Bond et. al. 2004)**

Table 1 and Figures 3 and 4 show these recent estimates of black and organic carbon emissions.

<sup>11</sup> Bond, T., Streets, D., Yarber, K., Nelson, S., Woo, J.-H., Klimont, Z., A technology-based global inventory of black and organic carbon emissions from combustion, *J. Geophys. Res.*, Vol.109, D14203, doi:10.1029/2003JD003697, 2004.

### 3. Sectoral Considerations

The meeting broke into three breakout groups. Each group was requested to address the following issues and questions:

- 1) How significant are the emissions for climate change?
- 2) What emissions are most important?
- 3) What are the principle estimation methods (e.g., top-down vs. bottom-up)?
- 4) What data are available?
- 5) What are the key uncertainties associated with emission estimates?
- 6) How important is the distinction between anthropogenic and natural emissions?
- 7) How important is secondary aerosol formation?
- 8) What is the importance of definitional issues (e.g., BC vs. EC vs. OC)?
- 9) What relevant work is being done in other fora such as the air quality community?
- 10) What are the priorities for future research?

The groups' main conclusions<sup>12</sup> are presented in sections 3.1-3.3. Annexes 1, 2 and 3 present their detailed reports.

There was a broad agreement on a number of topics between the groups. These included:

- The definition of Black and Organic Carbon needs to be improved. How estimates of these quantities can be derived from PM<sub>2.5</sub> and PM<sub>1</sub> inventories need to be considered. Existing particulate inventories are a useful starting point and can provide simple ways of producing inventories building on previous work.
- The operation and management of emission sources is very important in considering emission rates for aerosols. This is true for all sources, for example, open fires, small biomass stoves, cars, as well as larger boilers and industrial processes. This information is difficult to collect, often it is unobtainable. Thus emission estimates will be uncertain and laboratory measurements may not reflect real world practices and emissions. Emission abatement results in particle size dependent emission reductions specific to the abatement type and operation, and this also needs to be considered.
- There is a general discrepancy in the use of “anthropogenic” vs. “natural” emissions between IPCC WGI and NGGIP as used by the UNFCCC. Under the IPCC guidance (from the NGGIP), for example, emissions from “managed” land - whether caused by human fires or, say, lightning strike - would be considered anthropogenic and reported internationally as such, whereas IPCC WGI might categorise these emissions as natural.
- Methodologies for the estimation of precursor gases are generally available. While most of this was produced for North America and Europe much is applicable more widely, and emission factors from other parts of the world are becoming more widely available. While NMVOC and its speciation are available in some regions it is an exception: its existing methodologies may not be so transferable, as the emission rates are so closely linked to raw materials used, management and operation.
- While many methods and emission factors need improvement, all groups identified the need for improved activity data. For example, individual groups identified: the amount of biomass used as

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<sup>12</sup> These group reports were produced independently and so may contain some minor inconsistencies in terminology.

fuel; areas burnt in forest fire and their fuel loading; and better data on land types, their area and soil properties.

### **3.1. Sectoral Conclusions**

#### **3.1.1. Energy – Conclusions**

- IPCC brings together a group of experts representing broad areas (both technically and geographically) and it would be useful to convene additional expert meetings that would focus on specific issues particularly gaps in ongoing activities applicable to climate issues.
- There is a need for ongoing coordination within the IPCC (NGGIP and WG1) and involving external groups of experts to integrate understanding in relevant fields and identify areas important for further consideration. Some of areas of potential interest are:
  - Parameters of climate models
  - Definitional issues (i.e. definitions of Black Carbon, Organic Carbon, size fractions of interest)
  - Key issues in characterizing sectoral emissions

#### **3.1.2. Industry and Other Sources - Conclusions**

Further work by IPCC should include:

- defining which (non-combustion) sources have a climate impact taking into account the size and chemical composition and above-ground height of emission
- Facilitate discussion about international research priorities
- Dissemination of the report to important and relevant stakeholders for the purpose of promoting relevant research by national/international organizations
- Consider an IPCC expert meeting to review progress in research activities and methodology development on aerosol inventories since this first expert meeting; assess uncertainties and propose plans for future work.

#### **3.1.3. Land Use Emissions - Conclusions**

- Enhanced interaction between the NGGIP and the climate science community is recommended.
- A review and close links to the work done on air quality issues is needed to use information and methods already developed, particularly in areas such as particulate emissions from the many types of open burning, precursor emissions of NMVOC from forests and emissions from agricultural activities.

