Air quality and health: looking ahead

Over the years significant progress has been made in understanding the relationship between air pollution and health, and in reducing emissions and human exposure.

Evolving scientific insights over the past twenty years

The past twenty years have seen major changes in the techniques and findings of studies on air pollution and health, changes which set today's stage for looking forward to what remains to be learned. Beginning in 1993 and 1995, with the publication of the first modern population studies of long-term effects of air pollution in the Harvard Six Cities Study (Dockery *et al.*, 1993) and the American Cancer Society (ACS) Study (Pope *et al.,* 1995), a number of studies published in North America and Europe have found associations with premature mortality and other health effects at lower and lower levels of ambient air pollution (Hoek *et al.,* 2013).

These two studies have received intensive independent reevaluation (Krewski *et al.*, 2000) and extended analyses in these two cohorts (Krewski *et al.,* 2009; Lepeule *et al.,* 2012) have become the main contributors to national and worldwide estimates of the potential health impacts of air pollution. This work has in turn been used to support public actions to reduce exposure to air pollution in a number of settings. Most recently these studies and others of higher exposures have been combined into an integrated exposure response curve that has served as the basis for estimates of the global burden of disease (GBD) for outdoor air pollution. These estimates place outdoor air pollution in the context of larger health risk factors associated with smoking and diet.

This evidence and actions have been accompanied, at the same time, by substantial progress in reducing both emissions from the main sources of air pollution and ambient levels of air pollution. Industry innovation in fuels and vehicle technologies have resulted in significant reductions in individual source emissions. Many of these changes (e.g. US 2010 and Euro VI emissions limits for heavy-duty engines) promise continued progress as new technologies come into use and older technology is retired from the vehicle fleet.

Looking ahead—key questions remaining

In spite of this progress, a number of important scientific questions remain that deserve attention as governments worldwide consider what further actions, if any, they might choose to take. Some of the key questions are discussed below.

Can health effects really be measured at very low pollutant levels?

The world has seen a trend in both the developed and developing world toward lower ambient air pollution standards and the emission control measures that come with them. This has included the establishment of air quality guidelines for particulate matter (PM), ozone, and other pollutants by the World Health Organization, the setting of increasingly stringent US ambient air quality standards for PM and ozone, the establishment of $PM_{2.5}$ standards by the European Union, and the establishment of the first standards for $PM_{2.5}$ in developing countries such as India and China.

These actions have been accompanied by substantial reductions in air pollution, but, as governments consider further regulations, important questions about the robustness of effects at very low air pollution levels remain. In large measure, this is due to significant constraints on the statistical robustness of analyses done at the lowest levels of air pollution where fewer people are exposed. To address these issues for ozone, the Health Effects Institute (HEI) is supporting an extensive, multi-centre, controlled human exposure study of the effects of exposure to low levels of ozone on the cardiovascular system in 90 older subjects. This Multicenter Ozone Study in Elderly Subjects (MOSES) is designed to have sufficient rigor and statistical power to determine whether effects can be seen at the lowest levels.

In the epidemiologic area, a new study of 2.1 million Canadians offered better statistical robustness and suggested evidence for associations between cardiovascular and other mortality causes at $PM_{2.5}$ levels as low as 8.5 μg/m^3 (see Figure 1). This level is well below even the current WHO air quality guideline. The Canadian study began to take advantage of emerging techniques for using big data to address these questions. It is only one study, however, and did not evaluate some important health-related information on the subjects (e.g. their smoking behaviour). Substantial new efforts to test this concentration-response relationship at these low levels will be important.

Figure 1 The shape of the Canadian concentration-response function for $PM_{2.5}$

