



Australian Government

Department of the Environment, Water, Heritage and the Arts

Clean Air Research Program

**Workshop
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Workshop Report

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- CARP workshop participants

EXECUTIVE SUMMARY

The Australian Government's Clean Air Research Program (CARP) provided \$1.4 million to support research that directly informs national air quality management, with the aim being to address some of the major research gaps in the management of air quality in Australia.

A workshop was held in Canberra on 16 October 2008 to present the findings of research funded through CARP. The major objectives of the CARP workshop were to:

- make CARP research findings available to senior policy makers and the scientific community;
- identify new knowledge arising from CARP research, including findings that challenge established thinking;
- discuss policy implications of CARP research findings; and
- highlight priorities for further research.

The CARP workshop was a successful culmination to a significant commitment of Commonwealth resources towards air quality management research. The workshop atmosphere was positive, with a concerted effort made to discuss a diverse range of issues and identify future research needs. CARP workshop participants, who included policy managers and researchers from Australia and New Zealand, identified a range of research priorities that would assist future air quality management in Australia.

Significant policy issues arising from the workshop include:

- Climate change is predicted to lead to a significant increase in ozone levels by 2020 and 2050, to the point where current ozone management strategies may not be adequate to meet AAQ NEPM ozone standards. Hospitalizations as a result of ozone exposure are predicted to increase by 200% in 2050 as a result of climate change. New strategies may, therefore, be needed to reduce ozone levels in Australia's major cities.
- Secondary organic aerosols (SOA) are a significant contributor to urban air pollution, particularly on days where the AAQ NEPM PM standards are not exceeded. Therefore, air quality management actions aimed at reducing PM should take into account emissions of SOA precursors, in addition to primary PM emissions.
- Biogenic emissions, especially isoprene, are a significant contributor to urban SOA and ozone. However, the exact relationship between biogenic and anthropogenic precursors in forming SOA and ozone is poorly understood.
- Bioassay analysis determined that the gas component of urban air samples is more toxic than the particle component, and indoor air samples were more toxic than roadside samples for a number of samples. These results challenge current thinking on the impacts of air pollution.
- Woodheaters are a significantly higher contributor to urban PM pollution than current inventories suggest. The NPI emission factor for woodheaters needs to be revised to reflect this and the Australian/New Zealand Standard test method for woodheaters should also be revised.

Future research priorities identified at the workshop include the need to develop a better understanding of:

- the relationship between biogenic and anthropogenic SOA and ozone precursors and its role in SOA and ozone formation
- the key synergies and conflicts related to the management SOA and ozone precursors in Australian airsheds, and
- the relationship between the impacts of air pollution on bioassays and humans, and how bioassay impacts be extrapolated to humans.

This report is intended to inform future air quality research in Australia.

INTRODUCTION

Clean Air Research Program

The Australian Government's Clean Air Research Program (CARP) provided \$1.4 million to support practical research that directly informs national air quality management. CARP aims to address some of the major research gaps in the management of air quality in Australia. Its overall objective is to support and facilitate research activities that will underpin policies and management actions to minimise the human health impacts of air pollution.

To meet this objective, CARP provided funding support for quality research that:

- Has a strong public good focus
- Is applicable nationally, ie is not specific to a particular region
- Addresses the impacts of air pollution in Australia by improving our ability to:
 - Understand the major sources and health effects of air pollutants
 - Manage air pollution, particularly in the major population centres
- Provides decision-makers with the tools and methods necessary for the development of cost-effective and efficient policies and management actions that address the impacts of air pollution
- Addresses one or more of the priority research questions identified under CARP
- Can be readily used by decision-makers for the development of air quality policies and management actions.

A Technical Assessment Panel (TAP), consisting of research and policy experts from government and scientific agencies, was established to assess project proposals from Australian and New Zealand researchers. Following assessment, 13 projects that best met CARP objectives were selected for funding. Experimental work on all 13 CARP projects was completed by June 2008.

CARP workshop objectives and format

A workshop was held in Canberra on 16 October 2008 to present the findings of research funded through CARP. The principal objectives of the workshop were to:

- make CARP research findings available to senior policy makers and the scientific community;
- identify new knowledge arising from CARP research, including findings that challenge established thinking;
- discuss policy implications of CARP research findings; and
- highlight priorities for further research.

