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# CSIRO Submission 12/472

## Inquiry into The impacts on health of air quality in Australia

## Senate Standing Committees on Community Affairs

**March 2013**


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# I. Executive Summary

CSIRO undertakes a wide range of research on the air quality of Australian cities, industrial towns and rural areas. The research includes studies into factors that influence and control the emission, transport, mixing and transformation of air pollutants, including particulate matter. CSIRO provides advice to industry and the community and to government agencies, who are charged with setting environmental standards and the monitoring and regulation of air pollutants.

Air pollution refers to the presence in the atmosphere of chemicals, particulates, or biological materials that cause discomfort, disease, or death to humans, damage other living organisms such as food crops, or damage the natural environment or built environment. Examples of air pollutants include particulates, oxides of sulphur and nitrogen, carbon monoxide, volatile organic compounds, toxic metals (such as lead), ground-level ozone, and odours.

Air quality is compromised by the presence of air pollutants, whose sources are both natural and anthropogenic, that are transported, can undergo chemical transformation, and have impacts on people and ecosystems sometimes far removed from the emission source. Particulate matter (PM - solid and liquid particles suspended in the air) covers a wide range of sizes – from ultrafine to coarse particles. All have been shown to affect human health.

The health impacts of reduced air quality in general, and particulate matter specifically, have been documented. For example, a study[1] published in February 2013 comparing levels of air pollution across fourteen sites in nine countries found links between high levels of air pollution and low birth weights. Weight at birth is a factor affecting children's health including risks of infection and developmental delays. These results come at a time when severe air pollution in Beijing, China, led to advice from authorities for people to cease outdoor activities because the measured air quality index in January 2013 significantly exceeded levels considered dangerous to human health.

Australia does not have such widespread or hazardous levels of air pollution as some other countries but the 2005 Australian multi-city study (EPHC, 2010) established that there were significant impacts of coarse and fine particulate matter on the morbidity and mortality[2] of Australia's population. A CSIRO study (Beer et al. 2011) found that a 100% uptake of ethanol blend petrol had potential health cost savings of $42 million per annum, with over 97% of the estimated health savings resulting from reduction of the effects of fine particles (PM2.5) on mortality and morbidity associated with asthma and cardiovascular disease.

The following are key points regarding PM air pollution and its effects on human health.

- The main properties of PM that determine it's environmental and health risks are: concentration; size distribution; structure and chemical composition. The processes that control these properties are poorly understood and hence often poorly represented in models used to assess air quality levels and impacts and to develop control strategies[3].

[1] http://www.nature.com/news/air-pollution-delivers-smaller-babies-1.12358. The study is: Dadvand, P. et al. (2013), Maternal Exposure to Particulate Air Pollution and Term Birth Weight: A Multi-Country Evaluation of Effect and Heterogeneity. Environ. Health Perspect. http://dx.doi.org/10.1289/ehp.1205575 (2013).

[2] EPHC (2010). Expansion of the multi-city mortality and morbidity study. www.scew.gov.au/archive/air/index.html

[3] Solomon, PA et al (2012). Air pollution and health: bridging the gap from sources to health outcomes: conference summary. *Air Qual Atmos Health* 5:9–62.

- The size of PM is the principal determinant of how deeply it is inhaled into the human respiratory system, with smaller particles able to penetrate further into the lungs.
- Epidemiological studies have concluded that there is a statistically significant relationship between fine particles and human health effects, such as decreased lung function, increased respiratory symptoms, increased chronic obstructive pulmonary disease, increased cardiovascular and cardiopulmonary disease, and increased mortality (Pope and Dockery, 2006). Recent research has identified a strong link between PM2.5 and life expectancy (Pope et al, 2009).
- Many of the key questions and research priorities in understanding the impacts of air quality on health were identified at a major US conference in 2010 "Air Pollution and Health: Bridging the Gap from Sources to Health Outcomes" (Solomon et al, 2012).

The following issues are important for the impact of air quality and health effects in urban and regional Australia.

- Exposure to PM is a significant cause of air pollution morbidity and mortality in Australia, with health costs of air pollution estimated to exceed $4 billion per year in NSW alone[4]. Health impacts can be reduced through the control of PM sources but particles are generated from a wide range of primary and secondary anthropogenic and natural sources and so controlling the emission of particles is challenging. For example, the Sydney Particle Study[5] demonstrated that local urban sources (motor vehicles, wood combustion, and industrial sources) may contribute less than 50% of the fine particle mass in Sydney, with background sources (dust, smoke, sea salt, biogenic) comprising the remainder.
- Air pollution is often considered an urban problem but rural populations in Australia also are exposed to particulate matter due to wind-blown dust smoke from controlled burning, bushfires, and wood heaters, and particulate emissions from mining and other activities. Managing and reducing the human health impacts of particles on rural populations requires research into the relative importance of local sources (e.g. from wood fires, local industry) versus background sources (from wind-blown dust and large-scale bushfires) of rural particles.
- Factors linked to changes in the emission of PM in urban and regional Australia include:
    - Motor vehicles continue to be a large source of PM in urban Australia and although improved vehicle emission control technologies are likely to reduce tailpipe emissions, other emissions from road dust and tyre and brake wear will increase with increasing vehicle usage over time;
    - Changes in fuel type will lead to changes in particle mass and size distribution that impact on human health, e.g. a shift to diesel may lead to increases in particle mass and the number of ultra fine particles while a shift to ethanol blend petrol will reduce the emission of fine particles;
    - Wood heaters are a significant source of fine PM in temperate Australia, and concentrations can build up where atmospheric mixing is weak, especially in valleys;
    - Urban vegetation emits organic gases that lead to the formation of secondary organic aerosols that contribute to fine particulate matter but these emissions cannot be controlled directly;

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[4] NSW EPA (2012). New South Wales State of the Environment 2012, Chapter 2.1. www.environment.nsw.gov.au/soe/soe2012/chapter2/chp_2.1.htm

[5] Keywood, M., Galbally, I., Crumeyrolle, S., Miljevic B., Boast, K., Chambers S., Cheng M., Dunne E., Fedele R., Gillett, R., Griffith, A., Harnwell J., Lawson S., Molloy, S., Powell J., Reisen F., Ristovski Z., Selleck P., Ward J., Chuanfu Z., and J. Jiarong (2012). The Sydney Particle Study Stage I: Executive Summary prepared for NSW Office of Environment and Health. 26pp.