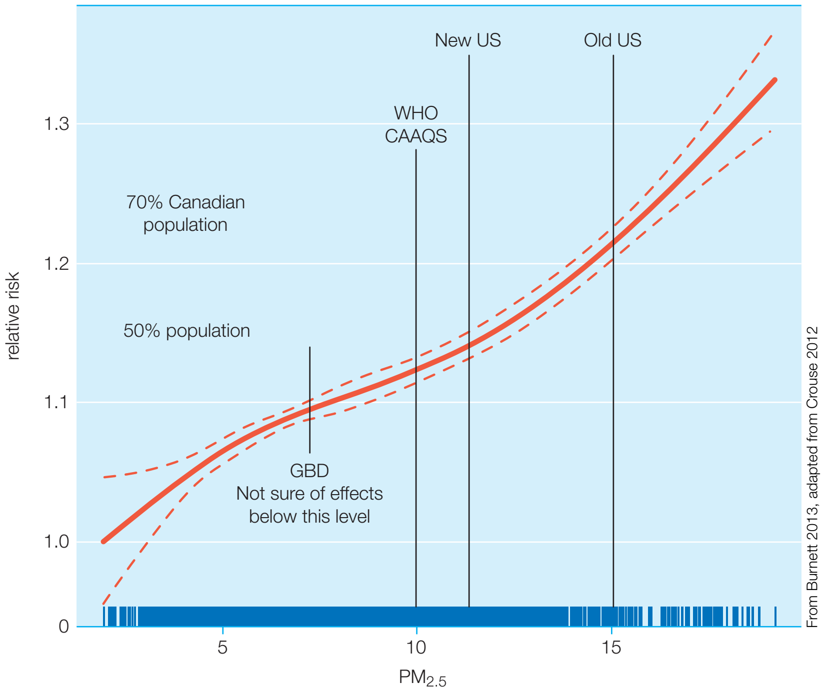
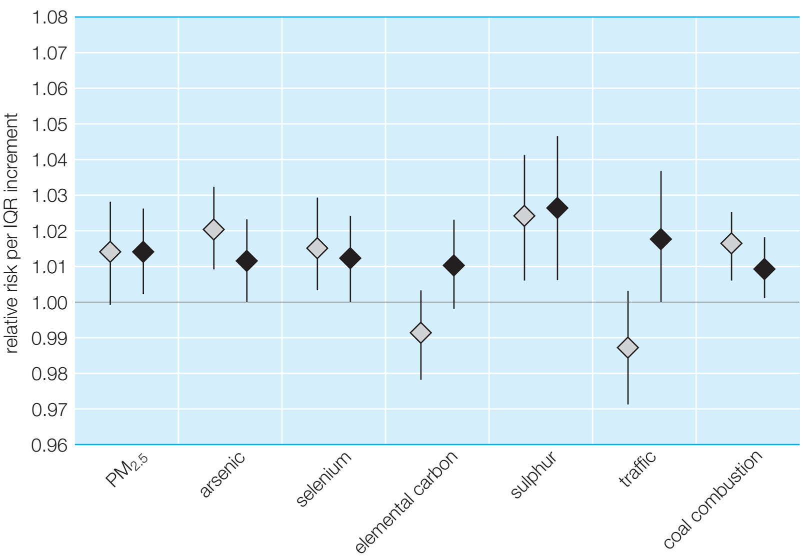


Figure 2 NPACT Study: relative $PM_{2.5}$ mortality risks from all causes



The results presented in Figure 2 are those that demonstrated the most consistently positive associations; the remaining results were not positive or significant. The grey and black diamonds depict results from the random effects Cox models without and with contextual ecologic covariates, respectively. Note that the IQR (interquartile range) varied by pollutant; e.g. the IQRs for $PM_{2.5}$ and sulphur were 3.13 µg/m^3 and 0.53 µg/m^3, respectively.

Are some PM components or sources more or less toxic?

PM is well understood to be a highly complex mixture of organic and inorganic components that are emitted from many sources. PM can be formed from both primary emissions and from secondary reactions with other gases in the atmosphere. One of the significant questions about the potential health effects of PM comes from this complexity of sources and composition.

A number of individual studies have used toxicologic or epidemiologic techniques to examine whether certain PM components or sources might contribute more to human toxicity than others, but no systematic, multidisciplinary approaches had been used until recently. In October 2013, HEI published results of its National Particle Component Toxicity (NPACT) study, which is the most systematic effort to date to combine epidemiologic and toxicologic analyses in an attempt to answer these questions. The NPACT study found health effect associations between secondary sulphate and, to a lesser extent, traffic sources (see Figure 2). But the HEI NPACT Review Panel, consisting of 14 experts who had no prior role in the study, concluded that:

> *"… the studies do not provide compelling evidence that any specific source, component, or size class of PM may be excluded as a possible contributor to PM toxicity. If greater success is to be achieved in isolating the effects of pollutants from mobile and other major sources, either as individual components or as a mixture, more advanced approaches and additional measurements will be needed so that exposure at the individual or population level can be assessed more accurately. Such enhanced understanding of exposure and health will be needed before it can be concluded that regulations targeting specific sources or components of $PM_{2.5}$ will protect public health more effectively than continuing to follow the current practice of targeting $PM_{2.5}$ mass as a whole."*
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> (Lippmann *et al.*, 2013, Vedal *et al.*, 2013).

Clearly, more work and new approaches will be needed to continuously improve our understanding of the effect of $PM_{2.5}$ on human health.

What about health effects due to traffic exposure?

Although substantial progress has been made in reducing emissions from modern vehicles, many studies continue to assess the potential health effects of exposure to traffic. As HEI concluded in its Special Report no. 17, *Traffic-Related Air Pollution: A Critical Review of the Literature on Emissions, Exposure, and Health Effects* (HEI, 2010), only a small number of these studies were conducted in a way that accurately characterised traffic exposure. However, attention to the effects of such exposures is likely to increase as government officials in both the EU and USA turn to roadside monitoring of PM and nitrogen dioxide to measure compliance with ambient air quality standards. With this emphasis, there is a strong and continuing need for better techniques to accurately estimate population exposure to traffic, and to better understand the relative contribution of traffic compared to other sources. Recently, HEI solicited applications for studies aimed at 'Improving Assessment of Near-Road Exposure to Traffic Related Pollution' and has identified a number of studies of this important topic which are expected to move forward in the coming year.

What is the future of diesel vehicle technology?