This workshop featured short, targeted, policy-oriented presentations from CARP researchers followed by a facilitated discussion of thematic questions covering four air quality themes:

- Theme 1: Air pollutant chemistry – implications for source management
- Theme 2: Exposure assessment – are we really measuring what we're breathing?
- Theme 3: Major sources of air pollution in Australia
- Theme 4: Tools to assist in the development of air quality management strategies

To facilitate discussions at the workshop, CARP researchers prepared policy summaries relating to their work, and these were distributed to attendees ahead of the workshop. A copy of CARP policy summaries appears in Appendix 1.

Following presentations and thematic discussions, a session was held to discuss the major policy challenges facing air quality managers and to identify key future research priorities that will address these challenges.

WORKSHOP PRESENTATIONS AND DISCUSSION

This section provides a summary of each presentation and highlights the key issues identified in each of the thematic streams presented at the workshop. This section also includes a summary of the major policy issues and priority research needs, as related to each theme, identified at the workshop.

Theme 1: Air pollutant chemistry – implications for source management

(a) Projects and key findings

1. Sources of ozone precursors and atmospheric chemistry in a typical Australian city

- An in-depth analysis of the relationship between atmospheric chemistry and ambient levels of ozone
- Determination of the factors that influence ozone formation on high ozone days, with a view to reducing ozone concentrations in Australia's major cities

Improved methods for estimating ozone concentrations in Australian cities were developed, based on new inventories, which will lead to better-targeted ozone precursor management strategies. Measurements and modelling results reaffirmed that vegetation, including bushfires, is a significant source of ozone precursors in a number of Australia's major cities. Observations indicate that current emission inventories, which do not account for atmospheric chemistry, overestimate ambient benzene concentrations. This means that benzene reduction activities may be more effective than indicated by inventories. Modelling results also indicate that climate change is likely to increase future biogenic precursor emissions.

2. Development of tools for the identification and quantification of secondary organic aerosol (SOA) in Australian cities

- Development of new practical and cost-effective tools to robustly identify and quantify SOA in Australian cities

Organic carbon to elemental carbon ratio (OC/EC) was found to be the most robust way to define SOA in Australian cities, while a method based on chemical transport modelling underestimated SOA by a factor of 10 – 20. SOA was found to comprise around 18% of the particle mass in Victoria, and this proportion is likely to be similar in other major Australian cities, as the sources are similar. Bushfires were found to be a significant source of SOA. SOA was found to be a major contributor to the ambient particle mass when the 24-hr Ambient Air Quality National Environment Protection Measure (AAQ NEPM) PM₁₀ standard was met. However, primary particulate matter (PM) was the principal contributor when NEPM PM standards were exceeded.

3. Composition and structural studies of the secondary organic aerosol component of PM_{2.5} arising from the NEPM air toxic precursors: toluene and m-xylene

- An analysis of the factors that influence SOA formation from the precursors, toluene and xylene, and NO_x.

Under smog chamber conditions, SOA was formed even with low NO_x concentrations. If this situation is also true in Australian cities, this has important implications for smog management strategies that rely on NO_x reduction. The study also found that SOA produced under smog chamber conditions is significantly smaller than 1 micron and very stable.

4. A methodology for determining the impact of climate change on ozone levels in an urban area

- Development of new models to predict future ozone levels as a result of the projected warming impacts of climate change

Modelling shows that ground-level ozone levels in the Sydney airshed are sensitive to even small increases in temperature due to climate change. Climate change is projected to result in a 40% increase in ozone-related hospital emissions by 2020 – 2030 and 200% by 2050 – 2060.

The results of modelling also indicate that under the projected climate change scenarios, even with the most stringent emission reduction regimes, it is highly unlikely that the current AAQ NEPM standard for ozone will be met by these dates, given that some cities currently exceed the ozone standard on a regular basis.

(b) Policy implications

The lack of knowledge surrounding atmospheric chemistry is a major complicating factor in the effectiveness of air quality management plans. Its role in the formation of secondary pollutants can erode air quality gains made through the control of primary pollutant emissions. Ambient levels of both the pollutants of major concern in Australia, particulate matter and ozone, are influenced significantly by atmospheric chemical reactions.