- Dust storm events carry with them extremely high concentrations of coarse PM, and climate change projections for Australia suggest likely increases in dust events in the future;
- Transport of bushfire smoke into densely populated centres can lead to high levels of exposure to PM, which may increase with time if climate change projections of significant increases in the frequency of high fire risk weather and substantial increase in the probability of extreme fire risk across Australia prove correct.

- There is an important nexus between Australia's air quality and a changing and increasingly variable climate because:
  - A likely increase in frequency and severity of bushfires and droughts would increase the PM levels in urban and regional Australia;
  - Photochemical smog, which affects all Australian cities, is influenced by air temperature as well as urban vegetation and levels of ozone and increased air temperatures due to global warming are likely to exacerbate the incidence and severity of photochemical smog events in Australia's cities;
  - The effects of air pollution will be in addition to other stressors that affect human health such as heat stress, with such combined effects very likely to adversely affect the morbidity and mortality of Australia's population.
- Managing and reducing the adverse human health impacts of air pollution both now and into the future will benefit from improved characterisation of PM (properties, sources, and transport) and of population exposure. Better coordination across jurisdictions to acquire inventory data and better coordination between air quality and population health researchers, regulatory authorities and those involved in urban and regional planning also will improve substantially our ability to manage air pollution and its effects, as will research on emerging trends in building and city design.

  The *research* that would contribute to this enhanced knowledge includes:
  - Developing better capability for measurements of all particle properties, including particle microphysical properties in real time;
  - New analytical methods for PM chemical composition to characterize primary and secondary PM sources;
  - Quantifying the links between health impacts and particle size distribution and composition;
  - Improving exposure estimates in epidemiological studies through improved simulation modelling and integration of measurements of air pollutants into these models;
  - Building simulation models and tools to quantify air quality risk, to identify optimum strategies for reducing risk, and to assess the impact of climate on future air quality combined with multiple environmental stressors.

  This research would be *enabled* by the development of a national air quality forecasting system, nationally consistent approaches for inventories and modelling, and a national, readily accessible database of air pollution data.

# II. Introduction

CSIRO welcomes the opportunity to provide input to the Senate Standing Committees on Community Affairs inquiry into - *The impacts on health of air quality in Australia*.

CSIRO has world class capabilities and delivers rigorous and comprehensive research in: measurements of air pollutants, their precursors and chemical transformation in Australia's atmospheric environment, modelling the chemical transformation, transport, and mixing of these pollutants in urban and rural environments, and projecting likely impacts of air pollutants under current and future climates. We work closely with the Australian and State governments to provide research to support setting environmental standards, monitoring, and regulation of air quality, and State of Environment (SoE) reporting. CSIRO has developed sophisticated tools to support public and private sector agencies in these tasks.

CSIRO expertise is in air pollution science primarily and we collaborate with other research agencies with relevant capabilities to research the health impacts of air quality. This means that CSIRO's contribution to understanding the science of air pollution and health is underpinned by our continuing engagement with Australian organisations, including government, universities, consultants and industry, and with national and international research programs and organisations. Long-term examples of such engagement include CSIRO's contribution to the Cape Grim Air Pollution Monitoring Program run by the Bureau of Meteorology (the Bureau) and our active involvement, including in executive roles, with bodies such as the Clean Air Society of Australia and New Zealand and the International Global Atmospheric Chemistry (IGAC).

CSIRO has developed air quality modelling tools for industrial, rural, and urban air sheds, including TAPM (The Air Pollution Model) and the CTM (Chemical Transport Model) that are used for CSIRO research and by external agencies under license. CSIRO also has developed an air quality forecasting system for Australian capital cities, which was run operationally for several years by the Bureau. More recently CSIRO has been developing a regional and national smoke and dust prediction system as part of its ongoing research into these air pollution sources.

Our response to the inquiry draws on this very broad range of scientific work. Our comments have been prepared by a team of scientists from across CSIRO with experience and international recognition in many facets of air quality research. This submission is focused on sections where CSIRO has undertaken research that is published or in the public domain.

The submission addresses each of the Terms of Reference, providing background information, commenting on the state of the science, significant knowledge gaps, and the priorities to address the gaps. A summary of some recent studies that demonstrate CSIRO research is provided in Appendix A. CSIRO welcomes any opportunity to discuss any areas in more depth with the Committee.

# III. CSIRO response to the Terms of Reference (TOR)

## a) ToR 1: Particulate matter, its sources and effects

Particulate matter (PM) in air pollution refers to solid and liquid particles suspended in air, with the PM and air mixture referred to as aerosol. Health impacts arise because PM is able to enter the human respiratory system and cause or exacerbate respiratory, cardiovascular, and allergic diseases. PM is often chemically active in the environment and in humans, can be transported long distances in the atmosphere, and can influence weather and climate.

The main properties of PM that determine its environmental and health risks are: concentration; particle size distribution; structure; and chemical composition. The processes that control these properties are poorly understood and hence often poorly represented in models used to assess air quality levels and impacts and to develop control strategies. The health impacts of PM are well-documented but the specific pathways by which it affects human health are not well characterised currently.

