Health Effects of Air Pollution: The Struggle for Context

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No question about it—air pollution continues to impact public health in the U.S., and the magnitude of that impact undoubtedly warrants further reductions of these emissions. Despite the downward trend in levels of most routinely-measured pollutant species over the last 20 years, statistical correlations between variations in air quality and adverse health outcomes can apparently be found whenever sought, given a database of sufficient size. Indeed, in large-scale epidemiology studies, the spectrum of health impacts attributed to outdoor air pollution is expanding, and pollution levels at which the associations are observed are falling, with no threshold in sight.

However, it is still not easy to parse the evidence into its component parts, e.g., the reasonableness, limitations, and interpretive value of the statistical treatments of epidemiological data, the contributory roles of the hundreds of air contaminants and their sources, and the relative importance of pollution-related health burdens within the spectrum of all causes of the same effects. Despite these uncertainties, it seems clear that air pollution is still an issue deserving our attention.

Air pollution has long been blamed for respiratory disorders ranging from minor irritation, to hay fever, allergies, aggravation of asthma, decreased lung function, increased respiratory illnesses, to, at its most extreme, lung cancer and even episodes of high death rates (e.g., the oft-cited Donora and London incidents). More recent studies have also demonstrated a connection between air pollution and premature birth, infant mortality, impairment of lung growth, shortened life span, altered heart and vascular function, and incremental increases in daily deaths from both respiratory and cardiac causes. Disturbingly, these associations are not just evident from unusually extreme pollution episodes, but are detected within the range of common day-to-day fluctuations in pollutant levels.

It seems that the closer we look—with better exposure documentation, more sensitive measures of health effects, larger study populations, increased focus on the most susceptible groups, and sophisticated new statistical analysis methods—the more problems we find. Moreover, we are finding problems at levels of some pollutants that approach "background," a concept much more difficult to define than one might think.

With no end in sight to the paradoxical increase in incriminating evidence in the face of generally improving air quality, it is high time that we stepped aside and contemplated the problem from a more integrated perspective that can put the air quality-health relationship into a clearer context. Failing to do so creates an increasing risk of making unwise decisions. However, doing so will require some "out of the box" thinking because, despite the obvious improvements, our current air quality regulatory-research paradigm does not facilitate "context."

Under the current version of the Clean Air Act, a few "criteria" pollutants drive most air quality debates and research initiatives. Under Sections 108 and 109, we (you will recall that the laws of our land are ultimately driven by we citizens) identify "criteria" pollutants that are "reasonably anticipated to endanger public health and welfare," and require EPA to establish "scientific criteria" for their effects, promulgate

primary (health-based) and secondary (welfare-based) National Ambient Air Quality Standards (NAAQS), and review the standards at five-year intervals with public input and peer review by the Clean Air Scientific Advisory Committee (CASAC). Criteria pollutants now include lead, sulfur dioxide, carbon monoxide, ozone (as the indicator for photochemical oxidants), nitrogen dioxide (as the indicator for nitrogen oxides), and particulate matter (in multiple respirable size classes). Because the NAAQS are the greatest motivators of federal, state, and local air quality policies, which, ultimately, focus on source emissions, and because one or more standards are almost always under spirited debate, despite our selectively ignoring the five-year review requirement, criteria pollutants absorb most of our attention and research resources. Today's successful application for air pollution research funding, for example, will most likely have some derivative of the word "particle" in the title.

A larger group of air contaminants and classes (currently 188) termed "hazardous air pollutants" (HAPs), or "air toxics" is addressed under Section 112 of the Clean Air Act. In contrast to the criteria pollutants, HAPs are managed by emission standards, rather than air concentrations. The review and promulgation of these standards receives little widespread public attention, rarely involves CASAC, and is only a minor driver of national debates and research agendas. EPA has initiated a process to periodically review exposures to, and risks from, HAPs, termed the "National Air Toxics Assessment." The most recent Assessment, drafted in 2001, reviewed 1996 data, and has caused little national stir, although it raises important issues. For example, even in Northeastern cities, EPA estimates that off-road sources are principally responsible for population exposure to diesel emissions. Even among the 188 HAPs, the 1996 Assessment limited its focus to only 33 species EPA identified as priority pollutants, or "Urban Air Toxics."

Focusing our attention and research efforts on just a few outdoor species among 39 criteria pollutants and Urban Air Toxics, generated largely by human activity, denies the reality that we all breathe hundreds, if not thousands, of indoor and outdoor air contaminants from man-made and natural sources every day. True, we don't have the understanding, research or management tools, or regulatory structure to deal with the integrated effects of all air pollutant exposures, but we should acknowledge that as the ultimate goal we should strive to achieve. We have sufficient evidence to conclude that we should be facing this dilemma more openly.

