Report of a workshop on environment and health: evaluating European air quality research and translating priorities into actions 19-20 January 2009

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ABSTRACT

Scientists, academics, regulators, and representatives of industry and non-governmental organizations from some 18 countries around the world convened at the Bedford Hotel and Congress Centre, Brussels, Belgium on January 19-20, 2009 to participate in a ***Workshop on Environment and Health: Evaluating European Air Quality Research and Translating Priorities into Actions***. The Workshop was organized by CONCAWE with contributions from the European Commission's DG Research, Session Chairpersons and other distinguished presenters. The workshop provided scientific updates in a number of key areas including toxicology, epidemiology and exposure assessment of airborne pollutants. Invited platform presentations and submitted posters followed by facilitated discussions amongst participants resulted in a series of recommendations which are summarized in the present report.

KEYWORDS

Air quality, health effects, research priorities, research timelines

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SUMMARY

Our environment has an important influence on our health. Many conditions, from asthma and allergies to new infectious and emerging diseases, have been linked in some way to the environment. Studies have shown that environmental pollutants, food contaminants, noise, and issues such as climate change can all affect our well-being. The European Union (EU) has been at the forefront of research in this area, expanding our knowledge of the complex links between environmental risk factors and effects on the health of individuals and populations. The European Environment and Health Action Plan (EHAP 2004-2010) has urged Europe to integrate its expertise in the environment, health and research sectors.

As of the time of this Workshop, milestones in the environment and health process in Europe included the WHO (World Health Organization) Fifth Ministerial Conference on Environment and Health in 2010, a review of the Thematic Strategy on Air Pollution in 2010, the next evaluation of the Air Quality Directive in 2013, a potential second phase of EHAP after 2010, and further calls for research proposals and financing of previously selected projects in the Seventh Framework Programme for Research and Technological Development (FP7) of the European Union.

An open international workshop was convened by CONCAWE to consider the current state of scientific knowledge in this area, propose a forward looking roadmap for the development of priorities, and identify emerging challenges and opportunities for policy-relevant research regarding air quality health effects. The workshop provided scientific updates from a number of key disciplines including epidemiology, toxicology, analytical chemistry and exposure assessment, as well as input by representatives of several European bodies that evaluate and use this scientific data for policy advice. Facilitated discussions were organized among participants to generate recommendations for new research topics and other organizational improvements.

Priorities were established for strategic issues, necessary scientific projects and interactions between science and policy.

For strategy issues these included:

- A series of focused workshops to provide updates and input on specific aspects of policy-relevant health research (epidemiology, pollutant measurement and monitoring and toxicology);
- Integrated accountability research as a fundamental aspect of the design of policy interventions;
- Assess possible implications from the use of new fuels (including biofuels), in terms of their emissions, exposure, and health effects, as well as a plan for an accountability assessment, would be timely and important.

Identified priorities for specific research studies included:

- Conduct multipollutant local studies of exposure and health in well-documented high-exposure situations;
- Mechanistic studies of dose response at realistic exposure levels (clinical or in vitro);
- Validation of exposure models - comparison of measured versus predicted data.

Identified priorities to facilitate the input of research outcomes within policy development included:

- A global burden of disease (GBD) analysis on particulate air pollution over the last decade to document anticipated population health benefits of reducing air pollution;
- Investigate the role of co-factors on air pollution health impacts;
- Conducting scenario analyses assuming different relative potency values for PM (particulate matter) constituents (employing toxicological data) to develop most cost-effective control strategies.

1. INTRODUCTION

1.1. PURPOSE

Our environment has an important influence on our health. Many conditions, from asthma and allergies to new infectious and emerging diseases, have been linked in some way to the environment. Studies have shown that environmental pollutants, food contaminants, noise, and issues such as climate change can all affect our well-being. The European Union (EU) has been at the forefront of research in this area, expanding our knowledge of the complex links between environmental risk factors and effects on the health of individuals and populations[1]. The European Environment and Health Action Plan (EHAP 2004-2010) has urged Europe to integrate its expertise in the environment, health and research sectors.

As of the time of this Workshop, milestones in the environment and health process in Europe included the WHO Fifth Ministerial Conference on Environment and Health in 2010, a review of the Thematic Strategy on Air Pollution in 2010, the next evaluation of the Air Quality Directive in 2013, a potential second phase of EHAP after 2010, and further calls for research proposals and financing of previously selected projects in the Seventh Framework Programme for Research and Technological Development (FP7) of the European Union.

CONCAWE was pleased to sponsor this international workshop as a follow-up to the 2007 CONCAWE Workshop on Environment and Health [1]. The workshop was organised to consider the current state of scientific knowledge, propose a forward looking roadmap for the development of priorities, and identify emerging challenges and opportunities for policy-relevant research regarding air quality health effects. A primary aim was to propose a roadmap for developing policy-relevant research actions.

The workshop fostered an international and multidisciplinary approach to:

- Identify, discuss and debate key policy-relevant research needs and opportunities;
- Prioritize those research needs and identify timelines;
- Propose a roadmap for establishing research actions necessary to meet those timelines.

Key headline tasks for the workshop were:

- How to develop health research actions that best support air quality management decision-making in a multi-pollutant world with limited research resources;
- How to develop relevant health-effects data that can inform the policy decision-making process;
- How to establish appropriate pollutant metrics that are relevant to health (what is ideal even if we cannot measure it yet);
- How to integrate air pollution and climate change research actions to address appropriate health effects;
- How to do hazard/risk screening for (combustion of) biofuels;

[1] http://ec.europa.eu/research/environment/index_en.cfm?pg=health

- How to provide evidence that air quality regulations and policies improve public health;
- How to understand underlying mechanisms of action of pollutants that impact on health;
- How to account for health benefits in cost-benefit analyses; and
- Overall, how to evaluate European air quality and health research and translate identified priorities into actions.

1.2. WORKSHOP FORMAT

The workshop was designed to maximise interaction between participants. Sessions included invited platform presentations, facilitated working group sessions and posters by researchers from academia and public health institutes and industry.

The five platform sessions were organised as follows:

- Current Research Programmes (overview);
- Pollutants and Human Health;
- Pollutant Metrics;
- Role of Research on Mechanisms of Action in Air Quality Management;
- Structuring Research to Inform Policy Development.

Facilitated roundtable working group discussions were held after each of the platform sessions with the exception of the first research overview segment. Their purpose was to address the relevant session's headline questions.

All participants were encouraged to submit posters on current or recently completed work in three areas:

- *Climate Change & Health:* How to integrate air pollution and climate change research actions to address appropriate health effects;
- *Vehicle Emissions & Health:* How to do hazard/risk screening for (combustion of) fuels (including fuels containing bio-materials);
- *Accountability Research:* How to provide evidence that air quality regulations and policies improve public health.

The detailed workshop programme is presented in **Appendix 1**.

Workshop participants are listed in **Appendix 2**.

2. PRESENTED MATERIALS

2.1. OVERVIEW OF MATERIALS PRESENTED

The workshop featured a series of lectures by well-known scientists and stakeholder representatives with the principal purpose of providing updates in their field of expertise or responsibility and addressing the key headline task for their session. These presentations provided important inputs into the subsequent discussions. In order to document the proceedings as carefully as possible, invited speakers were asked to provide an abstract, a short biography and a copy of their slides.

There were 21 posters presented during the workshop. A list of the posters is provided in **Appendix 3**.

Copies of platform presenters' material, poster abstracts, etc. can be found on CONCAWE's website: http://www.concawe.org/content/default.asp?PageID=607.

The presented materials were reviewed for recommendations; these were extracted and grouped against high-level themes by the authors of this report.

Summaries of the four Roundtable Discussion sessions are given in **Appendix 4.**

Finally, participants were invited to provide feedback on the value of the workshop and whether the event met their expectations. A summary of their comments is attached in **Appendix 5**.