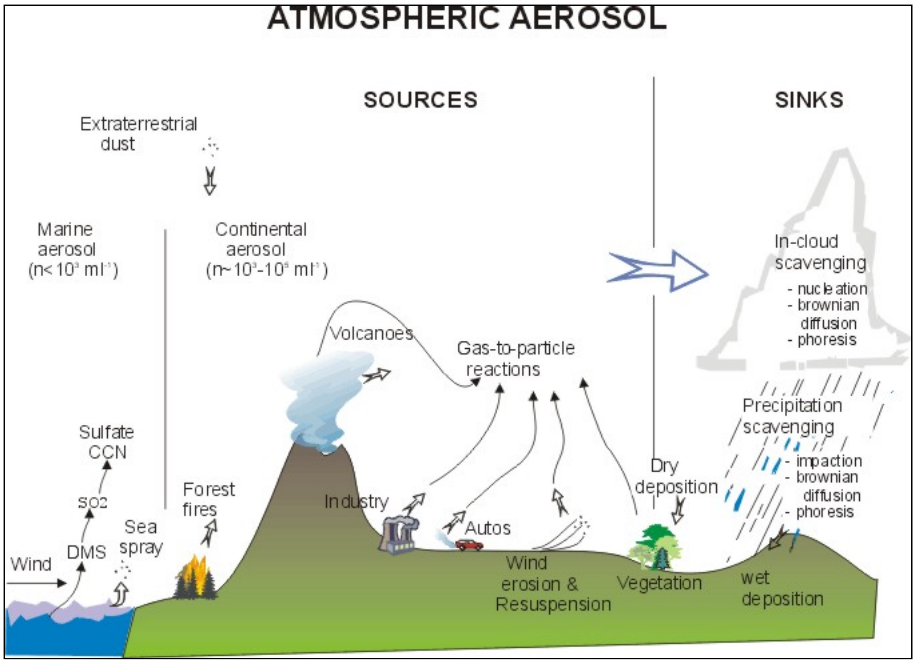


**Figure 1. Schematic of atmospheric aerosol sources. DMS refers to dimethyl sulphide and CCN refers to cloud condensation nuclei.[6]**

### PM sources and sizes

Atmospheric PM is classified as primary or secondary depending on its source.

**Primary particles** originate from both anthropogenic and natural sources as illustrated in Figure 1. Natural sources are derived from processes that occur naturally in the earth system, such as bubbles bursting on the sea surface which release sea salt aerosol into the atmosphere, wind-blown dust, and smoke from naturally-lit bushfires. Anthropogenic sources result from human activity and include: dust associated with agriculture, mining, urban developments, and road traffic; smoke from deliberately lit bushfires, prescribed burning, and household wood heaters; emissions from vehicle exhaust, industrial

[6] From www.ems.psu.edu/~lno/Meteo437/Aerosol.jpg, accessed 17 January 2013.

processing, and commercial activities; and spray drift from aerial application of agricultural and horticultural chemicals.

**Secondary particles** are formed by chemical reactions in the atmosphere that result in gases being converted to particles, which are also known as secondary aerosols. These conversions lead to the production of large numbers of very small particles (nucleation) and the growth in size of existing particles (condensation).

The size of PM is the principal determinant of how deeply it is inhaled into the human respiratory system. The total mass of PM in the air is referred to as TSP (total suspended particles), but this measure is usually restricted to assessments of dust nuisance. The particle size distribution of TSP typically has three characteristic peaks, as seen in Figure 2. Large particles are generally filtered in the nose and throat so that only PM10 (particles with an effective diameter less than 10 μm) reach the bronchi and lungs. PM10 is considered often in studies of the impacts of air quality on human health. PM10 measurements were the only widely available data on PM for epidemiological studies prior to about 2000.

Health focus has turned to finer particles more recently and consideration usually is given to PM10-2.5 (coarse), PM2.5 (fine) and PM0.1 (ultrafine) measurements and effects. This reflects the key role played by particle size in determining human health impacts because of the influence particle size has on the depth to which particles penetrate when inhaled. The smaller the particle the further it is able to penetrate into the human respiratory system.   Figure 3 shows that 40% of particles less than 0.1 μm in diameter (PM0.1) can deposit in the pulmonary alveoli of the lungs where they can pass into the blood stream, while 60% of particles 10 μm in diameter are deposited in the upper respiratory tract.

The sources of these different classes of PM are:

- PM10-2.5 primarily is derived from suspension or re-suspension of dust, soil, and other crustal material from roads, farming, mining, and dust storms, but also includes sea salt, pollen, mould, and spores;
- PM2.5 primarily is derived from direct emissions from combustion processes, such as petrol and diesel vehicles, wood burning, coal burning for power generation, and industrial activities such as smelters, cement plants, paper mills, and steel mills but also include the secondary aerosols described above;
- PM0.1 results from combustion-related sources (such as vehicle exhaust) and atmospheric photochemical reactions.

The lifetime of particles in the atmosphere before being deposited or washed out by precipitation also is related to their size, as well as atmospheric conditions, with PM10 typically remaining in the atmosphere for only a few days or less, PM2.5 having an atmospheric lifetime of around a week, and PM0.1 usually lasting only minutes to hours before growing rapidly through coagulation or condensation to form larger sized PM.