## 4. Conclusions and Recommendations

In addition to the conclusions of the TAR (see Box 3, below), this meeting reached some general conclusions from the inventory standpoint on steps to improve estimates of aerosols and ultimately reduce uncertainties in their radiative forcing:

- Global inventories of emissions of aerosols relevant to climate change have been produced. However they contain significant uncertainties. In addition, it is not possible, at this stage, to reliably produce internationally comparable national emission estimates or to estimate real differences in emission characteristics between countries. Work is needed to reduce some of the uncertainties and to pursue the research priorities identified in this report. Significant data gaps continue to exist. Most current global and regional emission inventories are based on a very limited and non-representative set of emission and speciation factors and often lack the required differentiation of activity data.
- To improve the quality of data used in global and regional inventories there needs to be consideration of the different measurement methods of each of Black Carbon, Elemental Carbon and Organic Carbon. Consideration of the development of standard methodologies that provide less ambiguous results, and the development of methods to relate results of different methods to each other, is urgently needed to reduce uncertainties surrounding these estimates. The NGGIP could review the implications of these differences on inventories estimates; however a wider consultation is needed to resolve this issue. While the role of the IPCC could be to encourage and facilitate this discussion, the IPCC is not itself the body to take responsibility for carrying out research programmes for setting measurement standards.

The meeting made specific recommendations for further work by the IPCC:

- Co-operation within the IPCC between the WG1 scientific work on climate change and the NGGIP global emission inventory work, started at this meeting, and was found to be valuable.
- Any future work on aerosol emissions, particularly by the NGGIP, should be focussed on the needs of the relevant research communities. Given the importance of “natural” emissions, the methodological overlap with other anthropogenic sources and the uncertainty of defining anthropogenic and natural emissions the NGGIP should not limit its consideration to anthropogenic sources.
- The meeting concluded that further similar meetings participated by WG1, NGGIP and other aerosol inventory experts (particularly from the local and regional air quality fields) should be held. These meetings should focus on some of the specific issues identified during the current meeting. Three main topics for consideration are:
  - ***Needs of speciated aerosols emission data and definitions.*** Climate model research would be significantly facilitated if required data are made available. There are no universally accepted unique definitions of Black Carbon, Organic Carbon or Elemental Carbon. Existing approaches work in the current state of models but for the development of comparable inventories clearer less ambiguous measurement methods would be needed. Agreed standard measurement methods for these parameters, or reference materials that can be used for method intercomparison need to be developed, most likely by bodies outside the IPCC. These definitions of aerosols need to be considered and conversion facilities between the different classifications and measurements of aerosols would be beneficial. Particle parameters to be inventoried also need to be defined in consultation

with climate modellers. In particular a basic convention on the appropriate size cut-offs to be used should be developed considering both the needs of the climate models and the data available to implement it in inventories. Possible aerosol parameters of interest include size distribution, number concentration, size segregated chemical speciation, hygroscopicity, light absorption and light scattering. The expected outputs may include:

- Develop convention on size cut-offs for particulate consideration for climate change relevance.
  - Definition of parameters needed for climate modelling.
  - Approaches to deriving these from existing particulate inventories and or emission factors (usually these will be mass based).
- ***Use of existing inventory information.*** Several issues should be considered such as: How can existing PM<sub>2.5</sub> inventories be used or improved for climate model research? How can information collected for health and air quality purposes be used? Exactly what information is available in these other fora? It is clear that in some areas (i.e. NMVOC from forests, aerosols from fires and fugitive emissions) much work has been done but its usefulness should be reviewed. This will depend on a closer interaction between the NGGIP, the air quality inventory community and climate model research scientists. Working in conjunction with other organisations (e.g. IGBP) could also address the additional needs of the NGGIP. The expected outputs may include:
- Descriptions of methods to base climate relevant aerosol inventories on existing inventories compiled for other purposes. Decisions on how to use PM<sub>2.5</sub> and PM<sub>1</sub> inventories and which aerosol inventories are not appropriate to be used in this way.
- ***Sectoral issues.*** Many sectors need to be improved. Some key sectors for further consideration include the use of biofuels (particularly small combustion); open burning; dust emissions and biogenic aerosols. The expected outputs may include:
- Consideration of material or inputs needed to improve estimates of these sectors.
  - Review of the impacts of management and operational issues on emission estimates

### Box 3 Conclusions on Aerosols from the TAR

The TAR WG1 (Climate Change 2001: The Scientific Basis) made a number of conclusions and recommendation to reduce uncertainty in estimates of aerosol radiative forcing and improve confidence in the role of aerosols in climate processes:

- **Systematic Ground-Based Measurements:** There is a need for countries of the world to develop and support a network of systematic ground-based observations of aerosol properties in the atmosphere that include a variety of physical and chemical measurements ranging from local in situ to remotely sensed total column or vertical profile properties.
- **Systematic Vertical Profile Measurements:** There is a paucity of systematic vertical profile measurements of size-segregated or even total atmospheric aerosol physical, chemical and optical properties.
- **Characterisation of Aerosol Processes in Selected Regions:** There is a need for integrated measurements to be undertaken in a number of situations to enhance the capability to quantitatively simulate the processes that influence the size-aggregated concentration and composition of aerosols and their gaseous precursors.
- **Indirect Forcing Studies:** There is a broad need for several carefully designed multi-platform (surface-based boat, aircraft and satellite) closure studies that elucidate the processes that determine cloud microphysical (e.g., size-distributed droplet number concentration and chemical composition, hydrometer type) and macrophysical properties (e.g., cloud thickness, cloud liquid-water content, precipitation rate, total column cloud, albedo).
- **Measurements of Aerosol Characteristics from Space:** An integrated strategy for reducing uncertainties should include high quality measurements of aerosols from space.