2.2. SUMMARY OF PRESENTATIONS

2.2.1. International research programmes

Within the European Union, the current Research Framework Programme (FP7) has a total budget of just over €50 billion over the period 2007 - 2013 [http://cordis.europa.eu/fp7/budget_en.html]. Within FP7 there are a number of research focus areas that relate to health and environment issues. These include climate change and health risks, chemicals and health risks, air pollution and health risks, electromagnetic fields and health risks, and the possible health risks posed by nanoparticles. The annual budget for all environment and health research areas is of the order of €80 million in FP7. The DG Research is clear in its support for science-based decision making.

Possible future areas of research interest under FP7 are emerging/neglected issues, support for evolving policies, specific issues of public or media concern, and issues of public health relevance. The most recent FP7 calls have included transportation-related air pollution and health impacts as a specific topic (following the Workshop, these calls resulted in the funding of the TRANSPHORM[2] large-scale integrating project). In prioritising topics for proposal calls, DG Research relies partially on work carried out by policy DGs and WHO with additional inputs coming from the scientific community and other stakeholders. It was noted that another large-scale integrating FP7 project ESCAPE (European Study of Cohorts for Air Pollution Effects)[3] was funded under FP7, in part, due to stakeholder input from the

[2] http://www.transphorm.eu/
[3] http://www.escapeproject.eu/index.php

2007 CONCAWE Workshop. The outcomes from ESCAPE will inform the review of the Air Quality Directive due in 2013.

The key research challenge for the Health Effects Institute (HEI)[4] is to produce science to meet international decision-makers needs requiring high quality relevant studies that target key questions. The HEI's current five year research plan focuses on the toxicity of particle components and gases, traffic related pollution, accountability, emerging technologies and fuels, and the health effects of air pollution in the developing world. The deliverables of the HEI strategic plan are designed to meet the needs of the international and regional regulatory community.

In setting priorities the challenge is to identify key environmental decisions over the next 5 – 10 years, consult broadly with stakeholders and plan research for both short and long term timelines. It is critical to have focus in the research and cover all the 'hot topics' with a clear timeline. Frequent review and revision of the plan is also required to maintain relevance.

HEI has a close relationship with the US EPA's (Environmental Protection Agency) Office of Research and Development which is charged with wide-ranging scientific responsibilities. The EPA has developed a number of multi-year research plans, including 'Clean Air', that are shaped by fundamental risk paradigms covering exposure, risk assessment, risk management and incorporating accountability. Five research themes make up the current research plan to 2012. They are: support to development of North American air quality standards, support for implementation of air quality regulations, pursuit of a multi-pollutant approach, identifying source-to-health links, and assessing health and environment improvements due to past EPA activities.

Internationally, the World Health Organization (WHO) has identified air quality and health as an area of significant research progress with a substantial increase of knowledge concerning health risks of air pollution based on research in the last decade. It has a continuing series of activities supporting WHO Guidelines on Indoor Air Quality, the convention on Long-Range Trans-boundary Air Pollution (LRTAP) and contributions to the Environmental Health information system. WHO has scheduled the release of its guideline on indoor dampness and mould in 2009 [2]. Guidelines on other specific pollutants will be developed later. In addition funding is being sought to produce guidelines on combustion products, allergens, and ventilation.

The WHO 2009 work plan included assessment of the health relevance of air pollution alert systems, assessment of the health risks of biomass combustion (both as a fuel source and in natural forest fires), and guidelines for monitoring and modelling of the health effects of air pollution. WHO assessments stress the policy-relevant evaluation of research evidence on health aspects of air pollution with a focus on effective risk reduction approaches while recognising we are in a world with transcontinental transfers of pollutants.

2.2.2. Epidemiology and Clinical Studies: How to develop relevant health-effects data to inform the policy decision-making process

Epidemiologists have investigated relationships between air pollution, mortality and morbidity for decades. The leading studies are US-based and found that life expectancy may be reduced due to anthropogenic fine particles. However, these

[4] http://pubs.healtheffects.org/

studies have proven to be complex and researchers are faced with a number of challenges in interpreting the results due to remaining uncertainties. Despite these uncertainties EU policy makers have been advised to use the outcome of such studies to introduce measures reducing the level of particulate matter (PM) in ambient air.

Specific EU epidemiological studies to investigate the link between long-term exposure to $PM_{2.5}$ (particles with a diameter of 2.5 microns or less) and health effects are currently not available. Short term evidence for $PM_{2.5}$ is limited to data from London over 2000-2005. Overall the EU data set on health effects of $PM_{2.5}$ is inadequate. Also the assumption that there is no apparent threshold for $PM_{2.5}$ health effects is not based on a convincing and robust set of data. Nevertheless the EU policy to progressively reduce exposures to $PM_{2.5}$ is based on this assumption. To improve the information available to regulators and policy makers there is need for the academic community to address temporal and spatial variation in $PM_{2.5}$ distribution in both indoor and outdoor air.

This gap in knowledge has been recognised by the European Commission and it is supporting the above-mentioned ESCAPE project that will be completed by 2012 prior to the review of the PM regulations in Europe. It will combine information from 30 existing research cohorts on birth and pregnancy outcomes, respiratory morbidity, cardiovascular morbidity, cancer and mortality.

The ESCAPE results should provide a better basis for the health impact assessment of PM and/or PM components, but there are a range of issues that will not be directly addressed by this study. The discussions during the epidemiology and clinical studies session highlighted a number of opportunities to build on the current ESCAPE project.

One of the key recommendations was to enhance exposure assessment in order to better understand and interpret the epidemiological data. There were two important angles to this; one was the level of exposure and second was the notion that not enough is known about the nature (air mix) of the exposure. One area that was identified for enhancement was the need to better validate the sophisticated geo-referenced (land regression) exposure models. A suggested approach was to initiate smart sampling campaigns using passive (and/or personal) samplers to test measured vs. predicted data.

ESCAPE could be further strengthened by parallel projects including:

- PM speciation;
- In vitro toxicity studies of air samples;
- Source apportionment; and
- Possible association between micro-vascular function and fine particles.

The focus of PM research has been on its effect on life expectancy with cardiovascular effects being investigated most as the leading cause of premature death. Controlled clinical (chamber) studies are seen to be complementary to epidemiological investigations and can help understand the effects of PM on morbidity. Such studies have found indications that, for example, diesel engine exhaust can reduce the body’s capacity to handle blood clotting, also diesel particles are claimed to induce neurodegenerative, inflammatory and even functional neurological health effects.

2.2.3. Pollutant Metrics: How to establish appropriate pollutant metrics relevant to health (what is ideal even if we cannot measure it yet)

To frame the discussion on air pollutants, it is first important to describe what they are. Air pollutants can be described in general terms as substances in the air that can cause harm to humans and the environment. These substances may be in the form of solid particles, liquid droplets, and/or gases. The following summary focuses mainly on the particulate or solid phase of air pollutants, but it is important to realize that other pollutants exist and that there is the potential for multiple pollutant effects.

In evaluating the health effects of pollutants, especially in light of potential regulatory control, it is important to consider the appropriate metric relevant to health effects. The consideration of relevant pollutant metrics should not be limited to those endpoints for which there are readily available instruments, but should consider the endpoint that correlates most strongly with adverse health effects. A number of different metrics have been investigated and the most commonly proposed or utilized parameters are:

- Solubility;
- Particle size;
- Particle concentration (e.g. Mass, Number, Surface area);
- Chemical Composition (e.g. Organics, Elemental carbon, Metals);
- Particle reactivity (e.g. Bioavailability of Substances, Surface Structure/ morphology Generation/Release of Free Radicals);
- Source / Emission Process;
- Other properties (e.g. hygroscopicity, solubility).