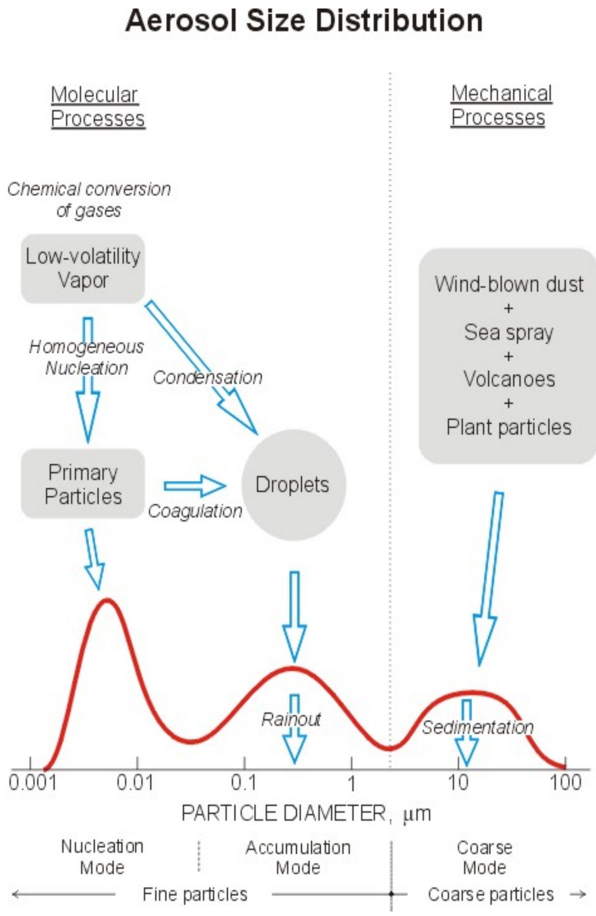


**Figure 2 Particle size distribution and origin[7].**

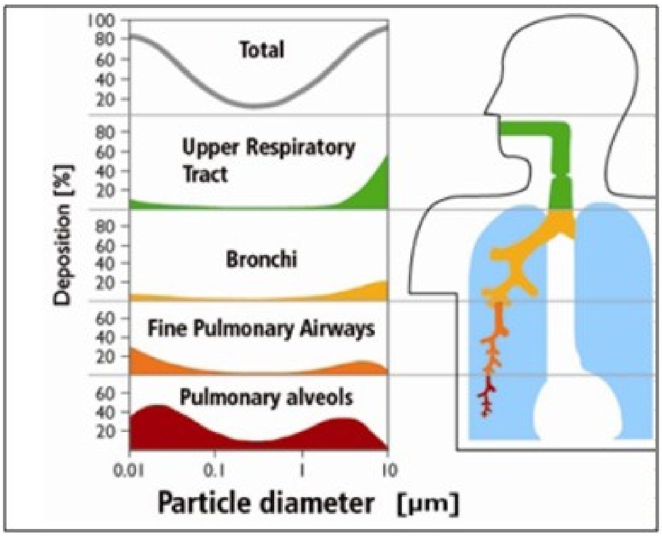


**Figure 3. Deposition of different sized particles in different segments of the respiratory system. Source: ICAO Information Paper CAEP-SG/ 20082-IP/05[8].**

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[7] From: www.ems.psu.edu/~lno/Meteo437/Aermode3.jpg, accessed on 17 January 2013

[8] From: www.icao.int/environmental-protection/PublishingImages/HealthEffects_2.jpg, accessed on 17 Jan 2013.

## PM effects

Epidemiological studies including the Australian multi-city mortality and morbidity study (EPHC, 2010; Simpson et al. 2004; Barnett et al. 2006) have concluded that there is a statistically significant relationship between fine particles and human health effects, such as decreased lung function, increased respiratory symptoms, increased chronic obstructive pulmonary disease, increased cardiovascular and cardiopulmonary disease, and increased mortality (Pope and Dockery, 2006). Recent research has identified a strong link between PM2.5 and life expectancy associated with these health effects (Pope et al., 2009). Current Australian research includes the Health in Men Air Quality Study (http://www.sph.uwa.edu.au/research/occ-resp-epi/environ-cancer/HIMAQS).

## CSIRO research

CSIRO provides research to:

- Better characterise the time and space distribution of PM in the environment;
- Understand the processes that determine particle concentrations;
- Develop predictive models to support epidemiological research;
- Aid government in developing and implementing policies to reduce the sources of particles and mitigate their impacts.

Understanding of PM in Australia has been advanced during the last decade through studies into fine particles, secondary organic aerosol, smoke impacts from wood heaters, fire management burns and bushfires, dust storms, and health costs associated the use of alternative fuels. The impact of climate change on PM and the impact of PM as a driver of regional climate change also have been investigated. Much of the research is done in collaboration with Australian and State government environment agencies, the Australian Nuclear and Science Technology Organisation (ANSTO), Cooperative Research Centres (CRCs), and Universities. Appendix A provides a list of some examples of this work.

## Current and emerging issues

Australia is not considered to have the severe air quality problems seen in some other developing and industrialised nations but there is a range of important current and emerging issues that affect our urban and regional air quality.

- **Motor vehicle use** continues to be a large source of PM, particularly in Australia's cities. Improvements in vehicle emission control technologies are projected to continue to reduce tailpipe emissions, but particle emissions from road dust and tyre and brake wear are likely to increase as vehicle use increases.

- **Fleet-scale changes in vehicle fuel type** can lead to changes in particle mass and size distribution that in turn affect human health. For example, Beer et al. (2011) found that 100% uptake of ethanol blend petrol had potential health cost savings of $42M per annum. Over 97% of the estimated health savings are based on reduction in PM2.5 impacts on mortality and morbidity (e.g. asthma, cardiovascular disease). Conversely, a trend of increased use of diesel may lead to increases in both emitted particle mass and the number of ultra fine particles. There is increasing evidence that the number of ultra fine particles is a more important factor than their total mass when considering their impact on human health (Green et al., 2004; Brugg et al., 2007; McConnell et al., 2010).

- **Effects from urban vegetation.** Fine particle mass includes a significant fraction of secondary aerosol, often comprising organic compounds derived from the chemical reaction of organic gases emitted from vegetation (Hallquist et al., 2009). The Australian Government's Clean Air Research Program explored this source of fine PM via field measurements in Melbourne (Keywood et al., 2011), and investigated the chemical reactions involved using CSIRO's environmental smog chamber. The presence of secondary aerosol greatly complicates the development of an effective strategy for reducing PM exposure as not all emissions can be directly controlled.

- **Wood heaters** are a significant source of fine PM in temperate areas of Australia (http://www.environment.nsw.gov.au/air/airinventory.htm). The impacts of the emission of PM from wood heaters typically are worse in valleys such as around Launceston in Tasmania (Keywood et al., 2000; Gras et al., 2001; Meyer et al., 2011).
- **Dust storm** events carry with them extremely high concentrations of PM10. For example, Leys et al. (2011) found the September 2009 Sydney event resulted in 24 hour PM10 concentrations at several locations in the Sydney-Newcastle region exceeding 1000 µg $m^{-3}$, compared to the Air National Environment Protection Measure (NEPM) PM10 standard of 50 µg $m^{-3}$. Climate change projections for Australia suggest likely increases in the frequency of extreme events, raising the prospect that the sequence of droughts and flooding rains may lead to increases in severe dust events.
- **Bushfire smoke** transport into densely populated centres can lead to high levels of population exposure to PM. For example, short-term PM10 peaks of 100 µg $m^{-3}$ were recorded in the suburb of Aspendale in Melbourne during the 2006 - 07 fires in Alpine Victoria. Management of bushfire risk through the use of control burns in non bushfire-prone seasons, however, also carries a risk of exposing large fractions of the population to elevated particle concentrations during cool, calm weather when meteorological conditions are more likely to be associated with poorer atmospheric mixing of PM (Reisen and Brown, 2006; Reisen et al., 2011). Climate change projections for Australia also suggest significant increases in the frequency of high fire risk weather and a substantial increase in the probability of extreme fire risk across Australia from grasses and forest by 2100. This has important ramifications for air pollution and its impacts on human health. There is also a link between PM and enhanced smog concentrations in the lower atmosphere on bushfire days with secondary particles of photochemical origin contributing up to 50% of fine PM.
- **Air quality and climate variability and change.** There is an important link between air quality, health impacts, and climate change in Australia. First, climate change projections indicate a likely increase in frequency and severity of bushfires and droughts, which would increase particulate levels in urban and regional Australia. Second, photochemical smog affects all Australian cities and is influenced by air temperature as well as urban vegetation and levels of ozone. Increased air temperature due to global warming is likely to exacerbate the incidence and severity of photochemical smog events in Australia's cities. Third, effects of air pollution will be in addition to other stressors that affect human health such as heat stress that also are likely to increase with changing climate and these combined effects are likely to adversely affect the morbidity and mortality of Australia's population.