See TAR, WG1, Chapter 5 Aerosols, their Direct and Indirect Effects) Sec. 5.6: Investigations Needed to Improve Confidence in Estimates of Aerosol Forcing and the Role of Aerosols in Climate Processes

## Annex 1 Report of Energy Group

Fuel combustion is an important source of both aerosols and aerosol precursors (SO<sub>2</sub>, NO<sub>x</sub> and NMVOC). It is important for a number of factors (for regional significance, for precursors, for BC and OC, for coarse and fine aerosols). The sector is composed of a variety of sub-sectors and all of these (power generation, industry, residential, transport etc) are important for at least one of these concerns. The main sources in the Energy use sector are:

- Power plants and industrial combustion
- Industrial furnaces and fuel conversion
- Residential/Commercial combustion
- Transport (Road, Land based off-road, Marine and Aviation)
- Waste incineration (only with energy recovery)

Table 2 shows the importance of individual sectors within the fuel use area. A source is considered important if it provides a significant fraction of global or regional (several countries) burden but not if it is important only on a local/urban basis.

**Table 2 Importance of Energy Sectors**

Source	Primary Aerosol			Precursors to secondary aerosols	Controls
	PM2.5 mass and light scattering	Coarse	Light absorption		
Electric Power Generation (Utilities) PC, FBC	2	2			*
Electric Power Generation (Utilities) GRATE	2	2	1		*
Electric Power Generation (Utilities) LIQUID/GAS				3	*
Industrial furnaces (process heat) ALL FUELS	2	U	2/U	1	*
Fuel conversion (coking, charcoal, briquettes)	3	U	3/U	2	*
Residential Fuel Combustion COAL	3	2	3	2	
Residential Fuel Combustion LIQUID/GAS (external combustion)				1	
Residential Fuel Combustion BIOFUEL	3		3	3	
Residential Fuel Combustion DIESEL (stationary internal combustion engine)			1	1	
Transport – diesel	3		3	3	*
Transport – gasoline	2			3	*
Marine <sup>a)</sup>	1		1	3	*
Air transportation <sup>a)</sup>	1 <sup>b)</sup>			1	
Transport - Non-tail pipe		1			
Waste incineration	U		U		*

3 = very important, 2 = important, 1 = less important and a blank = not important or zero. U = unknown, indicates that the group felt there was insufficient information to determine the importance

\*- Efficient controls (end-of-pipe) are available so the emission factor for a specific region will strongly depend on the penetration of the control technology.

<sup>a)</sup>- Impact on cloud formation

<sup>b)</sup>-The information on the impact of aviation will be provided in the Fourth IPCC Assessment Report

The method used to estimate emissions from these sectors is the standard emission factor equation<sup>13</sup>:

$$\text{Emission} = \text{Emission Factor} * \text{Activity Data}$$

Here the emission factor is often highly dependent on the actual combustion technology used; extent and type of control equipment used and its real world efficiency; and in the operation or management practices.

For some source categories (e.g. large emitters) it may be possible to use existing emission inventories or emission reporting developed for other purposes, though in these cases often there will be a need to apply a speciation or other conversion factor (size, chemical, etc.), to derive climate relevant quantities. However, for some inventories (e.g. PM<sub>10</sub>) further division is necessary before using this approach.

## **Data availability & quality**

Table 3 shows a review of data availability of the main fuel use sectors. However there are some more important and general observations:

- We are fairly confident about the quantity of fuel used for most of the source-categories but there is a large uncertainty (often a complete lack of knowledge) about the use by different technologies within each sector, for example, the share of fuel used in a specific type of installation with or without abatement technology.
- The uncertainties associated with quantity of biofuels used are usually far greater than for fossil fuels.
- The importance of biofuels to aerosol emissions appears greater than to emissions of greenhouse gases. The same is true for small combustion sources.
- We are moderately confident of the emission factors for on-road transport and large scale power generation in developed countries but we are not sure of the applicability of these factors in countries where there have been fewer measurements.
- Off-road transport is a challenge for all countries in terms of both activity data and emission factors

To summarise, experts confront three main situations:

- Emission data available in almost the appropriate form: can incorporate into global inventory using source specific conversion factors (e.g. mobile sources)
- Emission data not available but available estimation methods could be directly applied: further discussion on methods would be useful (e.g. aircraft)
- Emission data not available; existing estimation methods not mature, but underlying data are available: targeted efforts and consultations would improve data and estimation methods (e.g. biofuel use)

## **Uncertainties**

Overall the main uncertainties are:

- Data to distinguish the important technologies and use of controls
- Real-life operating practices (e.g., real world control efficiency, vehicle use – speed, driving patterns etc., small combustion operation and management)

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<sup>13</sup> See section 2.7, where a more detailed representation of this equation is presented

- Geographical variation in quality of information
- PM<sub>1.0</sub> vs PM<sub>2.5</sub>: Ongoing issue (climate vs health/urban)
- Measurements
- Size distribution
- Light-absorbing substance: how to measure? (EC/BC issue)
- Sampling issues

**Table 3 Data Availability for aerosol emission estimates for fuel combustion (the first item is for North America and Europe, the second for developing countries)**

Source	Data availability emission factor		Climate-Relevant Differentiation for Aerosols		Type of activity data	Priorities
	Primary aerosols	Precursors	Size	Composition		
Electric Power Generation (Utilities) Pulverised Coal, Fluidised Bed Combustion	A/C*	A/A	B/B	A/C	Fuel consumption	
Electric Power Generation (Utilities) Grate Firing	B/C	D/D	B/D	D/D	Fuel consumption	MODERATE – EF for aerosols and precursors
Electric Power Generation (Utilities) Liquid and Gaseous Fuels	A/B	A/A	A	B	Fuel consumption	
Industrial furnaces (process heat) All Fuels	B/D	B/D	B	D	Fuel consumption, commodity production	HIGH – EF for aerosols
Fuel conversion (coking, charcoal, briquettes)	A/D	B/D	B/D	B/D	Fuel consumption, secondary fuel production	HIGH – EF for aerosols
Residential Fuel Combustion - Coal	B/B	B/B	B/B	B/B	Fuel consumption	HIGH – improve quality of information on commercial and non-commercial use of fuels (primarily coal and biofuel) HIGH – EF for primary aerosols and NMVOC
Residential Fuel Combustion Liquid and Gaseous Fuels (external combustion)	B/C	B/C	A/A	B/B	Fuel consumption	
Residential Fuel Combustion Biofuels	B/B	B/B	B/B	B/B	Fuel consumption; per-capita consumption	
Residential Fuel Combustion Liquid Fuels (stationary internal combustion engine)	B/C	B/B	A/A	B/B	Fuel consumption	
Transport – Diesel	B/C	B/C	A/A	B/C	Fuel consumed, km driven, hours of operation	HIGH – EF off-road
Transport – Gasoline	B/C	B/C	A/A	B/D	Fuel consumed or km driven	MODERATE – modes of transportation in developing countries
Marine	B/C	B/C	B/B	B/C	Fuel consumed or hours driven	MODERATE – EF for precursors and spatial resolution
Air transportation	B/C	B/B	A/A	B/B	Fuel consumption, km flown	MODERATE -
Transport - Non-tail pipe	B/D	D/D	B/B	B/B	Km driven	
Waste incineration	A/D	D/D	B/D	B/D	Waste consumed	

A – Satisfactory

B – Some data; because of source variability, still needs more characterization

C – Data from some well-measured regions, but unclear how they apply to global sources

C\* - Primary difference between regions is control device; global data could be improved by obtaining size-dependent removal efficiency

D – No or very little data (when given for global sources, implies that combustion process or other characteristics may be very different in nature)

**Table 4 Key Sectoral Uncertainties**

<b>Source</b>	<b>Key uncertainties</b>
<b>Electric Power Generation (Utilities) – Coal ( Pulverised Coal, Fluidised Bed Combustion, Grate firing), Liquid and Gaseous Fuels</b>	Penetration of control technology Emission factor for grate firing
<b>Industrial furnaces (process heat) All Fuels</b>	Technological splits (developing countries); EF; size and chemical speciation
<b>Fuel conversion (coking, charcoal, briquettes)</b>	EF; chemical speciation
<b>Residential Fuel Combustion - Coal</b>	EF; size and chemical speciation
<b>Residential Fuel Combustion Liquid/Gas (external combustion)</b>	
<b>Residential Fuel Combustion -Biofuel</b>	Fuel use and type (accounting for non-commercial biofuel use, technological splits); size and chemical speciation; EF (representing real installations and their operating conditions)
<b>Residential Fuel Combustion Diesel (stationary internal combustion engine)</b>	Technology, fuel use and EF
<b>Transport – on-road</b>	Representing real vehicles and operating conditions; real-world EF (lab data vs road data)
<b>Transport – off-road</b>	Technology, activity and EF
<b>Marine</b>	EF (depending on quality of fuel)
<b>Air transportation</b>	Technological split (engine types); real-world EF (lab engine data vs real data)
<b>Transport - Non-tail pipe</b>	EF, chemical speciation
<b>Waste incineration</b>	Activity type and EF for small industrial facilities

