



## TNO report

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## The policy relevance of wear emissions from road transport, now and in the future

## Workshop report

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**The policy relevance of wear emissions from  
road transport,  
now and in the future**

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## Executive Summary

Airborne particulate matter (PM), usually characterized and studied by the size of the particles ( $PM_{10}$ , or  $PM_{2.5}$ <sup>1</sup>) has important adverse health effects. The present information shows that fine particles ( $PM_{2.5}$ ) are consistently associated with premature mortality and other endpoints such as hospitalization for cardio-pulmonary disease. Well-conducted cohort studies in Europe, indicate that air pollution emitted from road traffic, including PM, is of greatest concern.

The road transport sector contributes to ambient PM with engine exhaust particles and particles from road surface wear, tyre wear, brake wear and resuspension of road dust. In the past road transport emissions were dominated by engine exhaust emissions. Therefore, these emissions are targeted through increasingly stringent European emission standards. These policies succeed in effectively reducing the engine exhaust emissions, but do not address emissions due to brake wear, tyre wear and road wear, often referred to as "non-exhaust" emissions. In June 2011 a one-day European Workshop was organized which brought together experts from various disciplines to review the state of the art with respect to the importance of road transport wear emissions for ambient concentrations of  $PM_{10}$  and  $PM_{2.5}$  and possible health risks for citizens. The overall aim of the workshop was to provide a preliminary and indicative assessment of the policy relevance of wear emissions from road transport, now and in the future.

### Concentrations in air

While engine exhaust emissions are strongly reduced by EU emission standards in the past decennia, wear emissions are unaffected by measures. Currently, from the perspective of exceeding air quality guidelines it is not needed to address wear emission in most countries. The exception are Scandinavian countries where non-exhaust emissions contribute significant to exceedances of  $PM_{10}$  concentrations. Wear emissions could increase by factors like vehicle weight and power of the engine evoking more dynamic traffic behaviour. It is estimated that in 2010 emissions of  $PM_{10}$  from wear processes are about equal to exhaust emissions. If predicted progress of exhaust emission reduction materializes, wear emissions will dominate traffic-related PM emissions in the near future.

These general conclusions are supported by studies from various European countries. For example, an extensive field study in Switzerland representing important traffic situations showed that wear particles and resuspended road dust contribute more than 50% to real world traffic emissions. Brake wear was especially important in the urban location. In countries where studded tyres are used (e.g., Scandinavia), the pavement/tyre source is strong during winter and early spring and considerably contributes to exceeding of the  $PM_{10}$  limit value. Also when un-studded tyres are used, pavement wear contributes to  $PM_{10}$  composition, especially in the coarse fraction  $PM_{10-2.5}$ . Measurements in Switzerland showed that compared to  $PM_{10}$  resuspension "fresh" wear particle emissions from pavements in good condition are quite low in the range of only a few  $mg\ km^{-1}\ vehicle^{-1}$  if quantifiable at all. Considerable wear emissions, however, can occur from damaged pavements in poor condition. Vehicle induced resuspension was not strictly correlated with traffic counts but was also strongly influenced by available road dust. It is therefore difficult to describe with conventional emission factor models.

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<sup>1</sup>  $PM_{10}$  and  $PM_{2.5}$ ; particles with a 50% cut-off aerodynamic diameter of 10  $\mu m$  and 2.5  $\mu m$ , respectively

### Composition

The properties of non-exhaust particles differ greatly from exhaust particles. In general, the size of most non-exhaust particles is substantially larger than exhaust particles. Non-exhaust, therefore, contributes mainly to the PM<sub>2.5-10</sub> fraction. This is due to the processes of formation, which include mechanical abrasion, grinding, crushing and corrosion, whereas exhaust particles are formed in combustion processes. Important exceptions to the rather coarse size of wear particles may be nanometer-particles from tyre wear and fine particles from brake wear with a significant fraction of the airborne PM being released in the PM<sub>2.5</sub> size range. However, data on size distribution of wear emissions are scarce and sometimes contradictory. More data are needed to be conclusive.

The chemical composition of exhaust and non-exhaust particles differs drastically; non-exhaust particles contain more metals, metal oxides and mineral elements and relatively less carbonaceous material (elemental carbon and organic compounds) than exhaust particles. However, the difference between various types of non-exhaust particles may also be substantial in terms of chemistry, morphology, hygroscopicity and surface reactivity, potentially making one type of wear particle more toxic than others. Hence generalization of the health relevance of non-exhaust particles is difficult, if not impossible.

### Health Effects

Epidemiological research repeatedly reported on the association between exposure to air pollution from traffic and cardiovascular and pulmonary health effects in the general population. The role of non-exhaust in these effects is uncertain. Little is known about the specific contributions of wear particles, although it was suggested that e.g. adverse effects on heart rate variability in highway petrol officers were associated with stop-and-go traffic, pointing to a role of brake wear particles. Toxicological research suggests that brake wear particles lead to negative health consequences, possibly through the formation of reactive oxygen species (ROS) which then may lead to inflammation and cardiovascular effects. It is suggested that brake wear particles are an important element in traffic particle toxicology. Brake wear contains high levels of various (heavy) metals. The ROS-generation potential of metal and metal oxide particles is subject of ongoing research but initial results suggest that copper-rich particles are very potent in generating ROS, like most transition metals. The role of other chemical fractions in inducing adverse health effects is virtually unknown. Exposure of rats to respirable (<5.0 µm) tyre particles can cause acute pulmonary inflammation depending on the exposure concentration and duration. The adverse effect was related to the levels of water-soluble zinc and copper. The interaction between pavement and tyre is a source for wear dust and PM<sub>10</sub>. Short-term exposure to road dust has recently also been related to premature mortality. The particles produced have inflammatory potential in cells which seems to be depending on rock material properties.

In terms of health impacts it can be concluded that for all sources of non-exhaust emissions adverse toxicological effects have been reported. Wear emissions contribute significantly to the coarse fraction which impacts more the respiratory tract – this is certainly health relevant but may have a different impact than the fine fraction, which is often the focus of study. Currently available data do not yet allow quantification of health impact on the population e.g. effect on life expectancy or

(worsening of ) diseases. Moreover, the relative importance of wear particles compared to engine exhaust emissions cannot be assessed based on the available data and this is a major shortcoming at present.

### **Abatement measures**

An important observation during the workshop was that due to the importance of wear and resuspension emissions in urban environments, especially in Nordic countries, first experiences with emission reduction measures can be shared. The special winter conditions in Nordic countries with studded tyres and use of sand/salt makes road dust a more important source here than in many other countries in Europe. To abate the pavement/tyre PM source, studded tyre restrictions have been shown to be effective. Also pavement properties can be adjusted. For standard asphalts, stone rich pavements with more coarse and wear resistant rock materials reduce total wear as well as PM production. Some alternative pavements, even though data is scarce, seem to be able to reduce PM production. For instance, concrete has been shown to lower emissions in field tests, while porous pavements seem to give slightly positive results in central Europe, but not under Nordic conditions.

Another important factor controlling road dust emissions is the wetness of the road surface; the resuspension of road dust is suppressed drastically if roads are wet. The use of dust suppressants that keep road surfaces wet, have been shown to be efficient in reducing emissions of road dust, and resulting in 20%-40% lower PM<sub>10</sub> levels on dry days. Both field and lab tests have shown that increased vehicle speed increases road surface PM<sub>10</sub> emissions. Regulation of vehicle speed may therefore reduce PM<sub>10</sub> concentrations along highways.

Road dust already in the road surface depot can be abated through dust binding using different hygroscopic chemicals. Chloride salts (mainly MgCl<sub>2</sub> and CaCl<sub>2</sub>) and the more environmental friendly CMA (calcium magnesium acetate) is used for this purpose in some European cities. The effect is often short-lived and strongly depending on meteorology and traffic characteristics. Road cleaning (sweeping) using traditional cleaning machines has not been successful in reducing PM<sub>10</sub> concentrations, but in combination with dust binding or flushing, some positive results are obtained.

Finally, the current policy approach is that all PM is equally important for health effects and it may well be that certain measures to reduce wear and resuspension emissions would stand out positively in a cost-benefit approach. This has not been explored in Europe yet.

Harmonization across Europe is needed but should not be interpreted as unification (one factor to be applied everywhere). It should mean absorbing the local knowledge and explain assumptions leading to differences. This is especially true for resuspension. Wear emission can and should be separated from resuspension. Resuspension is related to atmospheric deposition, vicinity of building sites, the dust load on the road and ventilation of the street. This cannot be captured in an emission factor x activity approach. It is simply not the right approach for this PM source. However, resuspension is especially in the urban environment an important contribution to urban air quality and should not be ignored. For brake and tyre wear a harmonized emission factor approach may be feasible but it may take 5-10- years to have it matured. The European community should work towards a wear testing

cycle comparable to the exhaust approach. The results should be integrated in the 2009 EMEP/EEA air pollutant emission inventory guidebook as used by national

experts in EU Member states to estimate pollutant emissions from all anthropogenic sources. The Guidebook already includes a simple (Tier 1) and a more detailed (Tier 2) method for vehicular non-exhaust PM emission estimation. The Guidebook methods can and should be further improved and completed. There is insufficient data available of PM<sub>10</sub> and PM<sub>2.5</sub> emissions due to wear in relation to standard driving cycles to match the detailed emission modelling applied for exhaust emissions. Currently the guidebook does not cover emissions from studded tyres used in the Nordic countries, resuspension of road dust, and weather effects (e.g. wet or snow-covered roads).

### **Missing data**

For each of the different sources of wear particles it was concluded that data were scarce, too limited or incomplete. Chemical profiles as well as size distributions of wear emission sources are incomplete or out-dated and studies to fill these gaps are needed. Chemical speciation of PM and PM sources is scarce. There are simply not enough data to bring a form of chemical speciation into the epidemiology, making it possible to separate the health relevance of different types of PM. Sampling of wear emission material is complicated compared to engine exhaust and therefore few studies have been done to determine the toxicological properties of wear emissions. Last but not least very little is known about personal exposure to wear particles.

### **Outcome of the workshop**

There is consensus among workshop participants that health risks associated with wear emissions may not be neglected. With ongoing reductions in exhaust emissions, and uncontrolled wear emissions, the contribution to the total PM levels will certainly rise in coming years. It has indeed been shown that non-exhaust emissions are health relevant but the relative importance compared to exhaust emissions remains unclear. This is a crucial missing piece in the puzzle of health impact assessment of road transport. In epidemiological studies exposure to exhaust emissions and non-exhaust emission cannot be separated because they correlate extremely well. The uncertainties of traffic-related wear emissions of PM<sub>10</sub> are can be substantial and underrepresented in the knowledge-base, this is even more so for the PM<sub>2.5</sub> fraction. To unravel the importance of non-exhaust emissions, chemical speciation is crucial for receptor modelling, linking exposure to sources and understanding possible toxicological mechanisms. This requires construction and/or replacement of missing, incomplete or out-dated chemical profiles and size distributions of non-exhaust emissions. However, the motivation and funding to obtain such profiles is currently lacking because the toxicological and epidemiological evidence to identify the urgency of addressing non-exhaust wear emissions remains wanting. To break this circular reasoning, studies that can provide a good toxicity comparison expressed in comparable units between exhaust and non-exhaust emissions as well as chemical and physical profiling of non-exhaust emissions should be prioritized. This information will facilitate a balanced judgment on the health and policy relevance of wear emissions. Simultaneously, investigation of potential no-regret measures such as possibilities to change brake / tyre composition and the importance of road maintenance should be pursued and

communicated. However, the first priority should be to quantify how health relevant the wear emissions are relative to current and future exhaust emissions. Quick wins and pressing research needs are given in this report.



