

# COMMENT

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China's cities are among the world's worst in terms of air quality.

## China's choking cocktail

Cleaning up city and indoor air will require a deeper understanding of the unprecedented chemical reactions between pollutants, says **Markku Kulmala**.

**D**irty air threatens the health of billions of city dwellers around the world. China's megacities are among the worst, with concentrations of airborne pollutants 10–100 times higher than those in Europe or North America, and occasionally even 1,000 times higher. An estimated 2.5 million people in China die each year from the health effects of indoor and outdoor air pollution<sup>1,2</sup>.

Efforts to improve air quality are targeting only the tip of the iceberg. Cities such as Beijing routinely measure levels of particulate matter measuring 10 micrometres (PM<sub>10</sub>) and 2.5 micrometres (PM<sub>2.5</sub>) in size, as well as a few gases such as sulfur dioxide (SO<sub>2</sub>), nitrogen oxides (NO<sub>x</sub>), carbon monoxide (CO) and ozone. But urban air is a complex cocktail of chemicals whose poorly understood interactions and feedbacks

may exacerbate health problems. Efforts to reduce one pollutant can have perverse effects on others as conditions change.

The chemistry of China's polluted urban air is unprecedented. Higher populations, heavier industries and modern goods manufacturing, as well as the climatic conditions, make Beijing's smogs markedly different from the 'pea soupers' that afflicted London and other European cities ▶

► 50 to 100 years ago. Many atmospheric processes are nonlinear — meaning that the relationship between cause and effect is not proportional. So we do not know and cannot predict which harmful compounds are being formed. Whenever my colleagues and I make measurements with new instruments in China, we find unexpected results. Indoor air quality is equally affected.

The nation's urban air can begin to be cleaned only if a comprehensive monitoring and modelling approach takes atmospheric chemistry into account. To guide decisions, we need to know which hazardous pollutants are present and how they interact to generate secondary pollution.

Here I outline a road map for bringing China's cities up to European air-quality standards within a decade. Actions towards cleaner air, as well as improving health (see 'Deep clean'), will reduce greenhouse-gas and black-carbon (soot) concentrations and enhance freshwater quality<sup>3</sup> and food supply.

### TOXIC MIX

China's air pollution has worsened as emissions from industry, energy production and traffic have grown. China is responsible for 30–35% of the global SO<sub>2</sub>, NO<sub>x</sub>, CO and particulate emissions, and 40% of global particle numbers (PN) in the 20–1,000-nanometre size range (see [go.nature.com/uw3jx6](http://go.nature.com/uw3jx6)). The nation's share of global greenhouse-gas emissions is 29% for carbon dioxide and almost 20% for methane.

Government efforts are under way to reduce the emissions of all these.

*“As outdoor air gets cleaner, indoor air quality might even worsen.”*

But it is impossible to reduce secondary pollutants such as ozone and organic aerosols without a deep understanding of the chains of chemical reactions and physical processes that pollutants undergo. The formation and decay of secondary pollutants depend on temperature, humidity and wind speed as well as other chemicals and particles in the urban atmosphere. There is so much that we do not know. Results are hard to predict because many physical and chemical processes — such as surface chemistry, oxidation, clustering and dynamical effects — happen simultaneously<sup>4</sup>.

Attempts to control one pollutant can increase the concentration of others. Measurements in Nanjing, for example, show<sup>5</sup> that reducing NO<sub>x</sub> emission could cause a tenfold increase in summer ozone concentrations. Reducing smog increases sunshine levels and temperatures, and alters rain and snowfall patterns<sup>6</sup>.

Surprising reactions are going on above Chinese cities that do not occur in cleaner air. For example, small atmospheric



ADAM DEAN/THE NEW YORK TIMES/EYEVINE

Pollutant levels inside Chinese homes can be hundreds of times higher than those in European homes.

molecular clusters (measuring 1–3 nanometres) are tens of times more concentrated in Shanghai, Nanjing and Beijing than in European cities. Secondary aerosols (containing sulfates, nitrogen compounds and organics) form more readily in Shanghai and Nanjing than existing models predicts<sup>7</sup>. Unknown chemical pathways and physical processes must be occurring<sup>8</sup> that could create new types of oxidant or change the surface properties of aerosols, limiting their ability to take up condensable vapours.