### ***Possible contribution of IPCC***

- IPCC brings together a group of experts representing broad areas (both technically and geographically) and it would be useful to convene additional expert meetings that would focus on specific issues and further detail identifying gaps in ongoing activities as applicable to climate issues.
- This meeting identified a need for ongoing coordination within the IPCC (NGGIP and WG1) and involving external groups of experts to integrate understanding in relevant fields and identify areas important for further consideration. Some of areas of potential interest are:
  - Parameters of climate models
  - Definitional issues
  - Key issues in characterizing sectoral emissions

## Annex 2 Report of the Industrial Processes and Other Emissions Group

Table 5 lists potential sources of emissions, including precursor sources (sources of SO<sub>2</sub>, NH<sub>3</sub>, NO<sub>x</sub> and NMVOC) and an indication of their importance<sup>14</sup>. Some of these are additional sources to those described in the existing IPCC Inventory Guidelines for National Greenhouse Gases. There are many more sources that are considered to be of small global or regional relevance due to their overall activity level.

The likely most important sources are:

- Cement
- Petrochemical processes (mainly NMVOC)
- Iron and steel
- Solvents (mainly NMVOC)
- Road dust
- Waste handling
- Mining and quarrying
- Oil and gas upstream (including significant NMVOC emissions)

Climate modellers would like a wide range of parameters including mass emissions, size distribution, light absorption/scattering efficiency, chemical composition and water solubility per source. This list cannot be satisfied with data available currently or in the near future. However, the possibility to generate a simple standard model to derive this data for atmospheric research from available measured data should be investigated.

Some of the sectors considered here overlap with the other groups and in future work clear definitions need to be developed of the categorization and classification of the sources, especially as some are outside the existing guidelines.

Mass emissions of TSP/PM<sub>10</sub> are often available from large industries, but are missing for smaller industries and area sources. Size speciation is often missing or only available in scattered studies so these inventories may have little application for climate relevant aerosols, without further investigation of the smaller size fractions. Sometimes chemical composition is obvious, in other cases it is only available from scattered studies.

Estimation methods require activity data, technology specific emission factors and size and chemical speciation. Information on production technologies, control technologies and their shares are needed to implement the estimation methodologies. Currently uncertainties of industrial aerosol inventories are large and this uncertainty originates from all these input parameters.

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<sup>14</sup> A clear threshold and global emission estimates to assess significance is, however, missing (PM<sub>10</sub> likely to be larger than 1 Tg was used as a rule of thumb).

**Table 5 Main Sources of Aerosols and their Climate Importance**

Source	Importance	Aerosol, Precursor or both	Key Uncertainties
<b>Mineral Industry</b>			
Cement Production	3	Aerosols	Speciation for technologies
Lime Production	2	Aerosols	Speciation for technologies
Glass Production	1	Aerosols	
Mineral Wool	1	Aerosols	
Ceramics	1	Aerosols	
Other Magnesia Production	1	Aerosols	
Other Uses of Soda Ash	1	Aerosols	
Miscellaneous Uses of Limestone, Dolomite and Other Carbonate	1	Aerosols	
<b>Chemical Industry</b>			
Ammonia Production	2	Precursors	Emission factor
Nitric Acid Production (including fertilizer production but not use)	2	Precursors	Emission factor
Adipic Production	1	Precursors	
Carbide Production	1	Aerosols	
Caprolactam Production	1	Precursors	
Titanium Dioxide Production	1	Aerosols	
Soda Ash Production	2	Aerosols	Size distribution
Petrochemical Process	3	Precursors	Chemical speciation
<b>Metal Industry</b>			
Iron & Steel Production	3	Both	Size distribution
Ferro-Alloys Production	1	Both	
Aluminium Production	2	Both	Size distribution
Magnesium Production	1	Both	
Zinc Production	1	Both	
Lead Production	1	Both	
Foundries	2	Both	Size distribution, Chemical composition, Technology
<b>Non-Energy Products Use of Fuels</b>			
Asphalt Paving of Roads and Roofing	2	Precursors	Emission factor, Chemical speciation
Solvents and Other Chemical Product Use	3	Precursors	Activity data, Chemical speciation
<b>Other</b>			
Coal mining (Open mining)	3	Aerosols	Size distribution, Emission factor
Mineral mining	2	Aerosols	Size distribution, Emission factor
Construction and demolition	2	Aerosols	Size distribution, Emission factor, Activity data
Coal Stock Piles	1	Aerosols	
Rock Stock Piles	1	Aerosols	
Product Stock Piles (e.g. Cement clinker)	1	Aerosols	
Entrained Road Dust (including railway)	3	Aerosols	Activity data, Technology data, Emission Factor
Transport of bulk products	1	Aerosols	
Wood industry (including paper and pulp)	2	Aerosols	Size distribution, Emission factor for small plants
Handling of agricultural products and waste	3	Both	Technology data, Emission factor
Solid waste disposal (landfill, waste incineration, open burning)	3	Both	Size distribution, Activity data
Nano-particle production and use	1	Aerosols	
Food industry	2	Both	Size distribution
Oil & Gas, Upstream business and refineries	3	Both	Chemical speciation, Emission factor
Coke ovens	2	Both	Emission factor
Gas Flaring	2	Both	Activity data, Operational condition