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# 1 Introduction

Particulate matter (PM) are tiny particles of solid matter suspended in the atmosphere. Particulate matter is categorised according to its size in micrometres.  $PM_{10}$  refers to particles under 10 micrometres, and the coarse fraction represents particles between 2.5-10 micrometers.  $PM_{2.5}$  refers to particles under 2.5 micrometres, sometimes called the 'fine fraction'. Particles can cause irritation to the eyes, nose and throat and very tiny particles may reach deep into the lung and may be absorbed into the blood stream or cause lung problems. Both the size and composition of the particles determine any potential health effect. The Committee on the Medical Effects of Air Pollution (COMEAP) estimated that long term exposure to a  $10\mu\text{g}$  per  $\text{m}^3$  increase in  $PM_{2.5}$  concentrations leads to a 6% increase in 'all cause mortality', or total deaths. Across Europe particle pollution is believed to reduce the average life expectancy by 8 months (COMEAP, 2010).

## 1.1 Road transport particulate matter and the split between exhaust and non-exhaust emissions

A major source of particulate matter in European cities is road traffic emissions, particularly from diesel vehicles. These road transport emissions have been shown to strongly correlate with severe adverse health effects. Therefore, these emissions are targeted through increasingly stringent European emission standards. These policies succeed in effectively reducing the exhaust emissions, but do not address emissions due to brake wear, tyre wear and road wear, often referred to as "non-exhaust" emissions.

Is this a problem? To what extent do non-exhaust emissions contribute to ambient concentrations of  $PM_{10}$  or  $PM_{2.5}$ ? Even if this contribution does not lead to exceedance of air quality standards for particulate matter, do current or future exposure levels to particles from wear processes related to road transport cause significant health risks for citizens? That is a key question for environmental policy makers.

To work towards an answer of this question the Dutch Ministry for Infrastructure and the Environment requested TNO and RIVM to jointly organize a one-day European Workshop. This workshop was held on June 22, 2011 in Amsterdam, The Netherlands.

The workshop aimed to bring together participants from various disciplines to assess the current state of the knowledge regarding wear emissions from road transport from source to health impact:

- Measurements and size distributions of particles from transport wear processes.
- Emissions and ambient air quality of non-exhaust (wear) particles.
- Chemical composition and Relative toxicity.
- Exposure and potential health impact.

## 1.2 Workshop rationale

The workshop aimed to provide a preliminary and indicative assessment of the policy relevance of wear emissions from road transport, now and in the future.

## 1.3 Workshop structure

The workshop consisted of invited lectures by experts on various aspects of non-exhaust emissions by road transport. An overview of the workshop programme is presented in Appendix 6.1.

The topics addressed included:

- An overview of toxicity of tailpipe and non-tailpipe road traffic particulate.
- Properties, controlling factors and mitigation measures of wear particles from pavements and tyres.
- Potential health relevance of brake wear particles.
- Emission factors and source apportionment for wear and resuspension particles produced by road traffic.
- Tiered methodologies for non-exhaust PM calculations in the EMEP/EEA air pollutant emission inventory guidebook.

Furthermore, in-depth case studies on the importance of wear emission were presented for the cities of Stockholm (Sweden) and Rotterdam (The Netherlands).

The invited presentations are shortly introduced in Chapter 2 of this report.

After the lectures the workshop participants were asked to participate in breakout groups to discuss and attempt to answer a number of policy relevant questions. The summary of the breakout group discussion is presented in Chapter 3. Input to the discussion were also the results from a survey among participants which was initialized before the start of the workshop (Appendix 6.3) At the end of the parallel breakout group discussion the participants were also asked to fill in a short questionnaire to get their opinion on a number of relevant questions including their expert judgment on relevance for future city air pollution and possible research recommendations. The results of the survey and questionnaire are presented in Chapter 4. The workshop was finalized by conclusions from the parallel sessions. The overall outcome and summary of the workshop is presented in the Executive Summary for policy makers.

## 2 Road transport wear emissions – “state of the art”

The workshop brought together experts from the various disciplines necessary to assess the current state of the knowledge regarding tyre / brake/ road wear emissions from road transport from source to final health impact. Seven experts were invited to present the state of the art in their field of expertise with respect to wear emissions from road transport. This encompassed e.g.: overviews of ongoing studies, the results of the most recent experiments, in-depth case studies of Stockholm (Sweden) and Rotterdam (the Netherlands). In the next sections of this chapter the summaries / conclusions of these invited presentations are listed. The conclusions are based on the work covered in the entire presentations and references therein. For support of the wrapped-up conclusions we refer to the original workshop presentations as available from the TNO sharepoint<sup>2</sup>.

### 2.1 Overview of toxicity of exhaust and non-exhaust road traffic particulate

Miriam Gerlofs-Nijland, RIVM, the Netherlands

Traffic is an important source in relation to human health impact from particulate air pollution. Traffic emissions can be separated in several components from either combustion (soot, gases) or wear (tyre/brake/road wear) processes. Furthermore, new technologies and/or (bio)fuels may lead to lower emissions by mass, but other metrics that relate to the toxicity may become more important: particle number, surface or oxidative potential.

With respect to engine exhaust emissions it is concluded that:

- Engine exhaust emissions can cause pulmonary effects but also systemic effects. The cardiovascular system and the blood are important targets, and also the brain may be directly affected.
- Very little is known about personal exposure: Exposure x hazard = risk.
- The toxicity may not only be caused by the particles themselves, but can also be caused by chemicals on the surface of particles as well as depend on the particle size.

Based on a specific study (Gottipolu et al., 2008) which addressed the impact of non-exhaust emission on rats it was concluded that:

- Exposure to respirable (<5.0 µm) tyre particles caused acute pulmonary inflammation.
- The adverse effect is related to the levels of water-soluble zinc plus copper.
- At high concentrations these metals may cause cardiac effects.

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<sup>2</sup>Site URL: <https://as-ehv1-06.ient.tno.nl/sites/WearEmissions/>  
Contact: [magdalena.jozwicka@tno.nl](mailto:magdalena.jozwicka@tno.nl)

## 2.2 **Wear particles from pavements and tyres – properties, controlling factors and mitigation measures**

Mats Gustafsson, VTI, Sweden

Pavement and tyre interaction is a source for wear dust and PM<sub>10</sub>. The particles produced have inflammatory potential in cells which seems to be depending on rock material properties. Short-term exposure to road dust has recently also been related to mortality.

In countries where studded tyres are used, the pavement/tyre source is strong during winter and early spring and considerably contributes to exceedances of the PM<sub>10</sub> limit value. Also when un-studded tyres are used, pavement wear contributes to PM<sub>10</sub> composition, especially in the coarse fraction PM<sub>10-2.5</sub>. The contribution is affected by pavement construction and rock properties. Tyres and pavement binder (bitumen) seem to contribute less to PM<sub>10</sub>, but elemental composition suggests that the contribution is higher in size fractions below 1 µm.

To abate the pavement/tyre source, the use of studded tyres can be reduced and the pavement properties can be adjusted. For standard asphalts, stone rich pavements with more coarse and more wear resistant rock materials reduce total wear as well as PM production. Some alternative pavements, even though data is scarce, seem to be able to reduce PM production. For instance, concrete has been shown to lower emissions in field tests, while porous pavements seem to give slightly positive results in central Europe, while not in Nordic conditions.

Road dust already in the road surface depot can be abated through dust binding using different hygroscopic chemicals. Chloride salts (mainly MgCl<sub>2</sub> and CaCl<sub>2</sub>) and the more environmental friendly CMA (calcium magnesium acetate) is used for this purpose in some European cities. The effect is often short lived and strongly depending on meteorology and traffic characteristics. Road sweeping alone does not seem to be efficient for PM<sub>10</sub> reduction, but in combination with dust binding or flushing, some positive results are available.

## 2.3 **Potential health relevance of brake wear particles: evidence from cell culture and epidemiological studies**

Michael Riediker, IWH, Switzerland

Epidemiological research repeatedly reported on the association between traffic exposure and cardiovascular and pulmonary health effects in the general population (Maynard et al., 2007; Schwartz et al., 2002; 2005) and also in workers (Riediker, 2007; Riediker et al., 2004a; 2004b). One of these epidemiological studies suggested that brake wear particles contribute to these effects (Riediker et al., 2004a). To further study the effects of brake wear particles, we built an exposure system where epithelial cell cultures (A549-cells) got exposed under controlled conditions to freshly generated brake wear particles (Perrenoud et al., 2010). We found that large numbers of fine and ultrafine particles are released during braking, especially when full stops were simulated. The air-to liquid exposure system is likely to correspond to reasonable exposure conditions, as also suggested by the absence of any significant cell mortality as assessed with the LDH-test (Gasser et al., 2009). Still fluorescence assays showed the generation of reactive oxygen species (ROS) and carbon concentrations (Total and Organic Carbon) were

significantly and positively associated to the inflammation marker IL-8. A significant decrease of the protein Occludin was observed in correlation to exposure to the metal iron, manganese and copper. Coloring specific for Occludin suggested that this tight-junction protein got fractionated. This suggests that the presence of brake wear particles leads to damages of tight junctions well before any significant cell mortality occurs. We propose as mechanism the formation of ROS on the particles' surface which then led to oxidative damage to occluding and a cellular inflammation response. The ROS-generation potential of metal and metal oxide particles is subject of ongoing research. Initial results (Sauvain et al., 2009) suggest that copper- and copper oxide particles are very potent in generating ROS. In conclusion, current epidemiological and cell culture research suggests that brake wear particles lead to negative health consequences, possibly through the formation of ROS which then lead to inflammation and cardiovascular effects. It also suggests that brake wear particles are an important element in traffic particles toxicology and thus an important contributor to negative health effects associated with exposure to traffic particles. However, current data does not yet allow quantification of e.g. numbers of deaths or diseases attributable to brake wear particles. Further research seems not only warranted but seems to be urgently needed.

#### Conclusions:

- Traffic particles are associated to cardiovascular and pulmonary diseases.
- Trooper study suggested that brake wear leads to inflammation and cardiac rhythm changes.
- Cell studies demonstrated increased ROS-production, inflammation and cell damage from brake wear.
- There is not yet enough data to provide good estimates of overall relevance for general population.

## **2.4 Emission factors and source apportionment for wear and resuspension particles produced by road traffic**

Robert Gehring, EMPA, Switzerland

Based on an extensive field study at two sites in Switzerland representing important traffic situations (urban street canyon with heavy stop-and-go traffic and along a national motorway) real world emission factors for the most important non-exhaust sources were derived.