We know that the effects of at least some pollutants are not additive; that is, the effects of breathing a mixture cannot be predicted from the effects of breathing these components individually. We also know that air contaminants that receive little or no national attention, such as plant pollens, exert sizable health burdens. Try to convince someone suffering from hay fever or allergic asthma that tailpipes and smokestacks are the source of all pollutant evils! We know, or, at least, it appears to becoming clear, that exposures to combinations or sequences of man-made and natural air contaminants may be important (e.g., combustion emissions amplifying reactions to plant allergens). There is no question that all of us, even those of us with outdoor occupations, spend the majority of our time indoors, that air pollution generated both indoors and outdoors crosses the threshold in both directions, and, that our health is affected by both environments. Moreover, Section 103 of the Clean Air Act calls for research on "complex mixtures of air pollutants" and on health risks from exposures to both individual pollutants and "combinations thereof." It's time to stop ignoring that mandate.

We also have sufficient information to do a better job of placing the health burden of air pollution— and, thus, the contributions from its components and sources—into a clearer context within the total scope of health risks faced in today's world. Doing so, understandably, flies in the face of the standard approach of advocating for air quality policies, which isolates this concern from other health concerns through divisions of oversight among agencies, and then places value on emphasizing the effects of the "pollutant du jour" over the effects of other pollutants.

A thoughtful consideration of the relative public health importance of a pollutant, or air pollution in general, might follow a "top down" approach, beginning with a bounding analysis that estimates the plausible portion of the total burden of an effect (e.g., premature death, coronary vascular disease, or lung cancer) in context of all plausible contributions from confirmed or presumed sources of risk. Too often, the "bottom up" approach of estimating the (typically upper bound) risk from each source of risk (e.g. an air pollutant) results in estimated health burdens that well exceed reality for the population. While this situation is accepted by many as a reasonable outcome of the way we estimate risks, it is high time that we begin constraining our portrayal of risks within the bounds of the total public health burden.

So what should we do? In the air pollution arena, as in other fields of public policy where there is considerable uncertainty, it is much easier to cast stones than to offer sound alternatives. Any stones should be cast lightly. To the credit of our present system, it seems clear that our air quality regulatory/research paradigm has produced benefits, however difficult to quantify. But there is growing support among regulators, the regulated, and the scientific community (which is both), for the notion that we should not be viewing and managing the air quality-health relationship 20 years from now as we are today. It's time for a paradigm shift.

I suggest two paths forward. First, estimates of the magnitudes of health burdens from individual air pollutants (or sources) should include bounding

analyses that place, as best we can, that pollutant's contribution to the total burden of the health effect, and the most likely magnitudes of contributions from other air pollutants and non-polluting risk sources. Second, we need to move toward research strategies that place a premium on understanding the integrated effects of multiple pollutants and sources; i.e., adopt a multi—rather than a single—pollutant focus. Federal air quality research programs need to be structured to encourage atmospheric scientists, exposure specialists, epidemiologists, laboratory scientists, and risk modelers to conduct integrated work that clarifies the contributions of different natural and man-made air contaminants and sources—and their combinations—to the total public health burden. While research defining the actions of single pollutants will continue to be needed, it should be framed within an overall programmatic context of clarifying hazards and risks from air *pollution*, not from single air *pollutants*.

Shifting the air quality research paradigm will require considerable foresight and determination. Inertia of the single-pollutant focus is understandably strong. Whether or not—and how and to what extent—we should change the air quality regulatory paradigm is not yet clear. The Clean Air Act is not the problem. It has done considerable good, and legislation is a human product that can be created, terminated, or modified as needed when we have adequate knowledge on which to act. However, we need to get the air pollution research "horse" in front of the legislative "cart," rather than in its present position behind. We need to weave the atmospheric and health scientists together into a coordinated research strategy that acknowledges the whole truth about air pollution. It's time to take a step forward and begin thinking about, and studying, air pollution and its health impacts from a more integrated, multipollutant perspective.

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A veterinarian by training, Mauderly began his career as a comparative respiratory physiologist, studying interspecies differences in lung function, lung aging, and the health hazards from a wide range of occupational and environmental air contaminants, with particular emphasis on engine emissions. The past director of the Inhalation Toxicology Research Institute, a government-owned laboratory operated by Lovelace, he is also past chair of the Clean Air Scientific Advisory Committee of the EPA Science Advisory Board (SAB), and was a member of the SAB committee that reviewed the 1996 National Air Toxics Assessment, and chair of a workshop to review approaches to assessing risks from polycyclic aromatic hydrocarbons.

Mauderly is a member of the National Research Council Committee on Research Priorities for Airborne Particulate Matter, and recently chaired the NRC committee to review the NARSTO assessment of the atmospheric science of particulate matter. He holds adjunct professorships in Medicine and Pharmacy at the University of New Mexico, and serves on the advisory boards of several university research centers and the NIOSH National Occupational Research Agenda Mixed Exposures working group, as well as the editorial board of *Experimental Lung Research*.