With the wide range of endpoints the challenge often centres on how to identify the most relevant endpoint. Unfortunately, it is not practical to measure or model every potentially relevant parameter for each particle collected or produced. The evaluation of the different metrics is principally dependent upon two scientific tools. Firstly, the use of epidemiological studies which have the potential to link health outcomes to pollutant metrics especially when studying large populations. Secondly, toxicological dose-response studies which also link health effects and particulates, but have the power to identify the impact of varying dose on the system.

Part of the problem in identifying the ideal metric for particulate measurement is that one metric does not fit all the data sets. Differences in chemical composition of the particles due, in part, to the differences in particle sources can confound the identification of a single applicable endpoint. The metric that has been used historically to link health effects to particulate exposure is particle mass, which has demonstrated a reasonable correlation and is also one of the easiest parameters to measure. There is research that indicates a better correlation is obtained with particle surface area. However, methods for measuring particle surface area are not uniform and can often miss a particle component that has a critical role in toxicity: the semi-volatile fraction. This concept also needs to address the idea that different classes of surface area toxicity may exist. In particular, it is found that trends for transition metals are found outside those established by elemental carbon particulates.

What is the mechanism of toxicity for particles? This is certainly one area where more research is needed. There are proposed mechanisms with ancillary data, but a solid understanding of how particulate matter exerts its toxic potential is not clearly understood. One of the current hypotheses for particulate toxicity is that it may cause an increase in reactive oxygen species. This may occur via the surface properties of the particle, through the presence of organic compounds, or via the presence of transition metals, either adsorbed onto or part of the particle. The understanding of mechanism of action of air pollution is an important health consideration, but a focus is required on how this information can help us control the effects of, or reduce exposure to air pollutants.

Consideration should also be given to the concept that particle composition is not fixed. It can vary from source to source, and source apportionment has been proposed to link health effects to the source of pollutants. Also the question of the age of particles is still not fully understood. In a laboratory setting it is possible to age a particle for experimental purposes, but what is the age of the particles to which the general population is exposed? Age also impacts the composition of the particle via oxidation and loss of semi-volatile components. Of course, size can also have an impact on particle composition. Particulates with larger diameters may be dominated by metals while smaller particles are composed mainly of carbon. In addition to varying composition there is also the question of what impact size has on the potential risk of the material. If there is essentially little difference in the specific hazard of the particle, can smaller particles lead to a larger effective dose through an increase in size dependent uptake?

There is a need to identify and agree on relevant bioassays to be used for biomonitoring purposes. To evaluate the metrics, the relevant surrogate endpoint needs to be identified in order to rank the toxicity of the various particulates. Ideally such assays would be high throughput to allow for fast and reliable characterization/ benchmarking of the toxic potency of the materials.

There are still many unanswered questions about particulate toxicity. Because there are so many variables, it will be difficult to identify one single metric that indicates the greatest relevance to human health. There is a clear need for a standardized approach to particulate toxicity with a higher relevance/association to health effects. This correlation will have to be comprehensively documented and shown to be stronger then previously utilized models to allow widespread acceptance of the metric and establish its use as a standardized measurement.

2.2.4. Toxicology: How to better understand role of research on mechanisms of action in air quality management in a multi-pollutant world

Mechanisms research in this context studies the links between air pollution and adverse health outcomes (e.g. toxicity testing that supports the plausibility of causation). Mechanism research can be issue-driven and systematic, and is one important facilitator to optimizing air quality management (AQM). The overall context of the discussion was how mechanism studies currently fit into the AQM paradigm, and how this changes if researchers (and incentive/funding providers) are really serious about looking at the real (i.e. quantifiable) health effects of air pollution from a multi-pollutant, rather than a single-pollutant, perspective.

Overall, mechanisms research has contributed to our primary understanding that air pollution is unhealthy (to greater or lesser degrees) and affects many cell types and organ systems through multiple mechanisms. For example, a reduction of one pollutant that has a primary impact on lung tissue with a concurrent increase in another pollutant may have a primary impact on a different tissue and a related health outcome. In particular, PM causes differential effects according to its chemistry and size, and gas phase components may actually cause more responses and outcomes than particles. How can a systematic approach to mechanisms research best be utilized/conducted to inform AQM decision processes?

A goal is to move towards managing pollutants in a coordinated manner to achieve the greatest overall reduction of the pollution-related health burden. A better understanding of mechanisms could improve the understanding of exposure-dose-response functions, including thresholds at which further reduction of exposure is not likely to result in a meaningful reduction in population outcomes. A corollary to this issue is the fact that few, if any, of the observed outcomes are caused solely by air pollution. Estimates of the health impacts of air pollution and evaluations of the benefits of AQM actions would be improved by a clearer understanding of the proportional contributions of air pollution in comparison with other factors in different adverse health outcomes.

In order to develop a better mechanistic understanding about the health effects of air pollutant mixtures, it is critical to identify target organs, as well as dose to these tissues and adverse outcomes (i.e. is there a health consequence). The physicochemical characteristics of both particulate matter and the gas phase co-pollutants are diverse, making the linkage of sources to health effects a significant challenge.

For example, there is a hypothesis that the central nervous system (CNS) is a target organ for inhaled ultrafine particles. Data indicate that following exposures to ultrafine particles these particles can enter the brain. The remaining key question is what response or adverse outcomes might be linked to such exposure. A systematic approach to mechanisms research may help to address whether, or not, the inflammatory processes observed following exposure to ultrafine particles, traffic-related aerosols, and/or heavily-polluted urban air is necessarily and sufficiently linked to neurodegenerative changes that have also been found in animals and humans exposed to pollutant mixtures containing particles.

While reasonable progress had been made, a systematic, international approach is needed to focus mechanism research efforts and resources on key questions of regulatory interest, starting with relating toxicological data to epidemiologic data (i.e. identifying biological plausibility), elucidating what mixtures cause what toxicity, evaluating whether synergistic, antagonistic or additive responses occur when exposed to typical complex mixtures, defining the sources of air pollution that cause toxicity and evaluating whether production conditions and atmospheric transformation changes toxicity. The international research and policy community should learn from historical approaches and data regarding mechanisms research. In addition, there are opportunities to enhance methodologies to assess the toxicological implications of exposures to complex air pollution mixtures at environmentally relevant concentrations.

From a toxicological perspective, the concept discussed will require a shift from the traditional reductionist approach, which identifies toxic components within a complex mix, to the development of analytical and statistical methods that are capable (and sensitive enough) to compare and contrast response patterns across a broad range of mixtures that occur in the atmosphere. A logical starting point has been to study the effect of well-characterized emissions such as engine exhaust, coal and oil combustion effluents and concentrated air particles with, and without, co-pollutants such as ozone. In addition, other laboratories have made great progress in understanding the aging and photochemical processes that lead to secondary reaction products in the air. Efforts are now underway to compare biological responses across various fresh and aged emission atmospheres and to identify common biological outcomes, mechanisms of action and relative potency. This latter objective is a difficult issue to address because at present there is no common metric (e.g. mass per cubic meter, miles travelled, emissions per kg of CO_2, oxidative potential etc.) that can be applied to the various atmospheres in question. Nevertheless as exposure assessment and atmospheric modelling progress, it is quite possible that certain key mixtures can be identified and toxicity profiles derived for a range of concentrations. It is recommended that a complete synthesis of the historic and current policy-relevant research outcomes and learnings should be performed.

2.2.5. Structuring research to inform policy development

As toxicological investigations are completed and regulatory initiatives are put in place, the impact that these actions have on environmental and human health need to be assessed. This is accomplished most frequently through a cost-benefit analysis, where the costs associated with implementation and monitoring of programs are compared with the benefits of increased health measures such as longevity and quality of life. In this assessment there is a need to assess which programmes have the greatest impact for the money spent, as well as their input to informing decisions on improving regulation or relaxing standards without measurable benefits.