## Research priorities

Reducing levels of population exposure to PM is likely to deliver better health outcomes and reduce health-related costs. Furthermore, the links between air quality and climate mean that reducing and managing emissions may have effects that extend to the larger Australasian region.

Managing population exposure to, and human health impacts of, PM requires an improved knowledge of the formation, transport, deposition, and composition of PM. The research priorities that would contribute to this knowledge include:

- Developing new advanced analytical methods to identify and quantify chemical composition of PM to better characterize sources of primary and secondary PM;
- Determining the links between health impacts and compounds that affect health, for example, what are the health effects of various sizes and composition of particles?;
- Better understanding the role of intermediate chemical species in the formation of secondary aerosols so that these processes can be incorporated in assessment and predictive models;
- Assessing the accuracy and limitation of statistical methods used in the analysis of hospital morbidity and mortality data to deduce the major risk factors and their impacts on health outcomes;

- Assessing the potential changes in PM source composition (e.g. changes in balance of petrol/electric/diesel vehicles) and emission fluxes (e.g. of dust and smoke) that are likely under future climate change, urban design, and vehicle fleet scenarios;
- Quantifying impacts on human health of short-term (hours to daily) and long-term (annual to lifetime) exposure to PM. This includes assessing the risk of health impacts of smoke from prescribed burns in comparison to the impacts of catastrophic bushfires.
- Research on the composition of smoke from wood heaters and the factors that influence these emissions to improve modelling of wood heater emissions, which can comprise more than 50% of fine PM in urban airsheds, and underpin the development of better standards for wood heaters;
- Enhancements to atmospheric models to represent PM sources and chemistry more comprehensively to underpin development of more effective strategies to reduce PM exposure; and
- Enhanced integration of experimental observational and modelling studies to quantify better contributions by all particle sources to total particle exposure in a region.

## b) ToR 2: Those populations most at risk and the causes that put those populations at risk

The populations at greatest risk are those in residential areas close to significant pollution sources or in areas where there is poor dispersion due to a combination of meteorology, topography (e.g. valleys), and location factors (e.g. coastal regions with land-sea breeze circulations). Examples of these types of areas are:

- Locations with high traffic density (e.g. Keywood et al, 2011);
- Towns and suburbs in valleys with significant wood heater use (e.g. Meyer et al, 2011);
- Regional towns co-located with heavy industry (e.g., Gladstone, Kalgoorlie, Mt Isa, Port Pirie);
- Peri-urban populations (i.e. at the rural–urban interface) which may be vulnerable to spray drift from agricultural and horticultural sprays (e.g. McKinlay et al, 2008); and
- Residential, office, or schooling accommodation with poor indoor air quality as a result of high prevalence of mould, unflued gas heaters, new furnishings still off-gassing, or low air exchange, (e.g. EnHealth, 2007).

Galbally et al (2011) argued that indoor air quality is likely to be an increasing problem with the move towards more thermally efficient buildings.

Risks from PM are identified through epidemiological and population health studies. Australian studies include a Multi-city mortality and morbidity project (EPHCS, 2010; Simpson et al. 2004; Barnett et al. 2006) funded by the Environment Protection and Heritage Council and studies by the National Centre for Epidemiology and Population Health, Monash University Department of Epidemiology and Preventive Medicine, and University of Western Australia School of Population Health.

### CSIRO research

CSIRO provides research to:

- Develop integrated assessment frameworks that bring together key factors including population and demographic data, epidemiological information on exposure and responses to pollutants, and spatial variation in air quality;
- Attribute pollution sources and determine their relative importance using a combination of measurements and inverse modelling techniques;
- Assess population exposure across a range of fields, including evaluating the potential for electric vehicles to reduce the population exposure to pollution (Cope and Lee, 2011), estimating urban exposure to nitrogen dioxide ($NO_2$) by combining measurements and modelling of personal exposure with time activity data (Physick et al 2011), modelling pollution exposure around major

road tunnel vent stacks (Hibberd, 2006), and agent based modelling to assess the impact of reducing PM10 exposure (Newth and Gunaskera, 2012).

### Current and emerging issues

Integrated assessments are necessary in airsheds where there are many pollution sources or high levels of air pollution. They are currently undertaken in the major capital cities but have been very slow to occur – or even absent – in areas with rapid industrial expansion (e.g. Gladstone, Upper Hunter). Integrated assessments of air quality require sharing of emissions data for modelling and optimising monitoring networks. Planning regulations have sometimes been slow to reflect the need for integrated assessment or to require appropriate emissions inventories from development.

### Research priorities

Research required to support strategies and policies to mitigate risks to populations include:

- Improving exposure estimates in epidemiological studies through improved pollution modelling, including integration of measurements of air pollutants;
- Characterising indoor air quality (see also section d) in terms of pollutant sources and processes that cause reduced air quality and exploring how building standards and regulations can be used to ensure that indoor air quality is not compromised;
- Development of simulation models and tools to quantify risk and identify optimum strategies for reducing risk, including assessing the impact of an increasingly variable and changing climate and multiple environmental stressors (including heat);
- Exploring ways to improve urban environments to reduce risks to population health as a result of multiple stressors, including poor air quality, in the context of climate change.

## c) ToR 3: The standards, monitoring and regulation of air quality at all levels of government

Standards for air quality in Australia currently are undergoing a major development. The Ambient Air Quality National Environment Protection Measure (AAQ NEPM) in 1998 established national air quality standards for six criteria pollutants (PM10, ozone, sulphur dioxide, nitrogen dioxide, carbon monoxide, and lead). An advisory reporting standard for PM2.5 was incorporated in 2003 and an Air Toxics NEPM was added in 2004. A review of the AAQ NEPM in 2011 recommended several changes to the AAQNEPM, which the National Environment Protection Council has indicated will be prioritised and responded to via the development of the National Plan for Clean Air by the Council of Australian Governments (COAG) Standing Council on Environment and Water for delivery in 2014.