3 = very important, 2 = important, 1 = less important. Unimportant or zero emission sectors omitted.

There are problems in the distinction between black carbon and organic carbon emissions in cases where both of them are emitted together.

The method used to estimate emissions for all these sources is: emission factor times activity rate. This activity rate is a parameter such as amount produced; input substance consumed or distance travelled.

Precursor emission estimation methodologies are generally quite well developed (for NH<sub>3</sub>, NO<sub>x</sub>, SO<sub>2</sub> and NMVOC). NMVOC speciation is, however, often missing. Currently PM<sub>10</sub> and PM<sub>2.5</sub> inventories are being developed for air quality purposes. Emission estimation methodologies and chemical speciation data are

expected to be developed for the Convention on Long Range Transboundary Air Pollution (CLRTAP) and the European Union over the next years. It is expected that similar activities take place in other regions of the world.

Finally, there are a large number of potential sources in this sector and, in order to reduce the number of sources that need to be considered, further assessment the size of each source is required. Conclusions about which source fractions are important can only be made in consultation with climate modellers.

Suggested issues for further review and research include:

- Systematic measurements on size distribution and chemical composition for different industrial processes and control technologies
- Harmonization of Organic Carbon and Elemental Carbon sampling and analysis methodologies
- Development of a simple standard model to derive parameters to derive required aerosol parameters from available measured data
- Improved quantification of emissions from non-point sources
- Improved quantification of precursors emissions in developing countries (especially NMVOC and NH<sub>3</sub>)
- Classification and survey of relevant production and control technologies, including super-emitters
- Scoping study to further assess the importance of the sources listed, including case studies on specific sectors (cement, iron and steel, road non-exhaust).
- Identify and quantify uncertainties and systematically work to reduce them
- Identify particles size and emission rate threshold for climate relevance

Further work by IPCC should include:

- Facilitate discussion about international research priorities
- Dissemination of the report to important to relevant stakeholders for the purpose of promoting relevant research by national/international organizations
- Consider an IPCC expert meeting to review progress in research activities and methodology development on aerosol inventories since this first expert meeting; assess uncertainties and propose plans for future work.

## Annex 3 Report of Land Use Emissions Group

Table 6 shows the sources of aerosol emissions from different kinds of “land use<sup>15</sup>”. This sector covers emissions from the land surface, both natural and anthropogenic. Emissions can come from dust, fires and agricultural activities. Settlements, can also give rise to significant emissions.

**Table 6 Sources of Aerosol Emissions from Land Use and their Climatic Importance.**

Source	Forest land	Cropland	Grassland	Wetlands	Settlements	Other land <sup>a</sup>
Dust Emissions <sup>b</sup>						
• Soil Dust	1	2	2	1	1-2	3
• Agriculture						
Biomass Burning <sup>c</sup>						
• Wild Fires						
• Prescribed Fires, Slash & Burn	3	2	2-3	2 <sup>d</sup>	1	1
• Savannah Burning						
• Burning of Agricultural & Deforestation Residues						
Biogenic Aerosols						
• Pollen and Spores	2	2	1	1	1	1
• Leaf litter						
Biogenic Precursors						
• NMVOC Emissions	3 <sup>e</sup>	2	1	1 <sup>f</sup>	1	1
• Nitrogen & Sulphur Compound Emissions						
• Livestock (Nitrogen Compounds)						

3 = important, 2 = potentially important, 1 = not important

Notes:

- a Includes bare soils, rocks, ice and all unmanaged lands that do not fall within the above categories
- b Large emissions can occur due to land use conversions e.g. from forests to cropland
- c Also produces precursors – mainly nitrogen and NMVOC species
- d Peat fires in wetlands
- e Primarily terpenes and isoprene but also some NO<sub>x</sub>
- f Some sulphur emissions

There is a general discrepancy in the use of “anthropogenic” vs. “natural” emissions between IPCC WGI and NGGIP as used by the UNFCCC. Under the IPCC guidance (from the NGGIP), for example, emissions from “managed” land - whether caused by human fires or, say, lightning strike - would be considered anthropogenic and reported internationally as such, whereas IPCC WGI might categorise these emissions as natural.