Central to this accountability research is the question of inputs into the analyses used. The costs that should be included in a cost-benefit analysis are not clearly defined, since each analysis scenario is different, but most commonly included are the physical costs of installation and maintenance of control technologies as well as any societal costs that the controls might include. It is possible to estimate the physical costs with a fair degree of certainty, but the societal costs are often difficult to identify and quantify. The costs of air pollution reduction measures also do not apply equally across all of industry and it is important to accurately reflect the costs in individual sectors.

Similarly, evaluation of the benefits can be debatable. One of the main issues concerns the value assigned to human life. Surveys have been conducted to identify the value of a Quality Adjusted Life Year (QALY) with differing results. It is important to ensure the benefit is properly valued, because small increases or decreases can have huge effects when multiplied across large populations. In addition, another factor that is important to consider is whether benefits to the environment can be included and how to quantify them. Similarly, the place of impacts on climate, employment, and noise pollution in benefit calculations are questioned. All this leads to the conclusion that the impact of air pollution reduction measures can have varying and wide reaching impacts which are difficult to analyse.

One of the overarching themes that recurred throughout the discussions on cost-benefit analysis of air pollution regulations was the need for well collected, standardized baseline data. In conducting the analysis it is possible to collect information on deaths and hospital admissions, however the more elusive components are individual data such as number of respiratory symptoms experienced, or the use of interventions such as rescue inhalers. Individual studies have strived to collect this information, but with a non-standard data set, it is often difficult to compile and utilize the data from various studies into a comprehensive analysis.

The effect of duration of exposure is also considered in accountability. There are short-term and long-term exposures. With the pollutants of general concern (SO_x, NO_x, O_3, and PM) research has focused on long-term exposures, since the general population is exposed to varying levels of these pollutants on a daily basis for most of their lives. The benefit from pollutant reductions is also generally investigated over the long-term. However, there are studies that have investigated the short-term effects of emission reduction at events such as the Olympics, which can help identify markers for exposure and provide information on how readily the body can clear pollutants or their subsequent health effects. This data can then be used to study the impact that incremental decreases in ambient pollution provide.

Along with long- versus short-term – there is another time factor that it is important to evaluate in accountability research which is lag time. Lag time, when applied to accountability research, can alter the results, sometimes quite dramatically. For brief, but intense, air pollution events, the lag time can be crucial in evaluating the associated outcome from exposure. High ozone level days have been associated with cardiovascular deaths one or two days later. With accountability research lag time can also be applied over 40 year periods. Agreement on the use and interpretation of this data would be beneficial for policy makers.

The question that initiates accountability research is whether we can ensure that enacted regulations are achieving the intended public health benefits. This is addressed in part through the use of cost-benefit analyses, but there are still areas where additional information is needed. This has been highlighted for baseline data, well defined parameters for what should be included in cost-benefit analyses, and time aspects that should be considered. Accountability will become increasingly important as the focus on air pollution evolves. Those sources of pollution which have been identified as easy to correct have resulted in dramatically improved air quality. However, it will be increasingly difficult and expensive to achieve incremental increases in air quality, as well as successfully assessing the impact of small, gradual positive changes in air quality on the population.

2.3. SUMMARY OF POSTER SESSIONS

The main recommendations and consensus from the three poster sessions are "bullet-pointed" below. Details of the poster titles and authors are included in **Appendix 3**. These can also be found, together with the poster abstracts, on CONCAWE's website: http://www.concawe.org/content/default.asp?PageID=607

2.3.1. Climate Change & Health: How to integrate air pollution and climate change research actions to address appropriate health effects

- The sources of greenhouses gas emissions overlap with sources of traditional air pollutants.
- There is a need to integrate climate and air pollution modelling and further develop models that can predict local changes.
- Climate change is associated with a range of adverse health effects – experts believe that changes in pollen, moulds & spores might have an impact but they are less confident that effects will be observed because of changes in $PM_{2.5}$ and ground level ozone.

2.3.2. Vehicle Emissions & Health: How to do hazard/risk screening for (combustion of) fuels (including fuels containing bio-materials)

- Europe is encouraging the use of alternative fuels; however, there are concerns about the use of biofuels and related emissions.
- Combustion products of pure plant oil (rapeseed) have been tested for mutagenic potential (Ames assay) but there are conflicting results that seem to depend on the processing conditions for the oil.
- There is a need to define what components of fuel should be tested, and which (in vitro) tests should be performed to evaluate any potential hazard.
- Particle traps results in equal emissions for diesel- and petrol- fuelled vehicles.
- Non-evasive imaging techniques have been successfully used to investigate whether inflammation can be caused by tailpipe emissions.
- The contribution of traffic related 'non-combustion' particulate matter to the overall air mix remains to be investigated.
- Non-regulated emissions from bio-fuel combustion should be considered.
- Ultrafines and elemental carbon levels in ambient air may be better indicators for traffic density than $PM_{10/2.5}$.

2.3.3. Accountability Research: How to provide evidence that air quality regulations and policies improve public health

- Air quality guidelines (AQGs) are essential to successful air quality management.
- Successful implementation of air quality management policies requires a robust baseline and extensive monitoring programmes post-implementation for both air quality and relevant health endpoints.
- Decision support systems to help identify effective abatement measures are under development and have been successfully used in some EU regions – an example is the RIAT (Regional Integrated Assessment Tool).
- Accountability studies require careful design at the beginning of study/project planning and dedicated resources – securing funding for such studies can be an issue.

3. CONCLUSIONS AND RECOMMENDATIONS

In the course of the workshop a large number of inputs were generated in the form of recommendations presented by invited speakers, in posters, and collectively by the participants during the roundtable discussion sessions. The recommendations were grouped and prioritised by the workshop organisers in collaboration with the session chairs and other participants.

3.1. PRIORITY PROJECTS

3.1.1. Epidemiology and Clinical Studies: How to develop relevant health-effects data to inform the policy decision-making process

3.1.1.1. Develop EU-based risk coefficients for $PM_{2.5}$ (and ultrafine particles?)

This is a clear immediate priority. Assessment of long-term exposures could be incorporated within the studies being undertaken in the ESCAPE FP7 project. In order to determine shorter term dose-response relationships controlled clinical (chamber) studies are required.

3.1.1.2. Add-on projects for ESCAPE

Specific potential parallel projects that could be associated with ESCAPE in this area include:

- PM speciation;
- In vitro toxicity studies of air samples;
- Source apportionment;
- Non tailpipe emissions; and
- Possible association between micro-vascular function and fine particles.

3.1.1.3. Improved exposure assessment

Such assessments should integrate land use regression and satellite imaging data into exposure assessment and use time-activity patterns to obtain more accurate individual exposure data. Supporting clinical studies will also be required. There were two important angles to this; one was the level of exposure and second was the notion that not enough is known about the nature (air mix) of the exposure. A suggested approach was to initiate smart sampling campaigns using passive (and/or personal) samplers to test measured versus predicted data.

3.1.2. Pollutant Metrics Studies: How to establish appropriate pollutant metrics relevant to health (what is ideal even if we cannot measure it yet)

3.1.2.1. Standardisation of Measurement Approaches

Based on what we know today, common/harmonised approaches and methodologies for measuring pollutants should be established at a regional, national and international level. Consideration should be given to standard measures of PM and gases. A battery measurement approach with several different parameters (mass, surface area, etc.) for PM can be considered; but the approach should be uniformly accepted in order to help determine the link between exposure and health outcomes.

3.1.2.2. PM Speciation & Source Apportionment

Focused efforts should work to characterize and speciate PM. Determining methodology to speciate PM will help identify those characteristics that correlate with toxicity. A link to toxicity screening is one aspect of such work. This work would contribute to source apportionment efforts.

3.1.2.3. Atmospheric Transformation / Aging

Focused efforts should work to characterize the impact of atmospheric transformation / aging on toxicity.