### CSIRO research

CSIRO was the lead research agency and major contributor to most of the research projects done as part of DEWHA's Clean Air Research Program from 2005 – 2008, intended to address some of the major research gaps in the management of air quality in Australia. This has helped to shape the development of the National Plan for Clean Air.

CSIRO contributed to the development of the original NEPM, provided decade-long advice through the Air Quality Working Group of EPHC (Environment and Heritage Protection Council), and was a member of the sulphur dioxide/ozone NEPM Review Team in 2003-4. CSIRO also plays a role in the development of standards for measuring air quality as a member of the joint Standards Australia/Standards New Zealand Committee EV-007: Methods for Examination of Air for more than a decade.

### Research priorities

Research priorities for standards, monitoring, and regulation of air quality include the following.

- Develop nationally consistent approaches for emission inventories and modelling.
- Develop a national, readily accessible database of air pollution data such as the European Airbase (http://acm.eionet.europa.eu/databases/airbase) to provide researchers with ready access to the data, provide the community with greater transparency to inform debate, and foster better use of resources deployed for monitoring by avoiding duplication.
- Develop computationally efficient models that can be run on a desktop PC and emulate the features of complex, three-dimensional state-of-the-art models. The latter require access to major computer resources such as the National Computational Infrastructure (NCI) Facility. Simpler, more efficient emulators are starting to be used overseas and if developed for Australia would enable EPAs and consultants to use nationally-consistent models that encapsulate the latest features necessary for modelling Australian conditions, such as biogenic emissions (important in Australia) and the fact that there is much less need to model inter-regional transport in Australia than elsewhere. Such national modelling capability will become more important with the introduction of the National Plan for Clean Air that won't just set standards but will need ongoing modelling to optimise exposure assessments.
- Develop a more widespread capability for measurements of all particle properties, including particle microphysical properties such as ultra-fine particle concentrations, particle number size distributions, and particle composition in real time.

## d) ToR 4: Any other related matters

The issues addressed in this section are important aspects of air quality and human health that have not been addressed explicitly under the earlier ToR, specifically indoor air quality, persistent organic pollutants, mercury, and alternative fuels for cars.

### Indoor air quality

Widespread attention has been given to outdoor air quality for many years and as a result the relationships between outdoor air quality and human health have been investigated widely. Table 1 lists common pollutants and their sources found indoors. People are now becoming more conscious about the potential hazards posed by indoor air contaminants as a result of several factors, including:

- Changes in building design to improve energy efficiency in modern homes and offices, particularly those built after the 1970s oil crisis, to make structures more airtight than older structures;
- Increasing use of synthetic building materials, insulating products, furnishings, consumer products, hobby and craft materials;
- Poorly designed, installed, or operated heating systems that produce toxic by-products from the combustion process (e.g. unflued gas heaters);
- That the above changes to building design, materials, and heating systems may produce, and lead to build-up of, higher pollutant concentrations in indoor environments than are found outside;
- Recognition that prolonged exposure even to very low concentrations of chemical contaminants may result in delayed toxic effects;
- Evidence that people spend most of their time indoors (e.g., Robinson and Nelson (1995) reported that US people on average spent 88% of their day inside, 7% in a vehicle, and only 5% outside);
- Research indicating that indoor air quality is significantly affecting human health and productivity, with Ren (2002) suggesting that significant proportions of respiratory illnesses and lung cancers may be caused by avoidable indoor pollution and Mendell and Smith (1990) and Wolkoff (1995) claiming a significant percentage of the population suffers from eye and respiratory discomfort, headaches, and feelings of lethargy resulting from their occupancy of buildings with poor indoor air quality;
- Recognition of Sick Building Syndrome where the occupants of certain affected buildings repeatedly describe a complex range of vague and often subjective health complaints which may be associated with volatile organic compounds and radon inside buildings (Jones 1999).

Increasing risks to indoor air quality are likely as Australia moves toward lower or zero carbon emission buildings as these buildings become more airtight through energy efficiency measures. There is a need to explore what standards or regulations may be required to balance energy efficiency gains against the real costs of reduced indoor air quality and its impacts on health. Providing relevant evidence-based advice will require the development of tools for designing energy efficient and healthy buildings.

**Table 1. Major indoor pollutants and emission sources (adopted from Ren, 2002)**

| POLLUTANT | MAJOR EMISSION SOURCES |
|---|---|
| Allergens | House dust, domestic animals, insects |
| Asbestos | Fire retardant materials, insulation |
| Carbon dioxide | Metabolic activity, combustion activities, motor vehicles in garages |
| Carbon monoxide | Fuel burning, boilers, stoves, gas or kerosene heaters, tobacco smoke |
| Formaldehyde | Particleboard, insulation, furnishings |
| Micro-organisms | People, animals, plants, air conditioning systems |
| Nitrogen dioxide | Outdoor air, fuel burning, motor vehicles in garages |
| Organic substances | Adhesives, solvents, building materials, volatilization, combustion, paints, tobacco smoke |
| Ozone | Photochemical reactions |
| Particles | Re-suspension, tobacco smoke, combustion products |
| Polycyclic aromatic hydrocarbons | Fuel combustion, tobacco smoke |
| Pollens | Outdoor air, trees, grass, weeds, plants |
| Radon | Soil, building construction materials (concrete, stone) |
| Fungal spores | Soil, plants, foodstuffs, internal surfaces |
| Sulphur dioxide | Outdoor air, fuel combustion |

### Persistent Organic Pollutants

Persistent organic pollutants are pollutants that persist in the environment and accumulate in the fatty tissue of living organisms. They are toxic and hence have a detrimental impact on health of humans, other organisms, and ecosystems. These chemicals are (or were) generated as a result of human activity including pesticide use and industrial processes. Australia is a signatory to the Stockholm Convention on Persistent Organic Pollutants, the aim of which is to reduce or eliminate the use of these pollutants and their release to the environment. There are 21 pollutants currently listed by the Convention, with others continuously added as we use more and different chemicals. The Convention requires that the Parties provide evidence of the reduction of these pollutants in the environment. An important area for future research is to understand how the chemicals being used as replacement to the banned chemicals listed by the Stockholm Convention persist in the environment and whether these replacement chemicals are toxic. This will require environmental monitoring and modelling with sophisticated techniques.