<sup>15</sup> These land use categories are those used in the IPCC Guidelines on National Greenhouse Gas Inventories

## ***Dust Emissions***

These are soil particles, wind lofted in the coarse mode (with a modal diameter typically of a few micrometers). They are potentially significant for climate change (negative direct forcing) due to high emission rates and are mostly emitted from unmanaged land. Some agricultural activities were not considered for example, liming (spread from aeroplanes), fertilizer application and off-road machinery.

This sector is not currently included in the IPCC guidelines as it does not emit any of the greenhouse gases they cover.

The parameters of interest for the climate models are mass emission, optical properties, mineral composition and the size distribution. While PM<sub>10</sub> (particles less than 10 microns) is an ideal definition for climate change an understanding of particles up to 40 microns is also needed as this determines the mass emission properties.

The existing emission estimates are largely based on models of the emission process based on meteorological data and land types. These still need to be validated against observational data (including satellite data). Satellite measurements provide some constraints on the emission estimates. There do not appear to be many regional or national inventories.

These estimates could be improved by:

- Better data on aspects of land types. Parameters such as soil texture (mineral composition), soil moisture and vegetation index are needed. Current IPCC methodologies on land use and land use change can provide useful input;
- A better understanding of the meteorology (turbulent mix and wind speed) is needed;
- Measurements of emission flux to improve the methodologies are also needed;
- There is a need to validate the models against observational data.

## ***Open Biomass Burning and Wild Fires***

These are highly carbonaceous aerosols typically of sub-micrometer diameter plus many reactive precursors for secondary aerosol formation (i.e. gases such as NO<sub>x</sub> and NMVOC but also SO<sub>x</sub> and NH<sub>3</sub>). This source is highly significant for direct and indirect radiative forcing. The significance of anthropogenic and natural emissions varies by region but is mainly anthropogenic. The status of wildfires (natural or anthropogenic) may need more careful definition.

The parameters of interest for the climate models are mass emission of aerosols and precursors, optical properties, particle composition, speciation of NMVOC and the size distribution. Given the size of the aerosol emissions a size distribution up to PM<sub>1</sub> (particles less than 1 micron) is sufficient.

Some monitoring tools are established in this area but issues such as burnt areas, fuel load, combustion efficiency, and emission factors are still the source of key uncertainties. Current estimation methods depend on the mass burned (or a surrogate for the mass) and emission rates. Ways to estimate the amount burnt and a significant part of the methodology needed to derive biomass burning aerosol emission inventories already exist in IPCC-NGGIP Guidelines.

In many areas there is a lack of basic data such as area burnt and fuel load, the combustion efficiency and appropriate emission factors.

A better understanding of the reactive chemistry in the smoke plumes would improve understanding of the emissions. There needs to be better description of the physical and chemical properties of the resulting

aerosols. Current IPCC inventory methodologies would need to address the temporal and spatial resolutions to develop better resolved aerosol inventories.

### ***Biogenic Primary Aerosols***

These are primary particles including pollen, spores, bacteria, leaf litter, etc. mainly on the coarse mode fraction.

The area of biogenic aerosol inventories is still at a very early stage of developing the understanding of global aerosol and their effect on the climate system. The present scientific knowledge limits our ability to quantify the significance of these aerosols on the climate system. For primary particles, we need to develop generally accepted sampling and analysis methodologies.

The diversity of emission sources and emission mechanisms still are mainly unknown. Clearly this is an area where much basic research is needed.

### ***Biogenic Precursors***

These are precursors of secondary aerosol originating from biological activities, particularly from forest trees and soils. The secondary particles include organic aerosol from the oxidation of NMVOC, and nitrogen and sulphur compounds. Biogenic sources have a very high significance for the formation of secondary aerosols. Emissions from forests (primarily terpenes and isoprene but also some NO<sub>x</sub>) are a significant source of precursors, e.g. soil emissions. Those particles contribute mainly to the fine mode fraction and have a high potential significance for indirect forcing.

The existing NGGIP methodologies would offer a good starting point especially for soil emissions. Some work has been done, at regional scales, on inventories to address air quality issues (particularly photochemical pollution) and the emissions methods used there should be reviewed for their applicability for global use. A review of the methods available for speciated NMVOC estimates is needed and this area may require further work.

### ***General Conclusions***

- Enhanced interaction between the NGGIP and the climate science community (especially aerosols) is recommended.
- A review and close links to the work done on air quality issues is needed to use information and methods already developed, particularly in areas such as particulate emissions from the many types of open burning, precursor emissions of NMVOC from forests and emissions from agricultural activities.