3.1.3. Toxicology: How to better understand the role of research on mechanisms of action in air quality management in a multi-pollutant world

3.1.3.1. Better understanding of how air pollutants induce adverse health outcomes (mechanisms): Multi-pollutant exposures

This will require weight of evidence for causality, examination of dose-dependent transitions, and multi-pollutant air quality management (MPAQM) involving systematic comparisons of responses to different pollutant classes (timescale: 1-5 years), 'dissection of the causal components of mixtures (timescale: 1-10 years) and limited factorial studies on two to four pollutant classes (timescale: 1-10 years). Specific suggestions for targeted, high priority mechanistic studies are needed here. Understanding potential synergistic or antagonistic effects of mixtures will require the investigation of dose-dependent interactions (particularly synergistic interactions) in in vitro, animal and clinical studies including the scope to confirm (or not) that synergism is limited at low ambient exposures.

Significant effort and funding should be provided to develop approaches for multi-pollutant research as well as for the statistical analysis.

3.1.3.2. Mechanistic (in vitro and/or clinical) studies of dose-response at realistic exposure levels

This will require a comparison of toxicology models, with the latter inclusion of susceptibility models as well. The most promising assay for different categories of outcomes would be selected and then validated in terms of animal models, in vitro studies and clear human health links. Examination of (for example) birth, reproduction and development outcomes would look to establish links between responses and meaningful outcomes.

The dose-response and inter-model comparability part should be a 1-3 year project, building on current state-of-the-science. The work to identify mechanisms of additional outcomes besides those typically focused on and 'validation' of rapid assays should both be 3-6 year focused projects.

3.1.3.3. Improved hazard screening of air pollutants (PM and gases).

This is high priority and requires Moderate- to High-Throughput Screening of the constituents of air pollution. The data from such approaches may only be useful initially to identify differences in response. Building an appropriate health-based screening library database over time may be informative. Consideration needs to be given to relevant in vitro systems (i.e. outcome maps to known health outcome). The system (battery of tests) should be able to accommodate exposure to whole relevant mixtures (i.e. PM and gases).

3.1.4. Structuring research to inform policy development

3.1.4.1. Documentation of population health benefits of improving air quality

The would include examination of changes in the health status of populations following 'natural experiments' in which improvements in air quality have been observed and allow for estimates of the increase in life expectancy associated with decreases in air pollution adjusted for individual determinants of mortality (possibly using ACS, EPIC or other cohorts) as well as other objectively determined health outcomes (e.g. lung function).

3.1.4.2. Assessing the Global Burden of Disease associated with air pollution

A global burden of disease (GBD) analysis would be conducted on particulate air pollution over the last decade, to document anticipated population health benefits of reducing air pollution levels in most parts of the world. This would lead to an evaluation of risk coefficients over time - an implicit assumption in the above analyses is that such coefficients are constant.

3.1.4.3. Regional Integrated Assessments – Better understanding of the health effects of air pollution mitigation policies

On a regional level, this would require the conduct of an overall analysis of the full spectrum of health effects and socioeconomic impacts associated with air pollution control policies in cooperation with other stakeholders outside the air pollution community. Initial accountability research was largely designed to take advantage of opportunistic events but considerations should be given to conduct future studies in a systematic manner with a longer-term commitment to a specific area of research or a type of intervention. It would be particularly useful to incorporate accountability research as a fundamental aspect of the design and implementation of policy interventions, particularly of major regulatory programs, which occur over longer periods.

3.1.4.4. Develop approaches / tools to take relative potencies of PM constituents into account

This would require conducting scenario analyses assuming different relative potency values for PM constituents and using toxicological data (this would require new toxicological data to be generated) on relative potency of PM constituents to develop the most cost-effective control strategies.

3.1.4.5. Investigation of the role of co-factors (such as socioeconomic status, noise and nutrition) on air pollution health impacts

Such an analysis could be included within the ESCAPE FP7 project.

3.2. TIMING CONSIDERATIONS

In terms of timing of research planning with respect to opportunities to input research outcomes into policy there are a number of critical dates in the environment and health process in Europe:

- The WHO Fifth Ministerial Conference on Environment and Health in 2010
- The review of the Thematic Strategy on Air Pollution in 2010
- The evaluation of the European Air Quality Directive in 2013
- A potential second phase of EHAP after 2010

- Ongoing calls for research proposals in FP7, and
- Planning and programme formulation for FP8 for 2014 and beyond.

3.3. STRATEGIC RESEARCH DIRECTION

3.3.1. Coordination of research, synthesis and interpretation of research findings at EU level

For mechanisms research focusing on development of a matrix of exposure-response-pollutant speciation, improved inter-laboratory collaboration is required. A repository of standard test materials should be made available.

3.3.2. Funding models for large and long-term research projects

For mechanisms research focusing on development of a matrix of exposure-response-pollutant speciation, there is a need for coordination to assure resources are directed to the mixtures and pollutants thought most important to ensure no gaps in the information matrix. There is a need to provide funding opportunities and competitive incentives to conduct systematic research rather than 'random walk' discovery research.

4. GLOSSARY

AQGs	Air Quality Guidelines
AQM	Air Quality Management
CNS	Central Nervous System
CO_2	Carbon Dioxide
DG	Directorate General
EHAP	Environment and Health Action Plan
EPA	Environmental Protection Agency
ESCAPE	European Study of Cohorts for Air Pollution Effects
EU	European Union
FP7	EU Seventh Framework Programme for Research and Technological Development
GBD	Global Burden of Disease
HEI	Health Effects Institute
HTS	High Throughput Screens
LRTAP	Long-Range Trans-boundary Air Pollution
MPAQM	Multi-Pollutant Air Quality Management
NO_x	Nitrogen Oxides
O_3	Ozone
PM	Particulate Matter
$PM_{2.5}$	Particles with a diameter of 2.5 microns or less
QALY	Quality Adjusted Life Year
RIAT	Regional Integrated Assessment Tool
SO_x	Sulphur Oxides
VOCs	Volatile Organic Compounds
WG	Working Group
WHO	World Health Organization

5. ACKNOWLEDGEMENTS

CONCAWE wishes to thank all of the Chairs, speakers and participants for their inputs before, during and after the Workshop, especially Tuomo Karjalainen, Dan Greenbaum, Bob O'Keefe and Michal Krzyzanowski for their thoughtful inputs during development of the workshop programme. Special thanks go also to the Workshop Chair, Dan Krewski, and the Session Chairs, Bert Brunekreef, Tobias Stöger, Joe Mauderly, Carlo La Vecchia, Flemming Cassee, Selahattin İncecik, Paolo Boffetta and Fintan Hurley.

6. REFERENCES

1. CONCAWE (2007) Report of a workshop on environment and health: air quality research needs in the EU 7th framework programme of research, 15-16 January 2007. Report No. 5/07. Brussels: CONCAWE