Mass relevant contributions from wear particles and resuspended road dust were found mainly in the size range 1-10  $\mu\text{m}$ . In the street canyon, the traffic related PM<sub>10</sub> emissions (Light duty vehicles (LDV):  $24 \pm 8 \text{ mg km}^{-1} \text{ vehicle}^{-1}$ , heavy duty vehicles (HDV):  $498 \pm 86 \text{ mg km}^{-1} \text{ vehicle}^{-1}$ ) were assigned to 21% brake wear, 38% resuspended/abraded road dust and 41% exhaust emissions. Along the motorway (LDV:  $50 \pm 13 \text{ mg km}^{-1} \text{ vehicle}^{-1}$ , HDV:  $288 \pm 72 \text{ mg km}^{-1} \text{ vehicle}^{-1}$ ), respective contributions were 3% brake wear, 56% resuspended/abraded road dust and 41% exhaust emissions. No indication for an important PM<sub>10</sub> contribution of tyre wear was found.

Obviously the contribution of re-suspension and/or pavement wear is very important. However, specific differentiation between PM<sub>10</sub> emissions due to wear and resuspension from road pavement was not possible based on the field measurements at the traffic sites. Mobile Load Simulators, designed and used by

road engineers to test the properties and durability of road pavements in the field, allowed to tackle the issue for different types of road pavement (asphalt concrete, porous asphalt).

The measurements showed that compared to PM<sub>10</sub> resuspension "fresh" wear particle emissions from pavements in good condition are quite low in the range of only a few mg km<sup>-1</sup> vehicle<sup>-1</sup> if quantifiable at all. Considerable wear emissions, however, can occur from damaged pavements in poor condition. Resuspension of deposited dust can cause high particle emissions depending strongly on the dirt load of the road surface. Porous pavements seemed to retain deposited dust better than dense pavements, thus leading to lower emissions from resuspension compared to pavements with a compact surface structure. Vehicle induced resuspension is not strictly correlated with traffic counts but is also strongly influenced by available road dust. It is therefore difficult to describe with conventional emission factor models.

## 2.5 Tiered methodologies for non-exhaust PM calculations in the EMEP/EEA air pollutant emission inventory guidebook

Leonidas Ntziachristos, LAT-AUTH, Greece

The EMEP/EEA air pollutant emission inventory guidebook is used by national experts in EU Member states to estimate pollutant emissions from all anthropogenic sources. The Guidebook includes a simple (Tier 1) and a more detailed (Tier 2) method for vehicular non-exhaust PM emission estimation. Emission factors and algorithms are provided for tyre, brake, and road surface wear and for different PM size fractions, including typical chemical composition of the wear particles.

The EMEP/EEA methodology has been mostly based on the measured results of the European FP5 "Particulates" project, while literature data have been used to fill in gaps and cross-check the information provided. The method tries to be complete in terms of vehicle type coverage and driving conditions, in terms of mean travelling speed. Since measured data have not been available for all combinations, some of them may be just extrapolations from other vehicle types.

The methods proposed in the Guidebook can be further improved by, optimally, organize a measurement campaign to collect missing emission information. If this is not possible due to organization or financial reasons, the method could be further improved by taking into account recent emission information, since it has not significantly changed since 2003. In particular, road surface wear emission factors, and trends in tyre/brake characteristics as a follow-up of relevant regulations, including chemical speciation, should be better reflected. Furthermore, the methodology does not cover emissions from studded tyres used in the Nordic countries, resuspension of road dust, and weather effects (e.g. wet or snow-covered roads).

Despite these limitations, the Guidebook methods already represent a good starting point, as they offer the order of magnitude of emissions, and guarantee the completeness and the consistency of the national inventory. By using this methodology it becomes clear that non-exhaust sources gradually become the key contributor to vehicular PM emissions and in particular with regard to elemental carbon, organic carbon, and metals.

## **2.6 Road dust emissions – Controlling factors and presentation of an operational model for describing temporal and spatial variability (case study: Stockholm)**

Christer Johansson, ITM, Sweden

In Stockholm  $PM_{10}$  levels alongside densely trafficked streets exceed limit values and a large fraction of the local source contributions are due to non-exhaust emissions, mainly coarse mode (2.5 – 10  $\mu m$ ) road dust particles. A recent study has shown significant associations between urban background coarse particle concentrations and premature mortality among the population in Stockholm; strongly motivating non-exhaust particle mitigation.

The special winter conditions in Nordic countries with studded tyres and use of sand/salt makes road dust a more important source here than in many other countries in Europe. Studded tyre restrictions have been shown to be effective in reducing  $PM_{10}$ . Another important factor controlling road dust emissions is the wetness of the road surface; the suspension of road dust is suppressed drastically if roads are wet. The use of dust suppressants that keep road surfaces wet, have been shown to be efficient in reducing emissions of road dust, and resulting in 20%-40% lower  $PM_{10}$  levels on dry days. Both field and lab tests have shown that increased vehicle speed increases road surface  $PM_{10}$  emissions. Regulation of vehicle speed may therefore reduce  $PM_{10}$  concentrations along highways. Road cleaning (sweeping) using traditional cleaning machines have not been successful. Likewise using porous asphalt instead of traditional pavements has been not been shown to be efficient for reducing  $PM_{10}$ .

## **2.7 Exploration of uncertainty in wear emission parameters and related range in the contribution of traffic wear emissions to future urban kerbside concentrations of PM (case study: Rotterdam)**

Jan Hulskotte, TNO, the Netherlands

While engine exhaust emissions are strongly reduced by EU emission standards since three decennia, wear emissions are unaffected by measures. Wear emissions may even increase by increasing weight of vehicles and increasing relative engine power evoking more dynamic traffic behavior. In 2010 emissions of  $PM_{10}$  from wear processes are about equal to engine exhaust emissions. As far as can be foreseen by progress of tailpipe emission reduction about 75% of  $PM_{10}$  emissions in 2020 will be caused by wear processes. Current emission factors of wear processes are largely based on (mass balance) estimations that are supported by relative few laboratory and road-side measurements.

In this desk study wide ranges of wear emissions factors within 1 city corridor were calculated theoretically. No sufficient measurement data were available to check whether these wide bandwidths (within a few 100 meters) exist in reality. Average concentration of  $PM_{10}$  calculated with the CAR-model and standard emission factors were not in conflict with measurement results from 1 monitoring station during 1 year.

Standardized separate measurement protocols for brake wear, tyre wear and road surface wear do not exist thus far.  $PM_{2.5}$ -fractions are often derived from laboratory measurements. However, results from roadside measurements generally show much lower  $PM_{2.5}$ -fractions than results from laboratory measurements. The reason for this difference may be caused by the lack of wear emission measurements

under the regime of standard driving cycles together with a lack of knowledge of representative measurement protocols. Although it is known that a wide spectrum of materials is applied in brake pads, both metallic and non-metallic, average composition within vehicle fleets is not known. In this study comparison of measurement results of road-side aerosol (metallic) composition from 1 monitoring station with modeled concentrations did not allow firm conclusions about source and origin. More reliable composition data must be on the basis for better future understanding of evolution of ambient concentrations of substances to which human population is exposed.

Conclusions:

- The relative importance of traffic wear emissions of PM<sub>10</sub> are already significant and will be dominant in the near future.
- The uncertainties of traffic wear emissions of PM<sub>10</sub> are relatively big and underrepresented in the knowledge-base; This is even more for the PM<sub>2.5</sub>-fraction.
- There is insufficient data available of PM<sub>10</sub> and PM<sub>2.5</sub> emissions due to wear in relation to standard driving cycles that are applied in measurements of engine exhaust emissions.
- There is insufficient data available about chemical composition of wear substrates that allow conclusive interpretation of measurements.

### 3 Summary Report from breakout groups

Following the presentations that summarized the state of the art with respect to road transport wear emissions a discussion session was organized. Two breakout groups with mixed disciplines and expertise were formed (see table below). Each group addressed the same policy-relevant questions and contributed to a research agenda and/or identification of knowledge gaps. Here we present the synthesis of the discussion on both breakout groups.

| <b>Breakout group I</b>                                                      | <b>Breakout group II</b>                                                                 |
|------------------------------------------------------------------------------|------------------------------------------------------------------------------------------|
| Flemming Cassee (RIVM, Netherlands)<br>(Chair)                               | Menno Keuken(TNO, Netherlands)<br>(Chair)                                                |
| Leonidas Ntziachristos (LAT-AUTH,<br>Greece ) (Rapporteur to Plenary)        | Roy M. Harrison (University of<br>Birmingham, United Kingdom)<br>(Rapporteur to Plenary) |
| Fulvio Amato (TNO, Netherlands)                                              | Bert Brunekreef (IRAS, Netherlands)                                                      |
| Jean-Marc Andre (CITEPA, France)                                             | Bart Degraeuwe (VITO, Belgium)                                                           |
| Henk Baarbe (Ministry of Infrastructure<br>and the Environment, Netherlands) | Marieke Dijkema (GGD Netherlands)                                                        |
| Marieke Dijkema (GGD, Netherlands)                                           | Robert Gehrig (EMPA, Switzerland)                                                        |
| Mats Gustafsson (VTI, Sweden)                                                | Harald Jenk (Department of the<br>Environment, Swizerland)                               |
| Marie-Rose van den Hende (VMM,<br>Belgium)                                   | Klaas Krijgsheld (Ministry of<br>Infrastructure and the Environment,<br>Netherlands)     |
| Jan Hulskotte (TNO, Netherlands)                                             | Ulrich Quass (IUTA, Germany)                                                             |
| Christer Johansson (SU, Sweden )                                             | Edward Roekens (VMM, Belgium)                                                            |
| Thanasis Mamakos (JRC, European<br>Commission)                               | Luc Smeets (LF, Netherlands)                                                             |
| Yvonne Pang (AEA, United Kingdom)                                            | Ruud Verbeek (TNO, Netherlands)                                                          |
| Michael Riediker (IWH, Switzerland)                                          |                                                                                          |
| <u>Reporting</u>                                                             | <u>Reporting</u>                                                                         |
| Nicole Janssen (RIVM, Netherlands)                                           | Hugo Denier van der Gon (TNO,<br>Netherlands)                                            |
| Magdalena Jozwicka (TNO,<br>Netherlands)                                     | Miriam Gerlofs-Nijland (RIVM,<br>Netherlands)                                            |

#### 3.1 Report from breakout group I

- *What is the urgency to address wear emissions in terms of emission and air quality?*

Wear particles are part of the total PM mixture and as such they are regulated with current PM standards (PM<sub>10</sub>, PM<sub>2.5</sub>). Many European countries have already met or will soon meet these standards. From that (policy) perspective, it is not necessary to address wear emissions. An exception could be local hotspots, and these should be addressed by local measures not national measures. However, some issues can only be solved with national measures. In the Netherlands the political focus is on meeting AQ requirements assuming that then public health requirements are also met. At the same time there is also public awareness that even below currents standards health effects due to exposure to PM can occur.