The results of modelling reaffirmed that vegetation is a significant source of ozone precursors in a number of Australia's major cities. This has important implications for ozone management and the effectiveness of actions taken to manage anthropogenic precursors. Better information on biogenic precursors, such as isoprene, needs to be included in future atmospheric models as they are a major contributor to atmospheric levels of PM and ozone. Biogenic precursor emissions will be significantly influenced by climate change, with higher temperatures leading to increased emissions, and other effects due to rising atmospheric CO₂ concentrations and changes in the types and quantities of vegetation.

Current particle reduction strategies are principally focussed on primary particle emissions. However, particle pollution management strategies also need to take account of SOA formation to be fully effective, as some of these aerosols have been determined to be toxic. Such strategies should also take account of biogenic SOA precursors, such as isoprene, as modelling indicates that these may be more significant than anthropogenic precursors. Routine monitoring for SOA and ozone precursors should be considered, especially in Australia's major cities.

Future management strategies should account for commercial and domestic sources of SOA and ozone precursors, as modelling indicates that these will become responsible for a significant proportion of SOA precursors as vehicle technologies improve and domestic woodheater use is reduced. However, inventories for these sources are not well-validated.

New AQM strategies will be needed if current NEPM standards for ozone are to be met in 2020 and 2050, as modelling indicates that current strategies are likely to be inadequate.

Controlling VOC emissions is likely to be effective in reducing SOA and ozone. However, the case for NO_x reductions in some airsheds is not as clear cut, where small reductions in NO_x levels have been shown to increase ozone levels. Therefore, significant reductions in NO_x may be required to effectively reduce ozone and SOA levels. Reducing NO_x may also reduce energy efficiency, thus increasing greenhouse gas emissions. Although VOC and NO_x are the principal precursors of SOA and ozone, it is unclear at this stage which reduction strategy i.e. controlling VOC or NO_x, will deliver the greatest reductions in SOA and ozone. The optimum strategy is likely to be airshed-dependent.

Given the fact that SOA and combustion particles are significantly less than 1 µm in diameter, consideration should be given to setting a PM₁ standard.

(c) Further research needed

The following priority research needs were identified at the workshop:

- Systematic studies, both at the leaf and branch level in chambers, and in the atmosphere, of biogenic VOC emissions from Australian vegetation
- Better identification and quantification of SOA.
 - The contribution of SOA to ambient particle concentrations in other Australian cities should be assessed and compared against results obtained in Sydney to determine if a consistent SOA management strategy can be applied nationally.

- The chemical composition of SOA should be further investigated and the toxicity of these components should be determined, as their water solubility characteristics may have implications for their absorption by humans.
- Better estimates of hospital admissions as a result of increased ozone exposure arising from climate change to inform the case for early action on ozone management.
- A holistic examination of the synergies and conflicts between ozone and particle management strategies, particularly in the light of climate change.
- Analysis of how biogenic precursors interact with anthropogenic precursors to form SOA and ozone.
- Determination of the reasons behind discrepancies between CARP research findings with respect to VOC and benzene levels in Australian cities, and monitoring/inventory data.
- More information on the toxicity of SOA to better target particle management activities.
- Carbon 14 analysis of SOA precursors should be conducted to distinguish precursors emitted directly from vegetation, biomass burning and fossil fuel combustion, to inform an appropriate management strategy.
- A major chamber study to measure CO₂ emissions from trees is underway. It may be useful to measure biogenic PM and ozone precursors, as part of this study to get better information on the factors affecting biogenic emissions.
- Further analysis of the impacts of climate change on biogenic emissions of PM and ozone precursors.

Theme 2: Exposure assessment – are we really measuring what we’re breathing?

(a) Projects and key findings

1. Assessment of different approaches to determining personal exposure

- An assessment of new methods to determine personal exposure, which can be used to develop more robust concentration-response relationships for air pollutants

The tools developed in this study provide a robust method for assessing personal exposure, without the use of complex air quality models, and these can be applied to improve exposure assessment in epidemiological studies.

Measured personal exposure to NO₂ was significantly lower than NO₂ measured at ambient monitoring stations in Victoria. This indicates that the monitoring network in Victoria (and likely in other Australian cities) may significantly overestimate personal exposure. Therefore, epidemiological studies should use a more robust estimate of personal exposure that accounts for exposures from non-ambient sources. Short-term ambient PM levels were found to fluctuate significantly during the course of the study.