2. WHO (2009) WHO guidelines for indoor air quality: dampness and mould. Geneva: World Health Organization

APPENDIX 1 WORKSHOP PROGRAMME

Monday 19 January (Day 1 of 2)		
12:00	***Registration Starts - Posters Displayed - Lunch***	
12.45	**Opening Session**	
	Welcome	**Panos E. Cavoulacos**, Chairman, CONCAWE Board of Directors, Belgium
13:00	**Background & Task Description**	
	Workshop Task Headline: How to evaluate European air quality health research and translate priorities into actions	**Dan Krewski**, University of Ottawa, Canada *Workshop Chair*
	Introduction to Workshop Process	Diana Parry & Min-Min Teh, Facilitator's Overview
13:20	**Current Research Programmes**	
	Community-funded research on air pollution and health	**Tuomo Karjalainen**, European Commission RTD, Belgium
	Current WHO assessments of health aspects of air quality	**Michal Krzyzanowski**, WHO/ECEH Bonn, Germany
	Building a Roadmap for Environment and Health Research - Experience from the US Health Effects Institute and Environmental Protection Agency	**Dan Greenbaum**, Health Effects Institute, USA
14.20	**Session 1: Pollutants and Human Health Effects**	
	Addressing data uncertainties & opportunities for researchers	**Bert Brunekreef**, IRAS, University Utrecht, The Netherlands *Session Chair*
	Pollutants and human health effects	**Ross Anderson**, St. George's, University of London, UK
	The effects of particulate goes beyond the lung: changes on vascular and brain function in man	**Flemming Cassee**, RIVM, The Netherlands
15:20	***Briefing of Working Group (WG) Discussions***	Diana Parry & Min-Min Teh, Facilitators
15:30	***Coffee Break***	
15:45	Building a Roadmap WG I: Participant discussions regarding Pollutants and Health Effects	Task Headline: How to develop relevant health-effects data to inform the policy decision-making process.
16.45	**Session 2: Pollutant Metrics**	
	Health effects of combustion-derived nanoparticles: Particle toxicity as a product of oxidative potency and metabolic activation of organic compounds	**Tobias Stöger**, Helmholtz Institute for Inhalation Biology, Germany *Session Chair*
	Particulate Matter (PM) mass concentrations: The way to proceed?	**Thomas Kuhlbusch**, IUTA, Germany
	Metrics for Particulate Matter (PM): Uncertainties & Opportunities for Researchers	**Constantinos Sioutas**, USC, Particle Center, USA
17:45	***Break***	
18:00	Building a Roadmap WG II: Participant discussions regarding Pollutant Metrics	Task Headline: How to establish appropriate pollutant metrics relevant to health (what is ideal even if we cannot measure it yet).
19:00	**Poster Session I & Cocktails**	
	Poster Session I : Climate Change, Air Quality and Health Effects Research	**Carlo La Vecchia**, Mario Negri, Italy *Session Chair* Task Headline: How to integrate air pollution and climate change research actions to address appropriate health effects
19:50	Summary of Poster Content	
20.00	***Dinner***	

Tuesday 20 January (Day 2 of 2)		
08.30	**Recap Day One and Opening Day Two**	Workshop Chair: **Dan Krewski**, University of Ottawa, Canada
08.45	**Session 3: Role of Research on Mechanisms of Action in Air Quality Management**	
	Role of Mechanism Research in Facilitating Multi-pollutant Air Quality Management	**Joe Mauderly**, LRRI / NERC, USA *Session Chair*
	The Central Nervous System as a Target for Inhaled Air Pollutants	**Alison Elder**, University of Rochester, USA
	Toxicity testing of multi-pollutant atmospheres	**Ian Gilmour**, University of North Carolina, USA
09:45	***Coffee Break***	
10:00	Building a Roadmap WG III: Participant discussions regarding Toxic Action	Task Headline: How to better understand mechanisms of action to help air quality management in a multi-pollutant world.
11.00	**Poster Session II**	
	Poster Session II.a. (concurrent) Lifecycle analysis of fuels (focus on combustion of biofuels & health)	**Flemming Cassee**, RIVM, The Netherlands *Session Chair* Task Headline: How to do hazard/risk screening for (combustion of) fuels (including fuels containing bio-materials)
	Poster Session II.b. (concurrent) Accountability research	**Selahattin İncecik**, Technical University of Istanbul, Turkey *Session Chair* Task Headline: How to provide evidence that air quality regulations and policies improve public health
11:45	Summary of Poster Content	
12.00	***Lunch***	
12.45	**Straw Person Roadmap for Research**	
	Proposed roadmap incorporating and integrating suggested actions and discussions up to Session 3	**Dan Krewski**, University of Ottawa, Canada *Workshop Chair*
13.05	**Session 4: Structuring Research to Inform Policy Development**	
	Addressing uncertainties & opportunities	**Fintan Hurley**, IOM, UK *Session Chair*
	A policy perspective on scientific uncertainties	**Les White**, Les White Associates, UK
	Research needs for cost-benefit analysis and health impact assessment	**Heather Walton**, Health Protection Agency, UK
	Accountability research	**Robert O'Keefe**, Health Effects Institute, USA
14:15	***Break***	
14:30	Building a Roadmap WG IV: Participant discussions regarding Research to Inform Policy	Task Headline: How to structure research programmes to inform the development of policy.
15:30	**Synthesis and Closing Session**	
	Workshop Synthesis, Actions and Next Steps	**Paolo Boffetta**, IARC, France *Workshop Synthesis Team* **Dan Krewski**, University of Ottawa, Canada *Workshop Chair*
16.00	***Close and Coffee***	

APPENDIX 2 LIST OF WORKSHOP PARTICIPANTS

	Name	First name	Company
1.	Ågren	Christer	Air Pollution and Climate Secretariat
2.	Anderson	Ross	St. George's, University of London
3.	Andrés	Adolfo	Repsol
4.	Arce Duran	Eduardo	Repsol
5.	Arfire	Raluca	OMV
6.	Baarbé	Henk	Environment Ministry Netherlands
7.	Barratt	Ben	King's College London
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9.	Belkhiria	Sami	Dow Corning Europe SA
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21.	Brunzema	Thorsten	European Commission, DG ENTR
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24.	Cassee	Flemming	RIVM
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37.	González	Lucia	Repsol
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46.	Karjalainen	Tuomo	European Commission, DG Research
47.	Keuken	Menno	TNO
48.	Kobe	Andrej	European Commission, DG ENV
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50.	Krewski	Dan	University of Ottawa
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52.	Krzyzanowski	Michal	WHO
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64.	Money	Chris	ExxonMobil
65.	Newbold	Jane	University of Hertfordshire, STRI
66.	O'Keefe	Robert	Health Effects Institute
67.	Parry	Diana	The Falling Apple Consultancy Ltd.
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82.	Skouloudis	Andreas Nikolaos	European Commission, DG JRC
83.	Sram	Radim	Institute of Experimental Medicine
84.	Stöger	Tobias	Helmholtz Institute for Inhalation Biology
85.	Taalman	Rob	Shell
86.	The	Min-Min	MMT Consulting Ltd.
87.	Theunis	Jan	VITO

	Name	First name	Company
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89.	Van Bouwel	Eddy	ExxonMobil
90.	Van den Hout	Dick	TNO
91.	van Hees	Wim	vzw Ademloos
92.	Verbeke	Guido	vzw Ademloos
93.	Walton	Heather	Health Protection Agency
94.	Wander	Sander	Ministry of Transport, Public Works and Water Management
95.	White	Les	Les White Associates
96.	Williams	Martin	UK DEFRA
97.	Zarogiannou	Stella	Hellenic Petroleum

APPENDIX 3 LIST OF POSTERS

Poster Session I: Climate Change, Air Quality and Health Effects Research

How to integrate air pollution and climate change research actions to address appropriate health effects

1. Knowledge evaluation: Climate Change and Respiratory Disease
   Alena Bartonova, Norwegian Institute for Air Research

2. Integrating Climate Change Scenarios into Local Air Quality Health Risk Assessment: A 2FUN Project Case Study
   Elsa Casimiro, INFOTOX

3. New Evaluation Tools for meeting the EU Directive on Air Pollution Limits
   Valentin Foltescu, Swedish Meteorological & Hydrological Institute

4. Integration of Climate Change Scenarios in Air Pollution Models. Validation and Comparison of Statistical Downscaling Methods of Climate Change
   Pedro Lopes, University of Lisbon

Poster Session II.a: Lifecycle Analysis of Fuels (focus on combustion of biofuels & health)

How to do hazard/risk screening for (combustion of) fuels (including fuels containing bio-materials)

5. Local Traffic and Urban Air Quality in Flemish Cities
   Patrick Berghmans, VITO

6. Effect of Biodiesel Fuels on Emissions from a EURO4 Passenger Car
   Annette Borowiak, European Commission JRC

7. Metal Contents of Diesel and Petrol Fuel sold on the European Market
   Hugo Denier van der Gon, TNO

8. Ultrafine and Elemental Carbon: Better Health-related PM Metrics than PM2.5/10?
   Menno Keuken, TNO

9. Particle Emissions from Modern Vehicles
   Ken Rose, CONCAWE

10. Fluorescence Molecular Tomography (FMT) Imaging of Mice Health Responses caused by Intratracheal Instillation of Vehicular Exhaust Particles
    Zissis Samaras, University of Thessaloniki