Due to the decreasing levels of engine exhaust emissions, wear emissions are an issue and their role is rapidly increasing in Western Europe. This suggests that it is still of interest to know how much each emission source contributes to these adverse health effects including wear emissions. This information is necessary to mitigate them and to develop cost effective abatement measures. In the Scandinavian countries surface emissions are in particular causing exceedances of the PM standards in the dry spring period, when not only deicing salt is suspended but also the studded tyres that damage the roads produce a lot of PM. This phenomenon does not occur to that extent in the Alpine countries. There is also some evidence from Sweden that wear particles not only consist of the so called coarse fraction particles but also can be detected in the ultrafine mode. In the Mediterranean countries, now Heavy Metal (HM) protocol is getting more and more attention. PM standards are often met but limit values for HM are often exceeded. We may not have a problem with PM mass but with HM so understanding that can be the urgency. It is not a problem in Sweden. But it is a problem in Greece and in UK it is high on the agenda. The solution is to have more data on emissions and especially on brake, tyre, road wear. Moreover the spatial coverage should be improved. The situation differs a lot between countries: different sources, various pavements, tyres, meteorological and geographic conditions, diverse climates, etc. More information about the differences from different regions is crucial to understand what are the most important sources of wear emissions in these regions.

It is also important to understand the extent of wear emissions to improve models and understand the gap between measured and modeled PM emissions. At the moment models often underestimate wear emissions. It could be that for certain locations the emission factors should be much higher, but there is a clear lack of recent data. The composition of wear particles, in particular those of braking, changes over time due to innovations in brake pad production.

Conclusion: Wear particles are in general not of concern to meet current PM standards with the exception of the Scandinavian countries in the Spring. However, other standards such as those for heavy metals may be exceeded. Information to estimate local and regional contributions of brake wear is lacking, which impedes modeling as well.

- *What is the urgency to address wear emissions in terms of exposure and health effects?*

Wear particles have to be considered as a heterogeneous mixture, that varies more in space and time and for which it is therefore more difficult to estimate the population exposure compared to engine exhaust emissions. Traffic is similar everywhere and then spatial variation is also similar but industry and other sources make the exposure estimation more difficult. Of course it depends on the location and whether road traffic is the only source of emission. Particles from tyres, brakes, roads might be more toxic than the ones from the diesel engine exhaust. In particular copper and iron are known for the redox active properties resulting in a continuous production of reactive oxygen species upon interaction with biological systems. This in turn can result in oxidative stress in case the physiological defense systems fail.

It is mentioned that one can distinguish exposure to exhaust and non-exhaust PM. Temporal variation of coarse and ultrafine particles is very different and at present information is lacking to model (personal) exposure at a sufficient high resolution for health studies. Coarse particles come from road suspension, road humidity is important so we get different variations. When you look at various groups with different age you have different contribution (ultrafine and coarse).

The diversity of traffic will result in different emission characteristics. To study population exposure it is also needed to take into account different kind of roads (with various types of cars, specific fleet); mass is different but also the composition and sources are divergent. There are only a few studies which looked into differences in total exposure (mass exposure, composition exposure). So also for assessing the health issues it is not enough to separate exhaust and non-exhaust, we should start looking at exhaust, road surface wear, tyre wear, brake wear. We are really lacking good information in Europe about exposure to wear particles in general. E.g. coarse non-exhaust particles should be located closer to the road than other smaller particles, so people's exposure to non-exhaust particles will have a different pattern than exposure to exhaust particles.

In Switzerland they have the luxury of having the Sapaldia study, which demonstrated that in areas with improved air quality, respiratory health increased, so clear benefits in terms of health costs can be seen. Tyre wear emissions can be problematic at certain locations. Also brake wear could result in adverse health effects as shown by the outcomes from the police officers study in North Carolina (Riediker et al 2004), where the PM originate mainly from brake wear (and wear of road surfaces directly doesn't seem to contribute) and engine exhaust emissions of combustion engines. Because of these differences it would be interested to study in more detail the sources of particles. At least, before we will invest a lot of money in studies how to reduce mass of PM, we should understand different sources and then maybe we could find a better metric than mass to legislate. We should focus our energy to understand whether it makes sense to reduce the total mass or that other metrics have to be used to link wear emissions with adverse health effects.

The group agreed that we have to separate the different wear particles sources when we are talking about mitigation measures to make a single measure per category of the source. In addition, it is not only interesting whether or not the particles are having the effect on health but why they are affecting the health. To have these answers we need to separate some groups of particles but also combine some to check what the combined effect is. To understand for example why particles are so dangerous and why they are inflammatory we need to understand the process and how particles behave together with other substances.

For epidemiological studies we may consider the wear particles as just one fraction until it becomes clear if major differences in toxicity of these different wear particles are present. As long as the PM mixture is changing in its composition due to changes in emissions, also the risk should be estimated on a regular basis since this might change and affect the values of the standards. We do not have a good marker yet for wear particles, black smoke was suggested but this also contains the combustion derived PM.

The goal of policy makers should be to protect the society and they should be interested in getting two answers:

- 1) By what level does the health risk increase?
- 2) To understand why and which sources contribute how much to this health risk.

One idea is to assess the hazard of several fractions and assess them for differences in health importance. This way, we come up with the profile for each major source but we still need to know what the exposure is. Without the exposure you cannot calculate any risks. By using receptor modelling an estimate for (hour-to-hour) exposure can be obtained, and for this the chemical speciation of PM is needed. With receptor modelling the contribution of different sources may also be linked with the health effects.

It is a real challenge to assess the health effects without the data. There is a real difference in the tyre/brake material composition in US and in Europe (i.e. strategies towards asbestos). We can not explain differences without having the information. Some data are really difficult to get i.e. what is the tyre, brake composition. In addition, the composition of e.g. brake pads is still changing, so we have to deal with a 'moving target'. More data is needed, and it would be useful to monitor the composition of brake pads and tyres periodically (i.e. annually).

It is very difficult to say whether we should concentrate on primary, (re)suspended, wear, tyre or brake and what is the most important. It will be a challenge for scientific evaluations to look at the exposure. Using exposure data and their link to health as summarized in scientific studies can inform policy makers about sources to address, but it will be difficult to use exposure data to e.g. give penalties to emitters, seen that there is the difficulty to attribute exposure to source in individual cases.

Conclusion: The groups agreed that the health risk associated with wear emission may not be neglected and at present insufficient evidence is present. It is valuable to put the hazard of wear particles in perspective of e.g. engine exhaust emissions. Improve insight in exposure concentrations and durations to allow epidemiological studies and to link hazard and exposure to estimate the health risks.

- *Physical and Chemical aspects*

Road surface, brake, and tyre wear particles seem to be quite different among each other (road surface wear is rather coarse, brake wear seem to contain smaller particles) and obviously they have various chemical composition. Different sources have a different size distribution. Size distribution is important for particular groups of the population. Some particles can be more dangerous for asthmatic or elderly than others. There are metal components in wear emissions, which are used as tracers, but only knowing the composition is not sufficient, also the chemical form may be important since i.e. metal or metal oxides give different effects. So, both chemical speciation and size distribution need to be studied. It is important for health effects but also for modelling – to update/improve the knowledge on physical and chemical aspects of wear particles. We need to study also PM<sub>0.1</sub>, metals in the

particles. We need to understand the different technological, thermal and mechanical processes that create wear particles. We need to estimate also particle numbers, surface area and its contact, chemical reactivity to connect it better with health effects or toxicological studies.

The future could be to study not only purely chemical, physical analysis but also what is the reactivity. Several working group members mentioned the use of oxidative potential or redox activity measurements as a possibly more health relevant indicator for air quality (e.g. DTT, ascorbate depletion or ESR). For policy makers markers or indicators need to be stable over time. PM mass emission is a stable marker but how stable is the related oxidative potential? Finding precursors for oxidative potential could be a solution. If we understand how the oxidative potential is influenced by various PM sources we can use such oxidative potential tests to both monitor progress in PM reduction as well as health impact. This asks for further research to develop a tool or toolkit, select the right proxy or proxies such as the DTT or ROS tests that capture all the health relevant pollutants. Provided that the relation of the test to health effects is stable and known, such a reactivity test is appealing for both exhaust and non-exhaust. However, at present this is not yet feasible.

By regulating wear emissions you will not eliminate the health effects related to traffic emissions. Still more work need to be done, you need to plan the roads and how much traffic will be allowed, etc. When you have busy roads then even with the best brakes you can not eliminate certain emissions.

Conclusion: Chemical reactivity (redox potential) may provide insight in both the chemical composition as well as the hazard of various (sources of) wear particles.

- *Harmonisation across the Europe*

Obviously it is important to have a broad view. It is not enough to do it in one country and don't understand what other countries are doing. Tyre which is bought in Sweden can not be compared to a tyre you buy in Italy (differences between summer and winter tyre). You need to understand what comes from the tyre, what is the road (road surfaces are very different among countries), what is the contribution of different sources, etc. There is a need to understand it per country and not to extrapolate to other countries.

Guidebook tries to provide the harmonized methodology that member states will have at least some support in reporting emissions. Without methodologies member states would not report this source -this is the philosophy behind the Guidebook. With default methods, which you can use when there is nothing else, at least there is an order of magnitude of the numbers. In general the order of magnitude between countries (those using the Guidebook and those which use national data) is more or less correct (except for studded tyres – not included in the Guidebook) but of course more evidence is needed. The more detailed the analysis the more that the uncertainty increases. For example, primary particles versus (re)suspension, and tyre versus brake wear emissions may be differently split in different methodologies. Depends what we want to do but for AQ issues we cannot have a unified layer (like for national inventories). We have to make more local inventories or study hotspots.

Methods to assess wear emissions should be harmonized to have comparable results and they should be representative for a driving cycle. These which you obtain in laboratory are not representative. It should be certain that the calculations are done in the same way. ISO standards should be created, something comparable to exhaust emission.

Conclusion: A standardized approach to assess hazard and exposure in Europe is needed to compare results from the various studies.

- *What would be the core message to policy makers?*

In general, participants agreed that we need to improve our knowledge about emission, exposure and health effect of wear particles since this fraction of PM can not be neglected. There was a strong signal that politicians and policy makers should not think that the work is finished because tailpipe exhaust emissions are rapidly decreasing. In order to estimate the size of the problem, a good health impact assessment should be performed, for which crucial data is currently lacking. This will require dedicated funding by the national and European governments. So the groups recommends for being able to define the future policy, money on health studies, chemical characterization, for today's policy should be spend and also to put some money on abate measures and investigate the efficiency of these measures.

Conclusion: Create opportunities to assess the health impact of wear particles and to put this in perspective of cost effective abatement measures.

## 3.2 Report from breakout group II

### 3.2.1 *What is the urgency to address wear emissions in terms of emission and air quality?*

In Central / West Europe it is thought that the contribution of wear to ambient PM10 near roads would be 1-3  $\mu\text{g}/\text{m}^3$ . This suggests that it is not the source to be addressed to avoid exceedance of the AQ standards but important remarks to this statement are:

- The contribution could be substantially higher during inversions in street canyons where a build-up may occur (example Switzerland).
- Near some busy roads (example UK Marleybone road) estimate of wear contribution to a PM10 level of about 40  $\mu\text{g}/\text{m}^3$  would be in the order of ~5  $\mu\text{g}/\text{m}^3$  – making it substantial and relevant (> 10%).
- In the Nordic countries – with the use of studded tyres and/or road sanding – the situation is fundamentally different and road wear related emissions may dominate the PM10 exceedance.
- There is agreement that even in urban locations where the increment in PM due to wear is limited, the importance is growing and will be more important in the future.
- In relative sense the contribution is still minimal but the absolute additional contribution is growing. Even if this is the case it is undecided if this than will also make it critical.