2. Development of metrics for individual exposure assessment to traffic-related air pollution

- An analysis of a range of methods for assigning personal exposure to traffic-related air pollution, using NO₂ as a marker for traffic pollution

Land-use regression, a standard approach for predicting pollutant concentrations using concentration measures, GIS-derived spatial parameters, and site characteristics, was found to best characterise personal exposure, although other methods also performed reasonably well.

Personal sampling of NO₂ was found to be useful for describing the range of NO₂ exposures for adults and children in an urban setting. Personal NO₂ exposures, when adjusted for outdoor NO₂ levels around the house, were found to be related to indoor sources of NO₂.

3. Urban-scale population exposure to reactive air toxics: does chemical transformation need to be considered?

- An assessment of the role of chemical transformation in determining exposure to reactive air toxics

Exposure to formaldehyde, an Air Toxics NEPM pollutant, is dependent not only on its ambient concentration, but also on atmospheric chemistry. This can lead to formaldehyde being formed in-situ, with secondary formaldehyde formation leading to significantly increased exposure. Therefore, chemical transformation should be considered when estimating population exposure to formaldehyde. Exposure to ambient toluene and xylene, however, can be adequately characterised without the need to consider chemical transformation.

4. Towards integration of bioanalytical tools in air pollution assessment, regulation and management

- An assessment of the toxicity of real air pollutant mixtures on bioassays, as an alternative to the traditional approach of measuring specified individual pollutants in ambient air

A method was developed to assess the toxicity of a mixture of air pollutants, using bioassays. The gas phase of the ambient air sampled in the study showed greater bioassay toxicity than the particle phase, and indoor air showed greater toxicity than air sampled at roadways and near industry.

(b) Policy implications

Accurate exposure assessment is essential to the development of air quality management strategies designed to protect human health, including setting of air quality standards. Poor exposure assessment can result in exposure misclassification (the difference between estimated and true exposure), making it difficult to quantify an existing association between air pollution and health.

Ambient monitors can significantly overestimate personal exposure to certain air pollutants, such as NO_x. Therefore, to accurately quantify personal exposure, epidemiological studies should take into account exposures from non-ambient sources, also. Better information on how population exposure varies spatially within cities, and population demographics in different areas, is required. Personal exposure measurements may be used to investigate air quality complaints.

Land-use regression (LUR), a statistical technique that incorporates information about emissions from a range of local sources, is a robust tool for determining population exposure, and can be readily employed in epidemiological studies. Interpolation using kriging did not work as well as LUR for NO₂, probably due to the lack of spatial autocorrelation in the data. Better exposure assessment, which incorporates data additional to fixed-site ambient monitoring data, can lead to better exposure assessment for setting air quality standards. In addition, an understanding of the factors influencing personal exposure to pollutants such as NO₂ and PM in Australian settings is important, so that general advice regarding individual exposure can be framed in a policy context.

Consideration should be given to including chemical transformation in future exposure estimates for formaldehyde, because of the potential for secondary formaldehyde formation in Australian airsheds. This can be applied to selecting and prioritising Stage 1 and Stage 2 sites for the Air Toxics NEPM. Chemical transformation is not significant, near primary sources of formaldehyde precursors. Real-time formaldehyde monitoring can be used to determine personal exposure. In contrast, current methods that are used to determine exposure to toluene and xylenes are adequate, since chemical transformation is not significant for these pollutants.

Elevated one-minute PM_{2.5} levels were observed in Melbourne. These observations, along with epidemiological studies that demonstrate health impacts from short-term exposures, suggest that consideration should be given to setting standards for PM_{2.5} with a shorter averaging time than for current AAQ NEPM standards.

Bioanalytical tools offer a novel screening technique to assess air quality. They are currently used widely to assess water and food quality. If analysis of air through such techniques shows toxic properties, then further forensic analysis can be undertaken to determine the exact nature of the problem, and develop appropriate management responses. The time needed to conduct such analyses is too long for the technique to be used to develop health warnings. An integrated approach to air toxics exposure assessment is needed. This can be accomplished through the use of an air toxics “marker” pollutant, similar to the use of ozone as a marker for photochemical oxidants. The Air Toxics NEPM regulates benzo(a)pyrene (BaP), as a marker

for PAHs. However, BaP readily degrades and is hard to measure. Therefore, a better marker for PAHs is needed.