11. Impact of High Biodiesel Blends on Pollutant Emissions, Fuel Consumption and PM Toxicity
    Zissis Samaras, University of Thessaloniki

12. Exhaust Gas Emissions of Diesel Fuel, Biofuel and Biodiesel Blends
    Olaf Schröder, von Thünem Institute

13. European Hot Spot of Air Pollution by PM2.5 and B[a]P: Ostrava, Czech Republic
    Radim Sram, Institute of Experimental Medicine

14. SHAPES: A Systematic Analysis of Health Risks and Physical Activity associated with Cycling Policies – UFP Measurements in Transport
    Rudi Torfs, VITO

Poster Session II.b: Accountability Research

How to provide evidence that air quality regulations and policies improve public health

15. The London Low Emission Zone Baseline Study
    Ben Barratt, Kings College London

16. The Congestion Charging Scheme in London: Assessing its Impact on Air Quality and Health
    Ben Barratt, Kings College London

17. Particulate Matter Levels in Oslo in relation to changes in use of Studded Tyres
    Alena Bartonova, Norwegian Institute for Air Research

18. Calculation of Person-weighted Average Concentrations of NO_2, PM_{10} and $PM_{2.5}$ in Oslo for 1992 to 2002
    Alena Bartonova, Norwegian Institute for Air Research

19. Interpolation Methods for European Scale Air Quality Mapping: Application to European Population Exposure Estimate for PM_{10}
    Alena Bartonova, Norwegian Institute for Air Research

20. Effective Policies to control PM10 Exposures in Northern Italy
    Giovanna Finzi, DEA – Università di Brescia

21. Assessment of the Integration between Air Quality and Health, Quantification and its Milestones in Turkey
    Selahattin Incecik, Istanbul Technical University

APPENDIX 4 REPORT OF ROUNDTABLE DISCUSSIONS

***WG I - Epidemiology and Clinical Studies:* How to develop relevant health-effects data to inform the policy decision-making process.**

The main outcome of this Work Group session was to build on the FP7 ESCAPE environmental health project. Suggestions to enhance/enrich ESCAPE cover nine areas:

- Improve (personal) exposure assessment.
- Consideration of meteorological factors and noise as possible confounders.
- Characterisation of air pollution mix including PM speciation.
- Analysis of ultra-fine particles.
- Include ground-level ozone estimation in the exposure modelling.
- Understand source apportionment.
- Improve understanding of exposure-effect relationships.
- Consideration of additional cohorts to supplement ESCAPE.
- What health endpoint(s) should be in the main focus.

Two additional focus areas were discussed:

- Accountability research – interventions and their intended effects.
- Screening assessment tools for new technologies (i.e. new fuels and/or engine configurations.

A technology that was considered to be promising by a number of participants was satellite imaging/ Earth Observation as a tool to help predict ground level pollution.

It was recognised that the more variables you introduce into a study (ESCAPE) the more difficult it becomes to interpret the data, but limiting the study to $PM_{2.5}$ and NO_2 would miss opportunities for investigating associations with other relevant environmental factors and ‘confounders’. The influence of health determinants might be different per region and as so many regions are involved in ESCAPE it would be sensible to collect as much data as possible to eliminate less important factors.

There has been a tendency among air pollution epidemiologists to focus on similarities but more attention should be given to differences. To assist the analysis of differences, it was advised to identify ‘hot spots’ (with an apparent high level of pollution or increased morbidity) and areas that appear to be less affected. This requires the establishment of central databases for both air quality and health effects to ease regional comparisons and also facilitate consistency in reporting. Such databases could be set up in parallel with the real time AQ monitoring networks across Europe that could also serve purposes such as local alert systems for pollution episodes (e.g. high levels of ozone). In terms of policy there is a need for quick action on European “hot spots” (2 year timescale).

In addition, a comprehensive characterisation of PM is seen as high priority because the correlation between the currently used metric (i.e. mass per volume) and health outcome (mortality) is not strong. Again participants recognised that ESCAPE could act as a catalyst for parallel projects focussing on speciation and sources of PM.

Suggested focus areas were characterisation of non-combustion traffic generated particles (e.g. tyre wear, road dust, brake wear etc.), clarification of the ratio of primary vs. secondary particles and the need to seek clarification regarding what (local) factors determine the formation of secondary particles. An interesting aspect of the proposed speciation research was to assign certain types of PM or mixtures of PM types to specific sources or processes. There is a wide variation in vehicle fleets and traffic density in the EU regions (petrol vs. diesel, old vs. newer technology, road vs. other types of transport), that provides a unique opportunity to investigate health outcome and traffic characteristics. A suggestion was made to collect as many PM samples as possible (across the ESCAPE regions) and retain those for future analysis.

Policymakers would benefit from a more accurate estimation of the EU risk coefficient for $PM_{2.5}$ and it was recommended to give more attention to differences between long-term low and short-term peak exposures. There is also a need to focus on vulnerable populations that could help to elucidate whether there is more than one $PM_{2.5}$ risk coefficient. It is difficult to attribute risks to one single factor therefore it was recommended to conduct future analysis by combining risk factors e.g. combinations of $PM_{2.5}$, noise, NO_2/NO_x and ozone.

Most epidemiological studies investigate the relation between PM levels and ‘premature death’ and not the possible effects of PM on specific health endpoints. However, various types of PM health effects have been reported, usually from short-term high-level exposures and/or controlled experiments with human volunteers. It is believed that clinical studies could help identify the most relevant endpoints. Endpoints that were identified as candidates for research were:

- Neurological effects;
- Reproductive & Developmental effects;
- Respiratory effects and allergies.

Studies to verify that interventions have the intended effect rely on a set of parameters that have a substantial degree of uncertainty. These uncertainties in risk coefficients, relevant health endpoints, past and present exposure estimates etc. need to recognised and taken into consideration when designing accountability studies. Opportunities for conducting accountability studies are not frequent therefore there is a need to be more creative such as studies that compare old versus new cities with the aim of understanding how planning and design of new urban developments can help create high quality living environments with low levels of pollution. Accountability studies require a holistic approach and could be part of large wide-scope integrated environment and health impact assessment projects such as INTARESE[5] and HEIMTSA[6] (two FP6 projects). In addition, there is the need to address indoor air quality issues in parallel with WHO.

In terms of specific actions there is a need to definitively link health effects to PM species, define exposure measurements for use in health studies and develop a more detailed exposure assessment that can help validate exposure models.

Toxicological research (5 year timeline) must develop high throughput screening (HTS) tests, base endpoints on epidemiological study results, and develop biomarkers of exposure/effect.

Research on exposure and health effects (5 years timeline) should develop a network for $PM_{2.5}$ research in Europe, develop EU-based risk coefficients for $PM_{2.5}$, produce a centralized database on air pollution and health, and consider noise as a co-pollutant.

A final recommendation was the need for quick and reliable assessment tools for new technologies including new fuels (e.g. biofuels). Toxicological screening of combustion products should be a high priority and this requires standardisation on generating an atmosphere (combustion products) and a relevant set of high throughput toxicity tests which ideally would

[5] http://www.intarese.org/
[6] http://www.heimtsa.eu/

include in vitro screening only. Clinical studies and toxicological studies can be designed to support one another directly.

***WG II - Pollutant Metrics:* How to establish appropriate pollutant metrics relevant to health (what is ideal even if we cannot measure it yet).**

In order to develop the most appropriate metrics there is a need for the formation of interdisciplinary teams that includes chemists, toxicologists, and epidemiologists. There is a view that PM concentrations in Europe are now stable, but that the composition (size mix, chemical composition) is changing. To confirm and assess this, an overall integrated approach is needed.