### 3.2.2 *What is the urgency to address wear emissions in terms of exposure and health effects?*

In terms of health the impact may be much higher than impact on emissions and air quality. An important aspect for health impact of particles is the particle size distribution. Especially for metals there is agreement that metals in fine particulate are health relevant but the relative impact compared to exhaust remains highly uncertain. We need to know more and better in which size fraction(s) the metals are and what the health relevance of that fraction is. This is simply not known at present.

Another line of thought at least in the UK is that the current policy approach is that all PM is equally important – It may well be that certain measures to reduce wear emissions would stand out positively in a cost-benefit approach. For example to reduce 1-2  $\mu\text{g}/\text{m}^3$   $\text{PM}_{10}$  through wear emission reduction in the urban environment may well be cheaper than trying to achieve this with a further reduction of e.g.  $\text{SO}_2$  emissions across Europe. To our knowledge this has not been explored yet.

Other important remarks on the subject:

- The coarse fraction impact more the respiratory tract – this is certainly health relevant just different impact than fine fraction.
- Copper shows up deserving more attention and the possible importance of metals in  $< 1 \mu\text{m}$  should not be forgotten; in terms of mass it will be negligible but in particle number it may be substantial and we just don't know the mechanisms.
- Composition of a brake wear particle will be really different from the raw material put into the brake pads. Very high temperatures and friction will chemically change (oxidation) the nature of these particles. One test on one brake does not tell you enough.

### 3.2.3 *Physical and Chemical aspects*

#### **Is the size distribution ( $\text{PM}_{10}$ / $\text{PM}_{2.5}$ ) important? Or may the coarse fraction ( $\text{PM}_{2.5-10}$ ) be as health relevant as the $\text{PM}_{2.5}$ and is the uncertainty in the split acceptable / not relevant**

Size distribution is certainly important for several reasons:

- It impacts on respiratory deposition and impact on health outcomes.
- From regulatory principle the split  $\text{PM}_{10}$  /  $\text{PM}_{2.5}$  needs to be known.
- Attention for respiratory vs cardiovascular impacts (difference  $\text{PM}_{10}$  vs  $\text{PM}_{2.5}$  and possibly ultrafine particles).
- Knowing  $\text{PM}_{10}$  is important – the  $\text{PM}_{2.5}$  is felt to be less the correct metric to cover the fine particulates.

#### **Should chemical speciation or a ranking based on chemical composition be included in priority setting for PM abatement policy making?**

*Note – the survey thus far indicates that participants think that chemical composition of particles is (very) relevant for health impact but this is currently not reflected in AQ policies.*

Science is currently not able to answer priority setting in PM abatement based on chemical constituents of PM. We would need to be able rank health impact of PM by chemical components. For this one needs speciated exposure data for effects but “no clear knowledge” available yet.

### **Chemical speciation is crucial for receptor modelling and linking exposure to sources – should it be compulsory to collect such information in the urban environment**

- Chemical speciation is scarce. Epidemiology need exposure values, these are expensive and money can not be obtained unless epidemiological evidence is provided and there are simply not enough data.
- We do expect that in the long run chemical speciation may make it into regulation but not now or immediate years to come.
- In relation to this missing, incomplete or out-dated chemical profiles and size distributions of sources are a problem and studies to fill these gaps are needed.

#### 3.2.4 *Harmonisation across the Europe*

Harmonization across Europe is a very important issue but should not be interpreted as unification (1 factor to be applied everywhere). It should mean absorbing the local knowledge and explain assumptions leading to differences. This is especially true for resuspension: agree on HOW to do it – not exactly with which emission factor.

Wear emission can and should be separated from resuspension. Resuspension is also related to atmospheric deposition, vicinity of building sites (dirt on the road), anything else that influences the dust load on the road and ventilation of the street. This cannot be captured in an emission factor x activity approach. It is simply not the right approach.

For brake and tyre wear a harmonized emission factor approach may be feasible but we should work towards a wear testing cycle comparable to exhaust approach. This is certainly feasible although it may take 5-10- years to have it matured. Need to acknowledge that this takes time and initiating first steps now may be very timely.

Here the “chicken and egg” show up in the discussion– Do we than have a clear mark from health studies that it is sensible to do invest money in standardized cycle testing for brakes and tyres?

#### 3.2.5 *What would be the core message to policy makers?*

- More toxicological and epidemiological evidence is needed to identify the urgency of tackling wear emissions and guide policy makers: Good toxicity comparison expressed in comparable units between exhaust and non-exhaust is crucial info at present.
- In terms of priority setting brake wear appears more important than tyre wear but there is no full agreement on this: Some participants find the correct information on tyre wear is just too limited. Research on composition is quite important.
- Epi studies have a big impact on policymaking but very difficult to separate exhaust from non-exhaust because they always correlate highly. This needs further study and thought.
- Policy makers should be informed about potential measures no-regret, possibility to change brake / tyre composition (e.g. ceramic brakes have less emissions), importance of road maintenance.

A different notion is that we (and policy makers) should not forget how much progress was made with exhaust (orders of magnitude reduction) but also that it took 30-40 years to do so. However, the first steps in this process were very big – no reason why this would not apply to wear emissions. If we put our mind to it a reduction of a factor 2-5 should be feasible – just from experience with other issues - and it needs a big push to start this process.



## 4 Results of consulting individual participants

Specific input to the breakout groups discussion were the results from a survey which was initialized before the start of the workshop. Furthermore, at the end of the parallel breakout group discussion the participants were asked to fill in a short questionnaire (Exit Poll) to get their opinion on a number of relevant questions including their expert judgment on relevance for future city air pollution and possible research recommendations. Both of these sources of information were taken into account when the workshop outcomes / conclusions were formulated (see Executive Summary).

### 4.1 Survey

The Survey consisted of 10 open and closed questions (see Appendix 6.3). 21 participants have answered the questionnaire. The experts agreed that there is clearly lack of data and evidence in the field of wear emission. It is uncertain to what extent non-exhaust emissions contribute to ambient concentrations of PM<sub>10</sub> or PM<sub>2.5</sub> and how the problem of non-exhaust relate to exhaust in a relative sense, both in terms of emissions and air quality as in terms of human health. Although splits in emission calculations are available for non-exhaust and exhaust we do not know how site-specific these should be and what the role is of resuspension of wear emissions versus primary emission. It was generally agreed that as the trend towards cleaner, reduced exhaust emissions through the use of catalytic converters, Diesel Particulate Filters (DPF) and improved fuels and engines, continues, in the near future (if not already) non-exhaust particulates will surpass the exhaust PM in terms of emissions and may well become dominant in 2020. There was consensus that non-exhaust emissions are health relevant, also based on material presented during the workshop. However, a major knowledge gap is the relative toxicity and health impact of non-exhaust emissions versus exhaust emissions. Engine exhaust emissions seem to put more risk for adverse health impact due to their chemical nature (including soot or PAHs) but no firm evidence could be identified to split the contribution to health impact. So, simply, due to lack of primary data, the health impact of different traffic sources can not be definitely drawn. The majority of the experts ranked the importance of wear and resuspension emission compared to engine emissions in the future (2020 and beyond) as dominating (55%) in terms of PM mass. Exhaust emissions become an issue of decreasing importance because of the implementation of the stricter European environmental regulations and technical development. There is insufficient data on physical properties and chemical reactivity that controls toxicity. However, 63.2% of the experts indicated that in terms of PM toxicity non-exhaust may be equally important as exhaust emissions ( Figure 1).

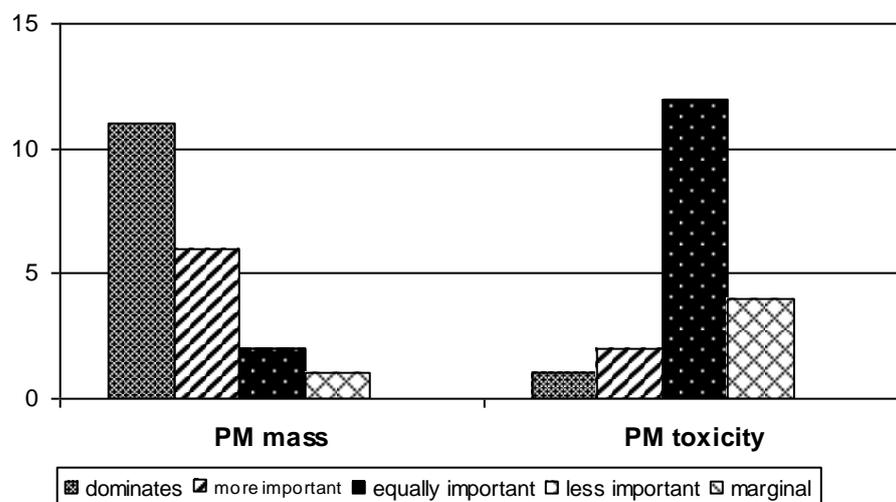


Figure 1 Experts' indications: How will you rank the importance of wear and resuspension emission compared to engine emissions in the future (2020 and beyond) in terms of PM mass and PM toxicity

In theory, it might be possible to separate wear emission from resuspension emissions for their relative contribution to air quality and / or human health. However, with the current knowledge it is extremely difficult especially in terms of wear and resuspension emissions' contribution to human health. 76.2% of the experts indicated that those emissions can be separated for their relative contribution to air quality and 55% pointed out that it is possible in terms of human health (see Figure 2).

| 3. Can wear emissions be separated from resuspension emissions for their relative contribution to |            | Create Chart | Download       |
|---------------------------------------------------------------------------------------------------|------------|--------------|----------------|
|                                                                                                   | Yes        | No           | Response Count |
| air quality                                                                                       | 76.2% (16) | 23.8% (5)    | 21             |
| human health                                                                                      | 55.0% (11) | 45.0% (9)    | 20             |
| Comment briefly how separation can be achieved                                                    |            |              | 18             |
| answered question                                                                                 |            |              | 21             |
| skipped question                                                                                  |            |              | 0              |

Figure 2 Experts' answers to the question: Can wear emissions be separated from resuspension emissions for their relative contribution to air quality and human health

In a qualitative manner wear emissions can be separated from resuspension emissions by identifying the distinct chemical marker of particles from brake wear, tyre wear and road dust suspension. The technical means to separate those emissions exists: modelling, lab / track studies can be performed to obtain primary non-exhaust emission rates, it is known how fast tyre and brake pads wear, using the measured size distribution of the wear particles the emission factor of what becomes airborne could be retrieved. However, in real life situation the separation is difficult due to similar elemental composition of wear emissions and resuspension emissions. To some extent the same particles are being resuspended so the split seems to be impossible in terms of health. Nevertheless, it was enerally agreed that more evidence on the linkage between resuspension and wear emissions and health effects need to be gathered.

Both epidemiological and toxicological studies link exposure to PM to a range of health outcomes.

Only few studies exist about specific health effects of brake wear PM however, more than a half (52.4%) of the group considers wear particles “relevant” for adverse health effect (see also Figure 3).