#### Mercury

Mercury also is persistent in the environment and toxic to humans and other organisms. It is long-lived in the atmosphere and the environment, and hence subject to transport by air masses on a global scale. Coal combustion is believed to be the main source of mercury emissions to the atmosphere. The concentration of mercury in the atmosphere is increasing. The Minamata Treaty banning the use of mercury will be signed in October 2013. An important research activity will be assessing the effectiveness of this ban by carrying out environmental monitoring for mercury.

## Alternative fuels for cars

Gaseous fuels such as CNG or LPG reduce particulate matter emissions as a general rule. This has positive benefits for air quality and human health, but in some cases the greenhouse gas emissions increase when considering the full life cycle as a result of leakages during production and distribution of such gaseous fuels (Beer et al, 2004).

# IV. References


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# APPENDIX A: Selected CSIRO research and papers

## 1. Fine particles

### Australian Fine Particle Pilot Study (AFP)

This pilot study was commissioned by Environment Australia and done between August 1996 and December 1997 by the CSIRO and ANSTO in conjunction with the relevant agencies responsible for ambient air quality monitoring in Sydney, Brisbane, Melbourne, Canberra, Launceston, and Adelaide. This limited duration study used a comprehensive package of aerosol measurement equipment to generate a large database on a wide variety of chemical and physical properties of atmospheric aerosol particles measured at six locations across eastern Australia.

Ayers, G. P., M. D. Keywood, J. L. Gras, D. Cohen, D. Garton, and G. M. Bailey.(1999). Chemical and physical properties of Australian fine particles: A pilot study. Report prepared for the Environment Protection Group, Environment Australia, June 1999,

Keywood, M. D., G. P. Ayers, et al. (2000). Size distribution and sources of aerosol in Launceston, Australia, during winter 1997. Journal of the Air & Waste Management Association 50(3): 418-427.

Gras, J. L., M. D. Keywood, et al. (2001). "Factors controlling winter-time aerosol light scattering in Launceston, Tasmania." Atmospheric Environment 35(10): 1881-1889.

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Keywood, M. D., G. P. Ayers, et al. (2000). Size-resolved chemistry of Australian urban aerosol. 15th International Clean Air Conference,. C.A. S. A. N. Z. Sydney, Australia.

### Sydney Particle Study

Keywood, M., Cope, M.E., Galbally, I., Emmerson, K., Crumeyrolle, S., Miljevic B., Boast, K., Chambers S., Cheng M., Dunne E., Fedele R., Gillett, R., Griffith, A., Harnwell J., Lawson S., Molloy, S., Powell J., Reisen F., Ristovski Z., Selleck P., Ward J., Chuanfu Z., and J. Jiarong (2012). The Sydney Particle Study- Stage-I: Executive Summary prepared for NSW Office of Environment and Health. 26pp.

### Hunter Valley

Nelson, P, Morrison, A., Halliburton, B., Rowland, R., Carras, J., Cohen,D., and Stelcer, E. (2007). Characterising and Assessing Fine Particle Concentrations in the Hunter Valley - Implications of National Environment Protection Measures for the Coal Mining Industry. ACARP report C13036.

## 2. Secondary organic aerosol (SOA)

### Clean Air Research Program

#### *Development of Tools for the Identification of Secondary Organic Aerosol in Australian Cities*

The contribution of Secondary Organic Aerosol (SOA) to particulate mass in Australian cities is poorly quantified. SOA is produced in the atmosphere by the oxidation of volatile organic compounds (VOCs) of biogenic or anthropogenic origin to produce semi-volatile compounds that partition to existing particles. SOA consists entirely of fine particles (PM2.5) and the contribution of SOA to the ambient PM load in Australian cities may lead to exceedence of the National Environment Protection Measure (NEPM) advisory reporting standard for PM2.5. Recent epidemiological research indicates that exposure to PM2.5 is associated with a range of health impacts. The mechanism for these impacts, however, including the role of SOA, is not well-understood. This project investigated four techniques for the quantification of SOA and aimed to incorporate SOA formation into a three-dimensional urban airshed model and evaluate prediction of SOA against observations.

Keywood, M. and M. Cope (2009), Development of Tools for the Identification of Secondary Organic Aerosol in Australian Cities. Report to Air Quality Section, Environment Standards Branch, Department of the Environment, Water, Heritage and the Arts 78 pp.
http://www.environment.gov.au/atmosphere/airquality/publications/pubs/tools-organic-aerosols.pdf

Keywood, M., H. Guyes, et al. (2011). "Quantification of secondary organic aerosol in an Australian urban location." Environmental Chemistry 8(2): 115-126.

### *Studies of the Secondary Organic Aerosol Component of PM2.5 Arising from the NEPM Air Toxic Precursors, Toluene and m-Xylene*

An account of 39 smog chamber experiments performed using toluene and m-xylene vapour. These experiments included a reactive organic carbon (ROC) matrix study comprising ROC/NOx regime and threshold experiments at three nitrogen oxides (NOx) concentrations of ~69, ~50, and 34 ppbv and four hydrocarbon concentrations of 89, 63, 34 and 13 ppbv. Five toluene/propene/NOx perturbation experiments and six secondary organic aerosol (SOA) collection experiments also were done. Field collection of PM2.5 aerosol was done over 3 days at Carlingford, a suburb of Sydney. An additional field sample collected at the NSW DEC Liverpool site by CSIRO Marine and Atmospheric Research (CMAR) was also acquired.