There is a need for more information on the relative toxicity of air pollution components and sources (i.e. diesel, gasoline, coal). This requires the use of high throughput toxicological screening of air samples to help in selecting appropriate pollution metrics. There is also a need for good source apportionment data.

A key decision is to agree on the definitive measure for PM – is it surface area or number or mass or…? In addition measurement methods will need to be developed for some pollutants (e.g. VOCs) species.

There is a need to review our current knowledge to find common ground and allow ranking of observed health effects and documentation of established exposure-response relationships. In addition there is a need to create standard measurement protocols for new exposure metrics, but these new metrics will need to be monitored in parallel with existing metrics for several years. The primary aim must be to identify those metrics that really relate to specific health effects.

A generic testing scheme has been proposed. It starts with ranking the range of adverse health effects observed. This could be addressed in part by evaluating what is known about composition-effect relationships. Confidence in the existing data sets should be considered and data gaps identified. To progress the scheme agreed standards/ protocols should be created for measuring pollutants and health effects. Through the data set it is possible to identify which component is linked with which health effect. With this information in hand, the grouping of metrics with health effects can proceed: for example, what health effects are linked to physical/chemical endpoints, which are outcome based, etc. From there it may be possible to identify the metric with the most reliable predictive power for identifying adverse health effects.

***WG III - Toxicology:* How to better understand role of research on mechanisms of action in air quality management in a multi-pollutant world.**

One significant knowledge gap is our lack of understanding of which pollutants and combinations are the strongest drivers of various health effects. This gap implies a need for a greater emphasis on understanding when effects of multiple pollutants are greater or less than additive. As it is not possible to study all pollutants and all combinations, it was proposed that research matrices based on grouping pollutants by biological response mechanisms might be informative. A better understanding of biological cause-effect time scales could help focus both epidemiological study designs and regulatory air sampling time scales. A better understanding of the mechanisms of susceptibility could also improve the accuracy of estimating health impacts in target subpopulations. The understanding of both health impacts and AQM accountability could be improved by better biomarkers of exposure and key biological responses. Improvements in biomarkers will necessarily be driven by mechanism-oriented research.

An emphasis should be on research that can inform assignment of causality among the components of pollutant mixtures (or to a ‘validated’ source mixture) to which people are typically exposed, allowing prioritization of regulatory actions. Research should include some more futuristic thinking about how the discovery and evaluation of mechanisms might, in a systematic manner, be used to make policy choices.

We need to better understand responses of ‘mechanism’ models, improve screening assays, and study mechanisms of outcomes for which response pathways are not yet understood. Increased mechanistic research will help to define new endpoints in epidemiological studies.

There is a need to validate toxicological models for human risk assessment. Research is needed on development of tests for toxicity of new technologies and fuels.

Research must move away from traditional animal-based studies (toxicology is moving in this direction anyway), towards in vitro high throughput screens (HTS) and controlled human exposure studies employing animal models only where absolutely necessary. For effective HTS work there is an urgent need to agree on what to measure (PM, gaseous components etc)? There is a need to consult with emissions specialists in selecting agents for toxicological investigation.

Possible ways forward are to identify the current state of knowledge at an international level. A series of small, focused workshops could be organized on the following themes:

Workshops to build a roadmap for mechanism research:

- Can “mechanism” research even be defined?
- Can this kind of research be managed within a “roadmap” framework?
- Would there be consensus on prioritization of issues?
- What is the potential for mechanisms research to be coordinated internationally (beyond the EU)?

Workshops on central health-related questions:

- Can we reproduce the epidemiological findings in the laboratory (biological plausibility)?
- Which chemical components of air pollution (either singly or in combination) cause health effects?
- What are the likely pollutant sources and do production conditions (e.g. engine type, combustion efficiency, fuel etc) and atmospheric transformation change toxicity?
- How does one take into account the potential for additive, synergistic or antagonistic effects in mixtures? Can we undertake more in-depth reviews of the range and nature of pollutant interactions?
- What are the mechanisms whereby combined pollutants modulate responses and outcomes in a more than additive fashion?

Workshops to examine organ system effects and outcome:

- Respiratory (non-immunological: lung function, lung development & growth, respiratory illness)
- Immunological effects (asthma, other respiratory allergies, systemic immune responses)
- Cardiovascular (MI, pro-atherosclerotic effects, ECG, vasoactivity)
- Cancer (lung and other organs)
- Neurotoxicity (functional and pathology)

Workshops on different assay type and level of biological organization:

- Acellular measurements of chemical reactivity, oxidative stress, modification of lung lining fluid constituents, etc
- In vitro cell systems measuring damage, proliferation, apoptosis, gene activation, altered function etc in lung epithelial cells and macrophages, endothelial cells, cardiomyocytes, mixed cell systems.
- Target organ toxicity testing (e.g. cardiopulmonary, neurological, reproductive, carcinogenicity) in healthy and diseased (e.g. cardiac, diabetes, hypertension, asthma, infection) animal models.
- Clinical testing in human volunteers, panel studies and epidemiological surveys.

Workshops on issues:

- Identifying causal pollutant species
- Relative potency of different pollutants
- Apportioning risk between pollutants and other factors
- Synergies and other inter-pollutant interactions
- Exposure-dose-response functions, including thresholds
- Limits of utility of in vitro models

The key objective must be to work towards the 2013 update of the European Air Quality Directive.

WG IV – Research to inform policy: **How to structure research programmes to inform the development of policy.**

A fairly unanimous view was that there is a need to examine the impact of indoor air quality on health. Although it was not clear how indoor air quality risk assessment differs substantively from outdoor air quality assessment.

The use of scenario analysis may not be needed if the relative potency of pollutant constituents can be established by toxicological means. We need to know the relative toxicity of air pollution constituents and develop better tools to assess source mixtures. Hazard/risk streaming of the constituents of exhaust gas is needed and grouped according to engine technology.

The need to develop inexpensive HTS methods and personal exposure assessment tools was reiterated; as was the need for mechanistic information on PM versus NO_2 to help with design and interpretation of epidemiological studies.

Exposure metrics should be linked to a validation process to ensure predictive values are obtainable. It is becoming clear that metrics are related to mechanistic interactions.

The role of atmospheric science (in chemical transport) should be considered in integrated pollution studies and dispersion modelling should be included to improve exposure assessment.

Biomarkers should be examined as realistic (personal) exposure level indicators and the use of appropriate biomarkers should be included in improved exposure assessment and in mechanisms research.

New AQM policies may flow from accountability analysis; accountability should be built into new policies.

“Do air pollution mitigation policies positively impact health?” The appropriate use of health impact assessment is essential in this area and in this respect there is a need to consider quality of life measures in addition to increases in life expectancy. We need to improve ways of estimating life expectancy changes associated with air quality (including impact delays or lags, etc.). This leads to a need for improved design and implementation of public health surveillance tools. The assessment of public heath benefits must link with other priorities. Noise and SES (socioeconomic status) should be considered simultaneously as co-factors with air pollution. It was suggested that susceptible sub-populations may be too few (i.e. too few subjects for study) to allow meaningful examination in detail.

The group again considered the ESCAPE project as a rich resource or starting point for investigating many of the proposed priorities in this area.

APPENDIX 5 SUMMARY OF FEEDBACK COMMENTS

Additional topics that would have been interesting:

- Exposure modelling studies.
- Explore the limits of epidemiology.
- More focus on CO_2 and VOCs (over emphasis on PM)
- More emphasis on relationship between air quality and noise.
- Future legislative developments.

Expectations and suggestions for follow-up:

- Input for future FP7 (and FP8) projects and other collaborative R&D projects on air quality and health.
- Information on the progress of programmes selected / initiated as a result of the workshop.
- More detailed discussions on developing the research ideas and the development of a comprehensive research agenda.
- Identifying long-term goals and timeline to achieve them (implementation).
- Translation of workshop output into funding programmes that address key issues.

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