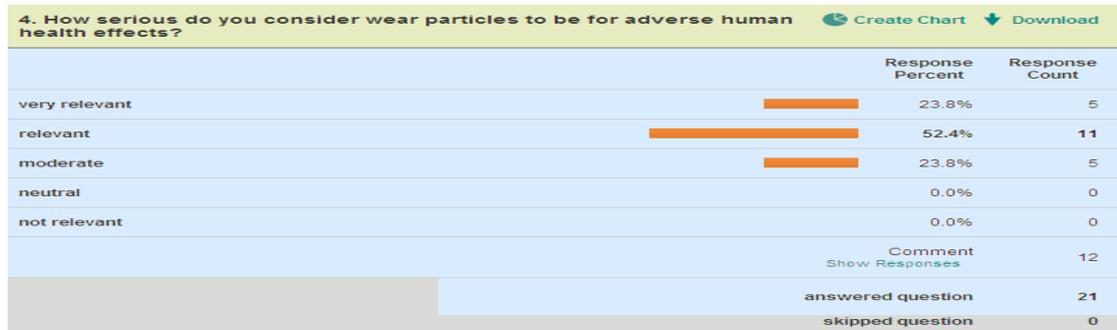


Figure 3 Experts' answers to the question: How serious do you consider wear particles to be for adverse human health effects?

Despite the fact that many studies demonstrated links between PM and adverse health effects, the chemical components of the PM mixture that cause injury are often unknown. Not all components of PM are equally toxic and that is why all the experts think that chemical composition is crucial to judge health relevance and "weigh" the contribution of a particular emission sources (see Figure 4).

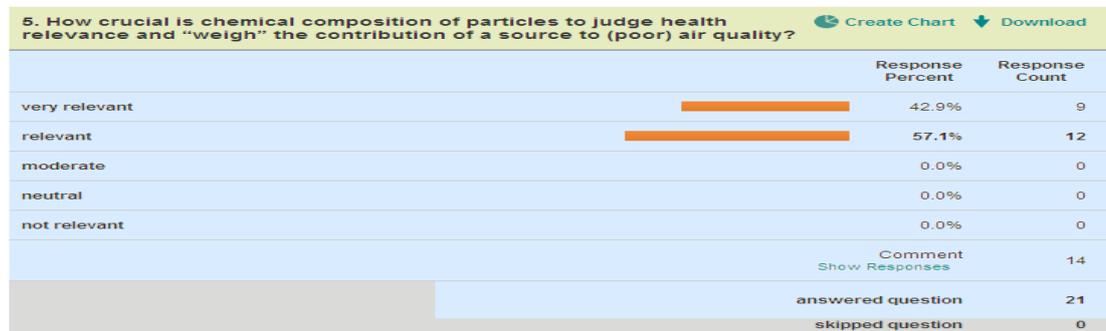


Figure 4 Experts' answers to the question: How crucial is chemical composition of particles to judge health relevance and “weigh” the contribution of a source to (poor) air quality?

Experts agreed that more studies are necessary to investigate wear emissions and their effect on human health. Particularly, they indicated what kind of studies should be performed to examine both emission and health effects of non-exhaust emissions. All of the experts think that epidemiological studies are crucial. Experts specified also other studies which in their opinion are should be performed (see also Figure 5). Those included: variety of studies to improve emission factors and to get information on the release of wear particles (nature in terms of size distribution and chemical composition and amount of emission) as well as information on average composition of brakes and tyres. These studies should be performed in a lab and also on road in real life situations. Moreover, dispersion modelling for PM and brake metals; detailed population exposure characterization and checking of effectiveness of possible mitigation measures / strategies should be performed.

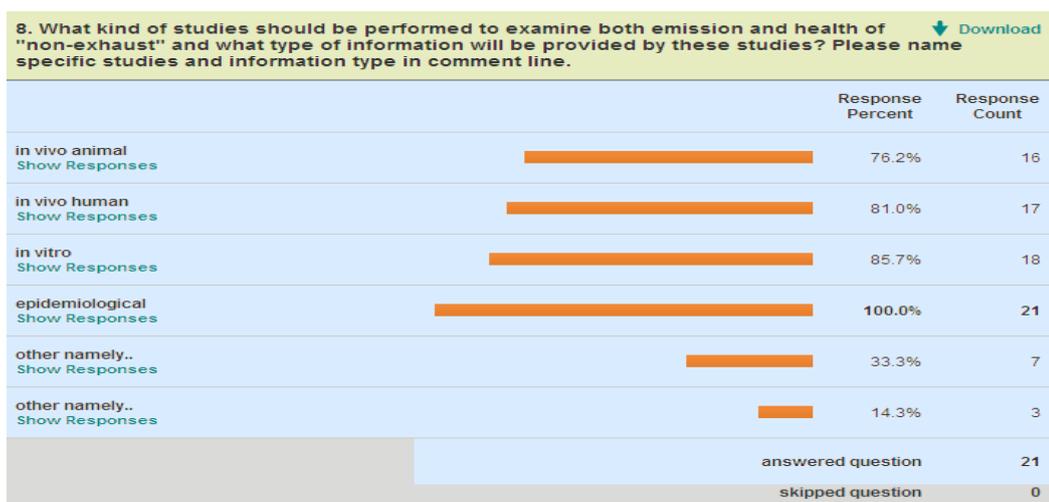


Figure 5 Experts' answers to the question: What kind of studies should be performed to examine both emission and health of non-exhaust?

Experts agreed that wear emissions have an adverse health effects for human health which need to be further studied. Moreover, there are groups which are more vulnerable than others. All workshop participants indicated that people living close to traffic will have increased susceptibility (see Figure 6).



Figure 6 Experts' answers to the question: Which populations will have increased susceptibility?

The other groups which were pointed by experts include: garage workers and other car maintenance staff, all people working near or on roads (drivers, police etc.), children and cyclists in the city centres, near busy roads and busy road crossings. Moreover, vulnerable sub-groups of the population such as: people with decreased lung capacity or other already sick, children, and elderly with heart problems.

#### 4.2 Exit poll

At the end of the parallel breakout group discussion the workshop participants were asked to fill in a short questionnaire. It consisted of 8 questions aiming to get experts' opinion on a number of relevant questions including their judgment on the relevance of road transport wear emissions for health risks and also on knowledge gap and research recommendations. In this section a summary of the experts' view based on their answers to exit poll is introduced but Appendix 6.5 presents all the answers Figure 7 in Appendix 6.5 illustrates the answers to 5 closed questions and further all the answers to the open questions are listed).

The majority (93%) of the workshop participants indicated that road transport wear emissions now and in the near future are not a marginal problem and that further actions (beyond what is currently being done) are necessary (question 1).

70% pointed that current evidence suggests that road transport wear emissions deserve specific abatement or mitigation (question 3). However, for more than half of the group it is not certain whether the currently growing in (relative) importance wear emissions may threaten reaching the specific objective for 2020 to reach 47% reduction in loss of life expectancy (LLE) as a result of exposure to particulate matter (question 4).

For the question about the clear health risks due to road transport wear emissions (question 2) the experts answers varied depending on type of wear emissions. 74% suggests that there is a clear health risk due to brake wear emissions, for tyre wear emissions and road wear emissions 30% and 37% respectively gave the positive answer. The rest thinks that the crucial data are missing. Almost all experts (89%) think that there is a need to follow-up this workshop in that it brings the “measurement / emission / distribution” community together with “epidemiological / health / toxicity” community through proposing a new COST Action<sup>3</sup> or similar network. The remaining 11% suggest that it is possible but more evidence should be collected.

The Exit Poll included also 3 open questions and the most popular experts' answers are listed below (Appendix 6.5 presents all the answers).

Q5: Can you think of any quick wins in relation of wear emissions to Air Quality and/or health impact?

**The experts indicated the quick wins in relation to Air Quality as follows:**

- Reduce traffic emission and exposure by actions such as: improving traffic management / control the traffic level; adjusting the speed limits; reducing traffic intensity in the city centers (congestion charge), enforcing traffic flow (less stop and go), investing in public transport and cycling infrastructure, making residential areas car free; introducing high fuel tax, etc.
- Identify the potentially toxic elements of tyres, brakes and roads. When the most harmful components/processes combinations are identified regulate them and look at technological possibilities for alternatives.
- Make more research to have more evidence and then (also meanwhile) implement road dust (source and dispersion) abatement measures such as: dust binding as an effective short term measure; chose carefully type of pavements, materials used, etc; improve maintenance of pavements, roads, etc; improve road cleaning; watering / cleaning main urban arteries (even more in South Europe due to few raining days).

Invest in brake, tyre and surface research and designs. Further, adjust the products and the usage of them, i.e.: regulate and if possible harmonize brakes and tyres used within EU; forbid brakes that emit particles by changing to contact-free electrical brake systems (contact brakes may still serve as a backup system); introduce mandatory regenerative braking; build air-tight drum brakes for busses; use ceramic brakes; regulate winter studded tyres (especially in Sweden).

- Influence on producers, engineers, i.e.: forbid specific metals or other components which are much more toxic than others.

<sup>3</sup> COST (European Cooperation in Science and Technology) Actions are networks centred around nationally funded research projects in fields that are of interest to at least five COST countries.

**The experts indicated the quick wins in relation to Health as follows:**

- More effort is needed to specify the health risk of different sources.
- Hazard assessment in vitro / ex vivo with a wide range of particle sources with known physical-chemical composition.

**Q6: What do you think is a major knowledge gap? How can this knowledge gap be closed?**

- According to the experts' judgment the major knowledge gaps in relation to road transport wear emissions include lack of information and evidence on the entire chain: emissions – transport – uptake – health effect. Appendix 6.5 presents all experts' answers.

According to the experts' judgment the ideas to close the major knowledge gaps in relation to road transport wear emissions include actions such as: initiating a variety of research, experiments and measurements (to see examples of proposed studies go to Appendix 6.5), furthermore, developing standard test procedure (to simulate real life situation); harmonizing of methodologies and testing procedures to improve results comparability; stimulating communication and networking between different communities ("measurement/emission/distribution" community and "epidemiological/health/toxicity" community).

In the last question (Q8) experts were asked for other comments or suggestions. The answers can be found in appendix 6.5.