The bioassay study also showed in a number of tests that the gas phase of the ambient air sampled indicated greater bioassay toxicity than the particle phase, and indoor air showed greater toxicity than air sampled at roadways and near industry. These findings are in contrast to the general belief that PM represents the greatest threat to human health from air pollution, and ambient air pollution presents a greater risk than indoor air.

(c) Further research needed

The following priority research needs were identified at the workshop:

- More information on the influence of pollutant mixtures on health impacts.
- Further work to identify a more appropriate marker for PAHs and other air toxics.
 - benzo(a)pyrene may not be appropriate due to its high reactivity.
- Determination of the cause of discrepancies between ambient formaldehyde levels determined through Air Toxics NEPM monitoring and modelled levels found in CARP reactive air toxics study.
- A better understanding of the factors that influence personal exposure to different pollutants. Additional space-time studies would be useful for this purpose.
- Further work to test LUR exposure models in different Australian settings and for different pollutants.
- Compositional analysis of gas and particle samples used in the bioassay study to determine why indoor samples were more toxic than roadside samples, and why gas phase samples were more toxic than the corresponding particle phase samples.
- Further work to determine how air pollution impacts on bioassays relate to human health impacts i.e. how bioassay results can be extrapolated to humans.

Theme 3: Major sources of air pollution in Australia

(a) Projects and key findings

1. Particles, ozone and air toxics levels in rural towns during prescribed burning seasons

- An assessment of the influence of prescribed burning on rural community exposure to selected air pollutants

Elevated particle and ozone levels in nearby rural communities were observed during prescribed burning episodes at Manjimup WA, Ovens VIC, Casuarina NT and Wagga Wagga NSW. Elevated ozone concentrations were only observed in plumes exposed to sunlight for several hours prior to impacting on rural towns. Prescribed burning was not found to be a significant contributor to benzene, toluene, ethylbenzene and xylene exposure.

Summer wildfires caused protracted periods of elevated ozone levels, which exceed the NEPM ozone standards. Crop stubble burning in the Riverina was the major source of particle pollution in Wagga Wagga. Chemical transport models did not accurately predict the observed concentrations of ozone in smoke-impacted towns.

2. New assessments of vehicle air pollution emissions and health effects using advanced on-road remote sensing technology

- Development of emission estimates for a range of pollutants emitted from in-service vehicles

Emissions from 53,000 vehicles were measured in Brisbane, Perth and Sydney and the data were analysed by vehicle type, fuel use, size and age. The study found that 10% of the vehicles for which emissions were measured produced 70% of the fleet's CO emissions, 60% of the smoke and hydrocarbon emissions and 50% of the NO_x emissions.

3. Measurement of real-world PM₁₀ emission factors from woodheaters by in-situ source monitoring and atmospheric inversion methods

- Measurement of emissions from woodheaters in Launceston households to predict ambient PM levels

Emission factors developed in this study produced significantly more accurate estimates for ambient air levels of PM than those using NPI emission factors, and show that current woodheater emission factors grossly underestimate emissions, thereby producing misleading inventories. This can result in misdirected air quality management strategies.

(b) Policy implications

An understanding of the key sources of air pollution in Australia's air sheds is critical to the development of effective air quality management strategies.

The emissions factor for woodheaters should be amended as a matter of priority, as current emission factors (e.g. the NPI) underestimate woodheater emissions by a factor of two, or more. This has major implications for air quality management strategies. More accurate inventories may be obtained using a range of emission factors, based on woodheater type. The NPI woodheater estimation manual is due for review shortly, and new information on in-service emissions will be considered in the review. The current test method for determining woodheater emissions, Australian/New Zealand Standard (AS/NZS 4013) should be amended to accurately reflect "real-world" emissions, as the current test method is based on ideal operating conditions. Studies of real-world emissions, however, indicate that good burning practices are not followed in a significant number of homes, thus producing emissions well in excess of AS/NZS emission limits.