Diesel engines have long offered significant power, endurance, and reliability benefits. In recent times, as GHG reduction issues have grown in importance, they are increasingly valued for their better fuel efficiency compared to gasoline engines. Emissions regulations in both the USA and Europe have also resulted in substantially lower emissions of regulated pollutants. There are, however, two important aspects where issues remain regarding the future of diesel engine technology in spite of this progress:

- Recent occupational studies of exposure to exhaust emissions from older diesel engines in mining and trucking environments have been cited by the International Agency for Research on Cancer (IARC) as a major rationale for upgrading diesel exhaust emissions from a probable human carcinogen to a Group 1 human carcinogen (IARC 2012). This escalation has resulted in careful scrutiny of the exposure in these studies and the suitability of these studies for quantitative risk assessment.
- Advances in new technology diesel vehicles, using diesel particulate filters, advanced NO_x control, and other enhancements, is substantially reducing diesel exhaust emissions compared to the older technology evaluated by IARC. These newer engines are being rigorously tested in the Advanced Collaborative Emissions Study (ACES) conducted by HEI and the US Coordinating Research Council. Initial results from this study have shown dramatically lower emissions and few health effects; final testing and analysis is in progress.

Together, these developments suggest that substantial progress is being made to advance the use of diesel engine technology. This can be done while also facing the developing world's challenge where vehicle regulations and fuel sulphur levels do not yet enable the introduction of the latest engine and aftertreatment technologies. The continuing need to document advances in these new vehicle technologies and fuels will be aided substantially by the upcoming publication in 2014 of all ACES' results for emissions and health, including rigorous comparison to health results from earlier diesel experiments. Continuing communication of these results will be required to ensure that the newest diesel vehicle technologies are introduced worldwide.

How do we know if we are making progress?

Assessing accountability of health outcomes

After more than 30 years of actions to improve air quality, one important question to ask is whether we can, after some time has passed, prove whether an action taken to improve air quality has had the predicted positive effects on ambient air pollution and health. This area of investigation has been growing in recent years, with HEI taking a leadership role in defining the field of health outcomes, or 'accountability' research. This has been done by defining the key approaches, and then funding and completing nine studies covering a range of interventions, from congestion charging zones to wood stove 'change outs'. These studies have included, for example, an analysis of London's congestion charging zone which found improvements in traffic but not in air pollution. Another study evaluated bans on coal use implemented across a number of Irish cities, and found that there was no improvement in cardiovascular health beyond that which could be attributed to broader changes in cardiovascular care and health, although there were improvements in air quality and respiratory health. HEI has four more similar studies in progress evaluating broader transport and stationary sources policies. These types of studies will play an increasingly important role as air quality regulations are tightened and the likely benefits of additional actions become smaller.

Progress, but there is more to be learned

The past decades have seen much progress in better understanding the relationships between air pollution and human health, and, importantly, in reducing emissions and human exposure. In spite of this progress, important scientific questions remain about exposures and health effects, and about the effectiveness of government actions taken to address these exposures and inform future decisions on air quality in Europe and the rest of the world.

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Dan is President and Chief Executive Officer of the Health Effects Institute (HEI), an independent research institute that provides public and private decision makers around the world with high-quality, relevant and credible science about the health effects of air pollution and at the air-climate interface. He leads HEI's efforts, supported jointly by government and industry to provide public and private decision makers—in the USA, Europe, Asia and Latin America—with high quality, impartial, relevant and credible science about the health effects of air pollution to inform air quality decisions in the developed and developing world. He has been a member of the U.S. National Research Council Board of Environmental Studies and Toxicology and vice chair of its Committee for Air Quality Management in the United States. He recently served on the NRC Committee on The Hidden Costs of Energy. He serves as well as Chair of the Board of the International Council on Clean Transportation (ICCT).

Dan has more than three decades of governmental and non-governmental experience in environmental health. He served as Commissioner of the Massachusetts Department of Environmental Protection from 1988 to 1994, where he was responsible for the Commonwealth's response to the Clean Air Act, as well as its award-winning efforts on pollution prevention, water pollution and solid and hazardous waste. He holds Bachelor's and Master's degrees from MIT in City Planning.

Robert is Vice President of the Health Effects Institute. He is responsible for management of key programmes, including the Institute's international programme to assess the health effects of air pollution in developing countries, and leadership in implementing HEI's ongoing research and review programmes on the health impact of particulates, ozone air toxics and other pollutants, and emerging technologies and fuels, including those driven by climate concerns. He oversaw the Institute's efforts to define and implement a programme of research on Accountability, a first-of-its-kind programme designed to understand the health impacts of environmental regulation. He is regularly called on to address prominent institutions, including the US Congress, the European Parliament, the National Academy of Science's National Research Council and Institute of Medicine and many other domestic and international bodies. Prior to coming to HEI he served for nine years at the Massachusetts Department of Environmental Protection, as Assistant Deputy Commissioner for Policy and Program Development and as Director of Planning and Budget. He is currently a member of the USEPA's national Clean Air Act Advisory Committee and is Chair of the Board of Directors of the Clean Air Initiative for Asian Cities.

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