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## 6 Authentication

Name and address of the principal

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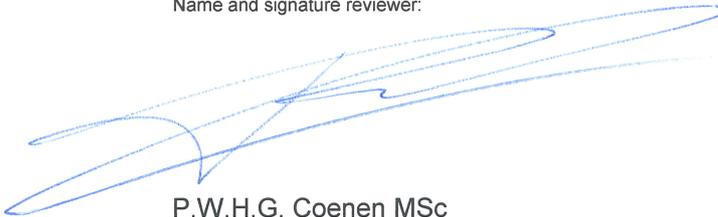
Names of the co-operators

H.A.C. Denier van der Gon PhD (TNO)  
M. Jozwicka MSc (TNO)  
F.R. Cassee PhD (RIVM)  
M.E. Gerlofs-Nijland MSc (RIVM)

Date upon which, or period in which the research took place

February 2010 – July 2011

Name and signature reviewer:



P.W.H.G. Coenen MSc

Signature:



H.A.C. Denier van der Gon PhD  
Lead author

Release:



Ir. R.A.W. Albers MPA  
Research Manager



## 7 Appendices

### 7.1 Workshop programme

| Workshop Programme                                                                       |                                                                                                                                          | Amsterdam June 22 2011                                                                                          |
|------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------|
| <b>The policy relevance of wear emissions from road transport, now and in the future</b> |                                                                                                                                          |                                                                                                                 |
| 9:15-9:45                                                                                |                                                                                                                                          | Registration and coffee                                                                                         |
| 9:45-9:50                                                                                | <b>Hugo Denier van der Gon</b><br><i>Netherlands Organisation for Applied Scientific Research, TNO, the Netherlands</i>                  | Welcome & aim of the workshop                                                                                   |
| 9:50-10:00                                                                               | <b>Klaas R. Krijgsheld</b><br><i>Ministry of Infrastructure and Environment<br/>Directorate Climate and Air Quality, the Netherlands</i> | Policy relevance of wear emissions from road transport, now and in the future                                   |
| 10:00-10:30                                                                              | <b>Miriam Gerlofs-Nijland</b><br><i>Centre for Environmental Health, RIVM, the Netherlands</i>                                           | An overview of toxicity of tailpipe and non-tailpipe road traffic particulate                                   |
| 10:30-10:55                                                                              | <b>Mats Gustafsson</b><br><i>Swedish National Road and Transport Research Institute, VTI, Sweden</i>                                     | Wear particles from pavements and tyres – properties, controlling factors and mitigation measures               |
| 10:55-11:15                                                                              |                                                                                                                                          | Coffee break                                                                                                    |
| 11:15-11:40                                                                              | <b>Michael Riediker</b><br><i>Institute for Work and Health, Lausanne, IWH, Switzerland</i>                                              | Potential health relevance of brake wear particles: evidence from cell culture and epidemiological studies      |
| 11:40-12:05                                                                              | <b>Robert Gehrig</b><br><i>Swiss Federal Laboratories for Materials Testing and Research, EMPA, Switzerland</i>                          | Emission factors and source apportionment for wear and resuspension particles produced by road traffic          |
| 12:05-12:30                                                                              | <b>Leonidas Ntziachristos</b><br><i>Aristotle University Thessaloniki, LAT-AUTH, Greece</i>                                              | Tiered methodologies for non-exhaust PM calculations in the EMEP/EEA air pollutant emission inventory guidebook |
| 12:30-13:30                                                                              |                                                                                                                                          | Lunch                                                                                                           |

| Workshop Programme |                                                                                                                                                                  | Amsterdam June 22 2011                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                                                                                                                                                                            |
|--------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 13:30-13:55        | <b>Christer Johansson</b><br><i>Department of Applied Environmental Science, Atmospheric Science unit and Environment and Health Administration, Sweden</i>      | Road dust emissions – Controlling factors and presentation of an operational model for describing temporal and spatial variability (case study Stockholm)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                            |
| 13:55-14:20        | <b>Jan Hulskotte</b><br><i>Netherlands Organisation for Applied Scientific Research, TNO, the Netherlands</i>                                                    | Exploration of uncertainty in wear emission parameters and related bandwidth in the contribution of traffic wear emissions to future urban kerbside concentrations of PM (Case study Rotterdam)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                                                                                                                                                                            |
| 14:20-14:30        | <b>Flemming Cassee</b><br><i>Centre for Environmental Health, RIVM, the Netherlands</i>                                                                          | <p>Plenary Introduction to breakout groups<br/>Explaining the aim of the parallel sessions – answer the statements based on expert judgment for the particular discipline</p> <ol style="list-style-type: none"> <li>1. Road transport wear emissions now and in the near future are a marginal problem and no further effort needed beyond what is currently being done. (No further actions are necessary)</li> <li>2. Road transport wear emissions are a relevant problem and should be abated or mitigated (Why and how?)</li> <li>3. Statement 1 and/or 2 cannot be validated because specific knowledge is missing (What knowledge and How can this knowledge gap be closed?)</li> </ol> |                                                                                                                                                                                            |
| 14:30-15:00        |                                                                                                                                                                  | Coffee/ tea break /                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                                                                                                                                                                            |
| 15:00-16:15        | Breakout groups with mixed disciplines: each addressing the policy-relevant questions and providing input to a research agenda /identification of knowledge gaps | <b>Breakout group I</b><br>Chair: <b>Flemming Cassee</b><br>Rapporteur to Plenary<br><b>Leonidas Ntziachristos</b><br><br>Reporting (writing):<br>Magdalena Jozwicka<br>Nicole Janssen                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | <b>Breakout group II</b><br>Chair: <b>Menno Keuken</b><br>Rapporteur to Plenary<br><b>Roy M. Harrison</b><br><br>Reporting (writing):<br>Hugo Denier van der Gon<br>Miriam Gerlofs-Nijland |
|                    | 16:15-16:30: All                                                                                                                                                 | Individually write short answers to 3 questions and provide suggestion / identify issue for research agenda on A-4 form                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                                                                                                                                                                            |
| 16:30-17:15        | <b>Chair Flemming Cassee</b><br><b>Rapporteurs of breakout groups</b>                                                                                            | Conclusions from parallel sessions, agreements and disagreements? wrap-up and further actions                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                                                                                                                                                                            |
| 17:15 – 18:30      |                                                                                                                                                                  | Drinks & snacks and soup / sandwich                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                                                                                                                                                                            |

## 7.2 List of participants

| Workshop Participation list                                                        |                          |                                                             |                                   | Amsterdam, June 22, 2011  |
|------------------------------------------------------------------------------------|--------------------------|-------------------------------------------------------------|-----------------------------------|---------------------------|
| The policy relevance of wear emissions from road transport, now and in the future. |                          |                                                             |                                   |                           |
|                                                                                    | Name                     | Affiliation                                                 | E-mail address                    | Breakout group            |
| 1                                                                                  | Fulvio Amato             | TNO, Netherlands                                            | fulvio.amato@tno.nl               | 1                         |
| 2                                                                                  | Jean-Marc Andre          | CITEPA, France                                              | jean-marc.andre@citepa.org        | 1                         |
| 3                                                                                  | Henk Baarbe              | Ministry of Infrastructure and the Environment, Netherlands | henk.baarbe@minvrom.nl            | 1                         |
| 4                                                                                  | Bert Brunekreef          | IRAS, Netherlands                                           | b.brunekreef@uu.nl                | 2                         |
| 5                                                                                  | Flemming Cassee          | RIVM, Netherlands                                           | flemming.cassee@rivm.nl           | 1 (Chairman)              |
| 6                                                                                  | Bart Degraeuwe           | VITO, Belgium                                               | bart.degraeuwe@vito.be            | 2                         |
| 7                                                                                  | Hugo Denier van der Gon  | TNO, Netherlands                                            | hugo.deniervandergon@tno.nl       | 2 (reporting)             |
| 8                                                                                  | Marieke Dijkema          | GGD Amsterdam, Netherlands                                  | mdijkema@ggd.amsterdam.nl         | 1                         |
| 9                                                                                  | Robert Gehrig            | EMPA, Switzerland                                           | robert.gehrig@empa.ch             | 2                         |
| 10                                                                                 | Miriam Gerlofs-Nijland   | RIVM, Netherlands                                           | miriam.gerlofs@rivm.nl            | 2 (reporting)             |
| 11                                                                                 | Mats Gustafsson          | VTI, Sweden                                                 | mats.gustafsson@vti.se            | 1                         |
| 12                                                                                 | Roy M. Harrison          | University of Birmingham, United Kingdom                    | r.m.harrison@bham.ac.uk           | 2 (rapporteur to Plenary) |
| 13                                                                                 | Marie-Rose van den Hende | VMM, Belgium                                                | m.vandenhende@vmm.be              | 1                         |
| 14                                                                                 | Jan Hulskotte            | TNO, Netherlands                                            | jan.hulskotte@tno.nl              | 1                         |
| 15                                                                                 | Nicole Janssen           | RIVM, Netherlands                                           | Nicole.Janssen@rivm.nl            | 1 (reporting)             |
| 16                                                                                 | Harald Jenk              | FOEN, Switzerland                                           | Harald.Jenk@bafu.admin.ch         | 2                         |
| 17                                                                                 | Christer Johansson       | Stockholm University, Sweden                                | christer.johansson@itm.su.se      | 1                         |
| 18                                                                                 | Magdalena Jozwicka       | TNO, Netherlands                                            | magdalena.jozwicka@tno.nl         | 1 (reporting)             |
| 19                                                                                 | Menno Keuken             | TNO, Netherlands                                            | menno.keuken@tno.nl               | 2 (Chairman)              |
| 20                                                                                 | Klaas Krijgsheld         | Ministry of Infrastructure and the Environment, Netherlands | Klaas.Krijgsheld@minvrom.nl       | 2                         |
| 21                                                                                 | Thanasis Mamakos         | JRC, European Commission                                    | thanasis.mamakos@jrc.ec.europa.eu | 1                         |
| 22                                                                                 | Leonidas Ntziachristos   | LAT-AUTH, Greece                                            | leon@auth.gr                      | 1 (rapporteur to Plenary) |
| 23                                                                                 | Ulrich Quass             | IUTA, Germany                                               | quass@iuta.de                     | 2                         |
| 24                                                                                 | Yvonne Pang              | AEA, United Kingdom                                         | Yvonne.Pang@aeat.co.uk            | 1                         |
| 25                                                                                 | Michael Riediker         | IWH, Switzerland                                            | Michael.Riediker@hospvd.ch        | 1                         |
| 26                                                                                 | Edward Roekens           | VMM, Belgium                                                | e.roekens@vmm.be                  | 2                         |
| 27                                                                                 | Luc Smeets               | LF-NL/G, Netherlands                                        | luc.smeets@lapinusfibres.com      | 2                         |
| 28                                                                                 | Ruud Verbeek             | TNO, Netherlands                                            | ruud.verbeek@tno.nl               | 2                         |

The policy relevance of wear emissions from road transport, now and in the future

\*1. How does the problem of "non-exhaust" relate to "exhaust" in a relative sense? Both in terms of emissions and air quality as in terms of human health.

\*2. How will you rank the importance of wear and resuspension emission compared to engine emissions in the future (2020 and beyond) in terms of

|             | dominates             | more important        | equally important     | less important        | marginal              |
|-------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|
| PM mass     | <input type="radio"/> |
| PM toxicity | <input type="radio"/> |
| Comment     | <input type="text"/>  |                       |                       |                       |                       |

\*3. Can wear emissions be separated from resuspension emissions for their relative contribution to

|                                                | Yes                   | No                    |
|------------------------------------------------|-----------------------|-----------------------|
| air quality                                    | <input type="radio"/> | <input type="radio"/> |
| human health                                   | <input type="radio"/> | <input type="radio"/> |
| Comment briefly how separation can be achieved | <input type="text"/>  |                       |

\*4. How serious do you consider wear particles to be for adverse human health effects?

very relevant     relevant     moderate     neutral     not relevant

Comment

\*5. How crucial is chemical composition of particles to judge health relevance and "weigh" the contribution of a source to (poor) air quality?

very relevant     relevant     moderate     neutral     not relevant

Comment

\*6. What type of health effects can be expected based on knowledge of (emission)measurements and chemical composition?

\*7. What will be the worst case situation with regard to emission and what is the relation to adverse health effects?

\*8. What kind of studies should be performed to examine both emission and health of "non-exhaust" and what type of information will be provided by these studies? Please name specific studies and information type in comment line.

in vivo animal

in vivo human

in vitro

epidemiological

other namely...

other namely...

\*9. Which populations will have increased susceptibility?

road workers

traffic participants

people living close to traffic

Other, namely...