Angove, D. White, S., Keywood M. and Azziz M. (2009). Studies of the Secondary Organic Aerosol Component of PM2.5 Arising from the NEPM Air Toxic Precursors, Toluene and m-Xylene Report to Air Quality Section, Environment Standards Branch, Department of the Environment, Water, Heritage and the Arts 44p
http://www.environment.gov.au/atmosphere/airquality/publications/secondary-organic-aerosols.html

## 3. Fires/smoke

### Clean Air Research Program

### *Particles, Ozone, and Air Toxic Levels in Rural Communities during Prescribed Burning Seasons*

Information on air quality in rural Australia is sparse. Smoke from biomass burning such as the prescribed burning of forests, wildfires, and stubble burning often is blamed as the major source of air pollution in regional centres but there are few data on the significance of its impact. This study monitored air pollutants at four sites in rural Australia between 2006 and 2008. Fine particle concentration (PM2.5), ozone ($O_3$) and BTEX (benzene, toluene, ethylbenzene, and xylene) were monitored for 12 months at Manjimup WA, Ovens VIC, and Casuarina NT. PM10 was monitored at Wagga Wagga, NSW. The specific issues addressed in the study were:

1. The seasonal exposure of rural population centres, defined as centres with more than 1000 residents outside the State capital cities, to priority air pollutants resulting from prescribed burning or agricultural waste burning activities;
2. The contribution of emissions from prescribed burning to ambient ozone concentrations experienced by these communities; and
3. The extent to which ambient pollutants from prescribed burning penetrate into houses and, hence, the potential impact of smoke on the total (ambient and in-door) exposure levels of the resident population.

Meyer, C. P( Mick).; Reisen, F.; Luhar, A. K.; Powell, J. C.; Lee, S. H.; Cope, M. E.; Keywood, M. D.; Galbally, I. E.; Linfoot, S.; Parry, D.; McCaw, L., and Tolhurst, K. (2008). Particles, Ozone and Air Toxic Levels in Rural Communities during Prescribed Burning Seasons. Final report to Australian Commonwealth Department of the Environment, Water, Heritage and the Arts. CSIRO Marine and Atmospheric Research; 2008, 218 p.

http://www.environment.gov.au/atmosphere/airquality/publications/particles-ozone-toxic.html

Reisen, F., C. P. Meyer, et al. (2011). "Impact of smoke from biomass burning on air quality in rural communities in southern Australia." Atmospheric Environment 45(24): 3944-3953.

### *Measurement of real-world PM10 emission factors and emission profiles from woodheaters by in situ source monitoring and atmospheric verification methods*

Domestic wood heaters are a major source of particle (PM10) pollution in Australia. Most jurisdictions require wood heaters to comply with the Australian Standard for wood heater emissions (AS/NZ 4013), which includes a particle emissions limit of 4g per kg of wood burnt, but there has been growing concern that even compliant heaters frequently do not meet this limit when operated in homes.

The key issue for policy development for air quality and environmental health is the contribution that wood heaters make to ambient concentrations of particulate and gaseous pollutants. A comprehensive understanding of the factors that influence the contribution of wood heaters to ambient PM levels involves at least three steps: verifying the heater's design characteristics; determining in-service emission PM factors for wood heaters; and quantifying the contribution of wood heater emissions to the ambient PM levels.

This project was commissioned to investigate the second and third steps by measuring in situ the emission rates of wood heaters for a small selection of households in the Launceston air shed in Tasmania. The specific objectives were:

1. To provide an estimate of real-world emission factors for wood heaters in Launceston;
2. To provide an estimate of patterns of wood- heater use and PM10 emission rates; and
3. To assess whether CSIRO's transport model (TAPM) using in-service emission factors as determined through this study can predict PM concentrations in the Launceston airshed accurately.

Meyer, C. P. (Mick), Luhar, A. K.; Gillett, R., and Keywood, M. D (2008). Measurement of real-world PM10 emission factors and emission profiles from wood heaters by in situ source monitoring and atmospheric verification methods. Final report the Australian Commonwealth Department of the Environment, Water, Heritage and the Arts . CSIRO Marine and Atmospheric Research; 2008, 77 p.

http://www.environment.gov.au/atmosphere/airquality/publications/emission-factor.html

## Bushfire CRC

Smoke from bushfires and fires prescribed for fuel reduction, silviculture (tree farming), and biodiversity management are the largest source of air pollutants in Australia. The major pollutants in smoke besides PM are carbon dioxide ($CO_2$), carbon monoxide (CO), methane ($CH_4$), other volatile organic compounds, and oxides of nitrogen.

Bushfires are an annual occurrence around Australia and in the last seven years at least one major urban area has been impacted by smoke from uncontrolled fires (e.g. Hobart January 2013, Melbourne in February 2009, Canberra in 2003). The smoke exposure of the population in the region of a bushfire may be significant, for example during the 2006-7 fires CSIRO's air quality station at Aspendale recorded that smoke affected Melbourne for eight days with concentrations of PM2.5 matter reaching approximately 100 µg/m$^3$, which is four times greater than the 24-hour Air NEPM PM2.5 advisory.

Extensive occupational health, toxicological, and epidemiological studies have identified the major causes of acute health impacts from bushfire smoke as fine PM, CO, and a small group of respiratory irritants and carcinogens within the thousands of compounds comprising volatile organic compounds – principally, formaldehyde, acetaldehyde, acrolein, benzene, toluene, and some polyaromatic hydrocarbons (Reisen et al, 2013).

The degree to which each of these poses a health risk depends on their local concentration. Concentrations of CO and fine PM in fire zones commonly exceed the short-term occupational health standards and can be between 100 and 1000-fold higher than ambient air quality standards. The health effects of smoke are not just direct as smoke also affects other air-quality measures. Secondary chemical processes, particularly photochemical reactions, result in products such as ozone and ultrafine secondary organic aerosol that both pose potentially serious health risks. The impact of smoke on people remote from the fires may, on occasion, substantially exceed the direct injury to people within the fire zone. There is a lack of understanding and operational tools to understand the extent of these impacts or to manage them.

The non-lethal impacts of fine particulate matter haven't been quantified, and although available models are reasonably reliable, the framework required to bring together all the components for forecasting smoke dispersion hasn't yet been developed for Australia. Both are essential for managing the diffuse impacts of severe fires and both are now in development.

Meyer, C.P. (Mick), Reisen, F, Keywood, M. and Crumeyrolle, S. (2011). Impacts of smoke from regeneration burning on air quality in the Huon Valley, Tasmania, Final report to Forestry Tasmania, CSIRO Marine and Atmospheric Research, August 2011, 78 pp.

Reisen, F., C. P. Meyer and M. D. Keywood (2013). Impact of biomass burning sources on seasonal aerosol air quality. Atmospheric Environment 67: 437-447.

## 4. Modelling

Cope, M. and Lee, S. (2011). Exploring the co-benefit of electric vehicle uptake and ozone pollution reduction in Sydney. CAWCR Technical Report No. 042. www.cawcr.gov.au/publications/technicalreports/CTR_043.pdf

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