Results from the vehicles remote sensing study indicate that there may be significant air quality benefits in Inspection and Maintenance (I & M) programs that target gross polluters, given that 10% of vehicles produce over 50% of emissions. Communication of remote sensing measurements to owners of grossly polluting vehicles can also be used to influence community behaviour by encouraging regular maintenance of vehicles. However, the greatest barrier to implementing I & M programs is the implication for social policy. Most of the higher emitting vehicles are from lower socio-economic groups and governments may consider it socially inequitable to target such vehicles for penalties. Social equity may be addressed through incentive programs for the purchase of newer, non-polluting technology, rather than forced scrappage, but incentive programs can be costly and promote debt among disadvantaged groups. Data obtained through remote sensing are very rich and much of the data obtained through the study are yet to be mined. Additionally, vehicle registration data can lead to detailed vehicle and owner data. The database of vehicle emissions can potentially serve as a benchmark against which future fleet emission profiles can be compared. This would allow a quantitative assessment of any improvements that have been achieved as a result of fleet turnover and/or new emissions reduction measures.

Significantly elevated levels of PM and ozone were observed during prescribed burning in rural towns. Therefore, prescribed burning needs to be carefully managed so as to minimise its air quality impacts on nearby communities, while not compromising community safety from an increased risk of wildfires.

(c) Further research needed

The following priority research needs were identified at the workshop:

- Better estimates of the influence of congestion on the quantum of traffic emissions.
- More information on heavy vehicle emissions and there may be value in a remote sensing program for trucks.
- Repetition of the on-road emissions measurement program in three years' time to assess if any improvements have been achieved through fleet turnover and/or the influence of emissions reduction measures.
- Further modelling work to assess how new vehicle technology and fuels will impact on air quality in the future.
 - This work should incorporate vehicle usage patterns and VKT.

- More information on indoor sources and their impacts on ambient air quality e.g. solvent use in homes has increased significantly over the few years.
- Improved characterisation and modelling of the formation of secondary combustion products in smoke plumes as plumes age during transport.
- Better characterisation of the contribution of ozone precursors advected into urban airsheds from biomass burning activities occurring outside the domain of urban emission inventories.

Theme 4: Tools to assist in the development of air quality management strategies

(a) Projects and key findings

1. Australian methodology for cost-benefit analysis of ambient air pollution health impacts

- A review of Australian and overseas literature to develop a “standard” methodology for assessing the health costs of air pollution

The proposed method provides clear guidance on how to conduct cost-benefit analyses for air quality. This guidance addresses a range of issues including double counting of health endpoints, selection of an appropriate concentration-response function, monetisation of benefits and sensitivity analysis.

2. Community based participatory research for air quality management

- A tool to engage the community in the development of air quality management plans

The project was assessed by various stakeholders as an excellent means for engaging the community and community involvement was found to be very important in the development of effective air quality management plans.

(b) Policy implications

Air quality management is complex and a number of tools, or models, are available to deliver consistent results in a range of situations. However, to be effective, such tools need to be demonstrated to be effective in the Australian context. Two key aspects of air quality management that could benefit from the adoption of a consistent methodology across Australia are the assessment of the health costs of air pollution, and community consultation.

There are issues associated with presenting details of sensitivity analyses to senior decision makers, and such data show exactly how imprecise some analyses are. There may be benefits in presenting a mean result, only, as this simplifies the message. However, such an approach may be deemed dishonest and, on balance, it is better to be upfront about uncertainties. A case in point is the recent review of the US ozone standard, in which the cost-benefit analysis showed a wide range of net benefits, ranging from positive to negative. The methodology developed in the health costs study is likely to be of value for the Air NEPM Variation process.

There needs to be a consistently applied Value of Statistical Life (VOSL) estimate in air quality cost-benefit analyses (CBA) in Australia. CBA is an essential part of gaining policy approval. A VOSL of \$2 million is used in road safety policy development. Willingness to Pay is the best way to monetise the health impacts of air pollution.

Currently, there is little weight placed on morbidity impacts of air pollution. There is a belief that air pollution has a “harvesting” effect, which only shortens life for the elderly by a very small period. However, this is not the real situation, as lives are generally shortened by many years. The length of life shortened overall is often used to cost air pollution impacts.

Concentration-response should generally be used in air quality risk assessment/CBA instead of dose-response because of the difficulty in estimating dose-responses for different individuals as a result of different breathing rates, exposure times etc.

The Community Based Participatory Research (CBPR) guide was found to be an excellent way to engage the community on air quality issues, and the level of professionalism within the community was found to be very high. The CBPR guide may also be used to elicit community input into the environmental impact assessment process.

(c) Further research needed

The following priority research needs were identified at the workshop:

- Robust quantification of Disability Adjusted Life Years (DALY)