\*10. What information is needed for policymakers with respect to

health impact

emissions and air quality

comment

## 7.4 Exit poll sheet

### Workshop Wear emissions – “Exit Poll” to be filled in at end of discussion session

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Name:                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| <p>1. Road transport wear emissions now and in the near future are a marginal problem and no further effort is needed beyond what is currently being done. (No further actions are necessary).</p> <p><input type="checkbox"/> Yes    <input type="checkbox"/> No</p> <p>2. Is there – in your opinion - a clear health risk of emissions due to:</p> <p>a. Brake wear    <input type="checkbox"/> Yes    <input type="checkbox"/> No    <input type="checkbox"/> undecided: Crucial data missing</p> <p>b. Tyre wear    <input type="checkbox"/> Yes    <input type="checkbox"/> No    <input type="checkbox"/> undecided: Crucial data missing</p> <p>c. Road wear    <input type="checkbox"/> Yes    <input type="checkbox"/> No    <input type="checkbox"/> undecided: Crucial data missing</p> <p>3. The current evidence suggests that road transport wear emissions deserve specific abatement or mitigation measures.</p> <p><input type="checkbox"/> Yes    <input type="checkbox"/> No    <input type="checkbox"/> undecided: Crucial data missing</p> |
| <p>4. Currently wear emissions are not abated and growing in (relative) importance. Do you think this may threaten reaching the specific long-term objective (for 2020) set out by the EU thematic strategy to reach 47% reduction in loss of life expectancy as a result of exposure to particulate matter in 2020 relative to 2000?</p> <p><input type="checkbox"/> Yes    <input type="checkbox"/> No    <input type="checkbox"/> undecided: Crucial data missing</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| <p>5. Can you think of any quick wins in relation of wear emissions to Air Quality and/or health impact?</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| <p>6. a) What do you think is a major knowledge gap?<br/>b) How can this knowledge gap be closed?</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| <p>7. Do you think there is a need to follow-up this workshop in that it brings the “measurement/ emission/distribution” community together with “epidemiological / health / toxicity” community? [I.e. through proposing a new COST Action<sup>4</sup> or similar network action on “transport wear emissions”].</p> <p><input type="checkbox"/> Yes    <input type="checkbox"/> No    <input type="checkbox"/> Possibly, but too early to tell</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| <p>8. Other comments / suggestions?</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |

<sup>4</sup> COST (European Cooperation in Science and Technology) Actions are networks centered around nationally funded research projects in fields that are of interest to at least five COST countries.

## 7.5 Answers to Exit poll

For the questions from Exit Poll see Appendix 6.4. Figure 7 presents the experts' answers to 5 closed questions. Further the answers to open questions are presented.

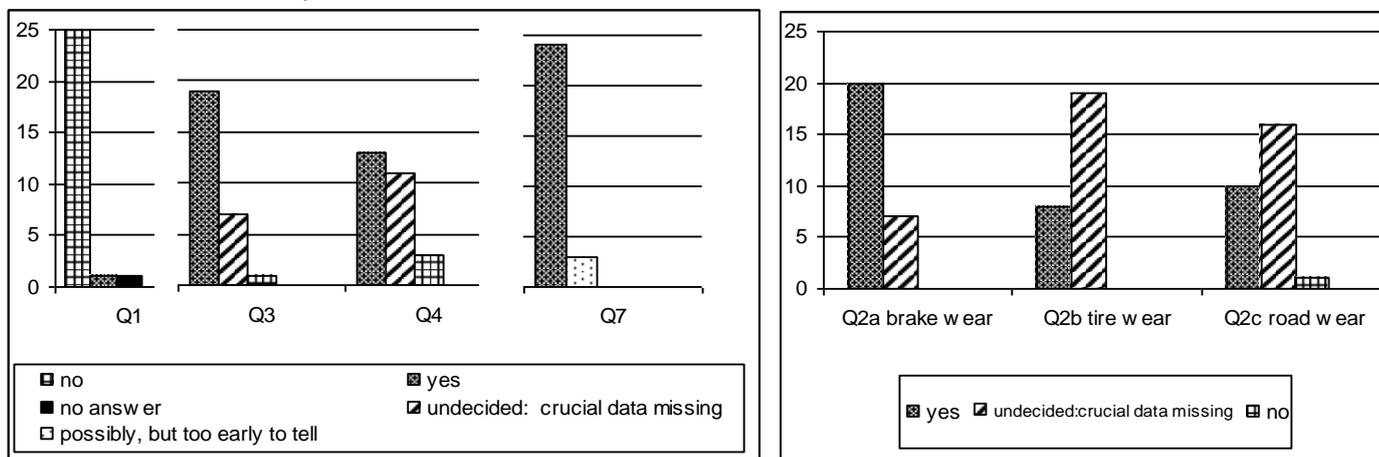


Figure 7 Workshop participants' answers to the questions from the "Exit Poll" (Q1, Q2, Q3, Q4 and Q7)

Q5: Can you think of any quick wins in relation of wear emissions to Air Quality and/or health impact?

**The experts indicated the quick wins in relation to Air Quality as follows:**

- Reduce traffic emission and exposure by:
  - Improving traffic management / control the traffic level
  - Adjusting the speed limits
  - Reducing traffic intensity in the city centers (congestion charge)
  - Enforcing traffic flow (less stop and go)
  - Investing in public transport and cycling infrastructure
  - Making residential areas car free
  - Introducing high fuel tax
  
- Identify the potentially toxic elements of tyres, brakes and roads. When the most harmful components/processes combinations are identified ban them and look at technological possibilities for alternatives.
  
- Make more research to have more evidence and then (or meanwhile) implement road dust (source and dispersion) abatement measures such as:
  - Dust binding as an effective short term measure
  - Chose carefully type of pavements, materials used, etc
  - Improve maintenance of pavements, roads, etc
  - Improve road cleaning
  - Watering / cleaning main urban arteries (even more in South Europe due to few raining days)
  
- Invest in brake, tyre and surface research and designs. Further, adjust the products and the usage of them.
  - Regulate and if possible harmonize brakes and tyres used within EU

- Forbid brakes that emit particles by changing to contact-free electrical brake systems (contact brakes may still serve as a backup system)
  - Introduce mandatory regenerative braking
  - Build air-tight drum brakes for busses
  - Use ceramic brakes
  - Forbid bad combinations of brake-pad-disk types by setting standards
  - Regulate winter studded tyres (especially in Sweden)
- Influence on producers, engineers
  - Forbid specific metals or other components which are much more toxic than others
  - Force car makers to reduce the weight of vehicles as this will reduce the braking energy and thus the associated wear
  - Obligate car manufacturers to build a water tank and spraying system to keep the road wet (maybe 0.1 l/km would be sufficient)

**The experts indicated the quick wins in relation to Health as follows:**

- More effort is needed to specify the health risk of different sources.
- Hazard assessment in vitro / ex vivo with a wide range of particle sources with known physical-chemical composition.

Q6: What do you think is a major knowledge gap? How can this knowledge gap be closed?

**According to the experts' judgment the major knowledge gaps in relation to road transport wear emissions include lack of information on:**

- The entire chain related to all wear particles: emissions-transport-uptake-effect (short/long term).
- Magnitude of brake, tyre, road wear emissions and resuspension (contribution to total PM<sub>10</sub>, PM<sub>2.5</sub> and also ultrafine PM).
- Specific tracers for non-exhaust emission.
- Emission factors to calculate emission.
- Emission estimates and modeling of resuspension.
- Chemical and physical characterization of wear emissions.
- Size distribution of PM in and near road traffic.
- Chemical speciation of size fraction of tyre/brake/road wear and resuspension.
- Source apportionment.
- Toxicity of particular components.
- Relative toxicity of all traffic related pollutants: NO<sub>x</sub>, BC, EC etc.
- Relative comparison with diesel engine exhaust emissions.
- Link between wear emission and health effects.
- Health effects of different sources (tyre, brake road and resuspension).
- Dominant role of traffic emission in health but NOT in exposure PM<sub>10</sub>—how to “weigh” traffic PM.
- Personal exposure assessment.
- Optimization of abatement measures.

**According to the experts' judgment the ideas to close the major knowledge gaps in relation to road transport wear emissions include:**

- The variety of research, experiments and measurements, especially:
- chemical tracers for wear emission studies

- chemical composition of wear emissions studies
  - exact chemical composition (range) per emission source (not only split in elements)
  - studies of metal content and state of change of metals in different size fraction (including ultrafines)
  - size distribution studies
  - comparing wear emissions with diesel exhaust emissions
  - lab and field test of emission factors
  - specific field test combined with model evaluation
  - broad research projects with field trials in different regions/countries to specify differences between them
  - receptor modeling studies
  - studies to get data on the composition of tyres, brakes etc
  - more in-depth comparison of different brakes/tyres
  - experiments with the representative drive cycle
  - research in real life situation
  - determining health effects per wear emission source
  - toxicological research
  - epidemiological studies addressing typical wear components
  - multicity studies on exposure (combined toxicological and epidemiological studies)
  - parallel exposure experiments of cell cultures/ humans
  - corresponding to health studies the measurement programs
  - comparison with toxicological tests of PM or PM fractions
- Develop standard test procedure (to simulate real life situation).
  - Harmonization of methodologies and testing procedures that the comparability of the results will be improved.
  - Data and evaluation of comparable effects allow to identify effective measures.
  - More communication between different communities (“measurement/emission/distribution” community and “epidemiological/health/toxicity” community).
  - Exchange and share knowledge and results with other communities.

#### Q8: Other comments / suggestions?

Some of the workshop participants took the opportunity to share their ideas and to comment on the issues related to the relevance of wear emissions from road transport, now and in the future. **Experts’ suggestions:**

- Do not forget other mode of transport like train/subways/harbors where wear emissions are high.
- Harmonize testing strategy and methodology.
- There might be evidence that wear emission have (clear) health risk. However it is far from clear that those health risks are more important than health risk caused by diesel exhaust emission. One has to take care that growing attention to wear emission does not cause a reduced attention to other, maybe from health perspective more relevant particles.
- Epidemiological studies near combustion and wear activities to distinguish health impacts of exhaust versus non-exhaust emission.
- Assess the toxicity of soot versus non-exhaust components.

- Applied research on abatement measures should be parallel with health research.
- Chemical speciation of PM should be implemented in AQ Directives in order to know what sources are contributing most and which sources are the most health relevant.
- Collect data and evidence on this “new” issue that tyres do not contribute to PM<sub>10</sub>.
- Engineers/producers should provide the data about the brakes / tyres / road surface they produce (released amounts and chemical-physical characteristics).
- Stimulate producers of brakes and tyres to think about product composition that may reduce particle emission rate or use of toxic elements.
- Include industry (suppliers) to give information on market shares different technologies, for input tests procedures, for evaluation of possible options for improvement.
- It seems that there is plenty off data in Nordic countries. They however focus on studded tyres. Maybe re-evaluate their data with our situation in mind.
- Different communities (emission and health) should cooperate more.
- Institutes and Universities in Europe working on the same or similar project should work more closely together.
- Some kind of research programming (coordination) is needed.
- COST Action or similar network is indeed a good idea.
- Control whether the lobbying too significantly funds the research (FP7/8).