## Annex 4 Agenda

### IPCC National Greenhouse Gas Inventories Programme

Expert Meeting  
on Emission Estimation of Aerosols Relevant to Climate Change  
2-4 May 2005  
Geneva, Switzerland

#### Provisional Draft Annotated Agenda (ver. 2005.03.31)

##### 09:30 Opening

Opening and introduction by TFB Co-chairs, IPCC Secretary and TSU

##### 10:00 – 12:00 Plenary Session I: Keynote Presentations:

###### **Direct effects of aerosols on climate: What do we know?**

Prof. Joyce Penner, University of Michigan, USA

###### **Indirect Effects: Aerosol and Cloud Microphysics**

Prof. Ulrike Lohmann, Institute for Atmospheric and Climate Science,  
Switzerland

###### **EC/OC Emissions: Current Understanding & Relevant Issues**

Dr. ZHANG Xiaoye, Centre for Atmosphere Watch & Services, China

###### **Aerosol Coupling with Photochemistry of Greenhouse Gases**

Professor Michael Prather, University of California, USA

##### 12:00-12:30

Discussion on data, including characterisation of aerosols required for greenhouse gas impact research.

##### 12:30 – 14:00 LUNCH

##### 14:00 – 16:30 Plenary Session II: Current Knowledge:

###### **Definitional Issues for Aerosols**

Dr. Tami Bond, University of Illinois, USA

###### **Soil Dust Emissions**

Dr. Ina Tegen, Institute for Tropospheric Research, Germany

## **Practical Experiences of Aerosol Inventory Preparation - European Perspective**

Dr. Kristin Rypdal, CICERO & Dr Zbigniew Klimont (IIASA)

### **Aerosol Emission Measurements**

Dr. Lisa Graham, Environment Canada

### **Global Estimates of Carbonaceous Aerosols using Bottom-Up Methods**

Dr. Tami Bond, University of Illinois, USA

**16:30 – 18:00**

General Discussion on extent of current inventories and their applicability to greenhouse gas issues.

### **Day 2 and Day 3 (Morning Hours): Breakout Groups**

BOG Facilitators will be nominated and they will lead the discussions..

#### **BOG 1: Fuel Use**

Fossil Fuel Emissions (including transport exhaust emissions)

Biomass used as a fuel

Other Energy Sources?

Mining, Transport and Processing of Fuels?

#### **BOG 2: Industrial Emissions**

Industrial Process Emissions

e.g. Cement

Mining & Quarrying (non-fuel?)

Precursor Emissions (SO<sub>x</sub>, NO<sub>x</sub>, NH<sub>3</sub>, NMVOC)

#### **BOG 3: Land Use**

Dust Emissions from Different Land Uses

Biogenic aerosols

Characterization of this “Dust”

Definition of Anthropogenic Emissions

#### **BOG 4: Other Sources**

Other Sources Including:

Entrained Road Dust

Construction

Stock piles

Transport of bulk products

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Note: 1. “Emissions” includes both quantity and parameters characterizing the emissions.

General Questions:

1. Which sources’ emissions can be estimated?
2. How can these emissions be characterized?
3. Is mass the best quantity unit? What size information is needed?
4. What distinction can be made between natural and anthropogenic emissions?
5. Should emission estimates cover direct emissions and precursor emissions or include some estimates of secondary emissions?

### **Day 3 Afternoon: Conclusion**

## Annex 5 List of Participants

### Expert Meeting on Emission Estimation of Aerosols Relevant to Climate Change 2 – 4 May 2005 WMO Headquarters, Geneva, Switzerland

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## **Annex 7 Key Note Presentations**

### **Direct effects of aerosols on climate: What do we know?**

Prof. Joyce Penner, University of Michigan, USA

### **Indirect Effects: Aerosol and Cloud Microphysics**

Prof. Ulrike Lohmann, Institute for Atmospheric and Climate Science, Switzerland

### **EC/OC Emissions: Current Understanding & Relevant Issues**

Dr. Zhang Xiaoye, Centre for Atmosphere Watch & Services, China

### **Aerosol Coupling with Photochemistry of Greenhouse Gases**

Professor Michael Prather, University of California, USA

### **Definitional Issues for Aerosols**

Dr. Tami Bond, University of Illinois, USA

### **Soil Dust Emissions**

Dr. Ina Tegen, Institute for Tropospheric Research, Germany

### **Practical Experiences of Aerosol Inventory Preparation - European Perspective**

Dr. Kristin Rypdal, CICERO & Dr Zbigniew Klimont (IIASA)

### **Aerosol Emission Measurements**

Ms. Lisa Graham, Environment Canada

### **Global Estimates of Carbonaceous Aerosols using Bottom-Up Methods**

Dr. Tami Bond, University of Illinois, USA