Indoor air quality is also a problem. City dwellers spend more than 90% of their time indoors, particularly if outdoor air quality is poor. Cooking, smoking, heating and furnishings release PM, PN, CO, volatile organic compounds (VOCs) and NO<sub>x</sub>,

adding to pollutants drawn in from outside. Little is known about the pollution levels in Chinese homes, but my team's preliminary findings indicate that concentrations of some pollutants are higher than those outdoors (especially for PN and VOCs) and 100–1,000 times higher than inside European homes. My colleagues and I estimate that indoor air pollution contributes almost as much as outdoor smog (which causes more than 1.3 million deaths per year) to the pollution-related death toll.

Again, little is known about the secondary production of chemicals indoors. Ventilation systems filter large particles but not gases such as VOCs, NO<sub>x</sub> and SO<sub>2</sub>, which can go on to form ultrafine sulfates, nitrates and organic particles. The risk of secondary aerosol production from these gases rises in filtered air because there are fewer grains on which to condense. As outdoor air gets cleaner, indoor air quality might even worsen.

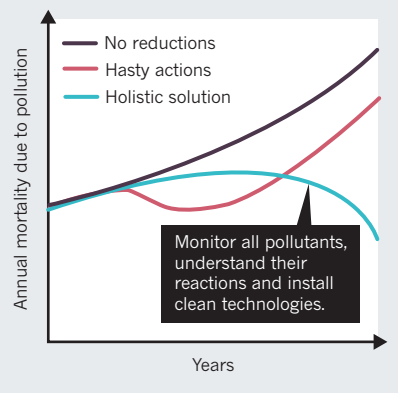
### CLEARING THE AIR

It is important to continue efforts to cut pollution. But meeting the Chinese central government's goal of improving urban air quality to levels typical of the United States and Europe requires more: simultaneous tracking of all air pollutants relevant to health and their feedbacks and interactions — over at least a decade. We need to understand how the mixture and its toxicity changes as air quality measures are implemented. Short campaigns are not sufficient.

Central and regional governments, research institutes and universities should collaborate to do the following, with help

### DEEP CLEAN

Deaths from air pollution will rise as cities and industries expand. Limiting single pollutants will buy time, but only a concerted effort will clean China's urban air for good within a decade.



SOURCE: M. KULMALA/P. PAASONEN, UNIV. HELSINKI



from atmospheric chemists from around the world.

First, establish and fund a network of 'flagship' stations<sup>9</sup> to monitor: concentrations, fluxes, interactions and feedbacks as well as more general air quality and meteorology data. Around 5–8 such stations (costing between US\$7 million and \$11 million each) would suffice for a major city. These should be complemented by mobile measurement platforms on cars and aeroplanes, remote sensing of air columns from the ground, satellite observations and smog chambers. Major sources of pollutants can be identified using historic data.

Second, indoor air-quality measurements and monitoring must be conducted concurrently in a representative selection of residential and office buildings.

Third, atmospheric chemists must model secondary-pollutant production pathways and feedback mechanisms under high concentrations of various pollutants. These models must then be compared with observations.

Fourth, the links between air pollutants and mortality and other health effects need to be established. That way the most health-relevant pollutants and their sources can be identified and mitigated first. A database should be developed to track health impacts.

Fifth, long-term sustainable engineering solutions such as improving processes and material flows in industry must be implemented to maintain low levels of air pollution. This will require capacity building across the Chinese authorities and institutes on using air-quality assessment data in decision-making, in developing legislative tools and in clean-air action plans.

Only by understanding atmospheric chemistry will China clean its air. ■

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The mysterious Indus unicorn on a roughly 4,000-year-old sealstone, found at the Mohenjo-daro site.

# Cracking the Indus script

**Andrew Robinson** reflects on the most tantalizing of all the undeciphered scripts — that used in the civilization of the Indus valley in the third millennium BC.

The Indus civilization flourished for half a millennium from about 2600 BC to 1900 BC. Then it mysteriously declined and vanished from view. It remained invisible for almost 4,000 years until its ruins were discovered by accident in the 1920s by British and Indian archaeologists. Following almost a century of excavation, it is today regarded as a civilization worthy of comparison with those of ancient Egypt and Mesopotamia, as the beginning of Indian civilization and possibly as the origin of Hinduism.

More than a thousand Indus settlements covered at least 800,000 square kilometres of what is now Pakistan and northwestern India. It was the most extensive urban

culture of its period, with a population of perhaps 1 million and a vigorous maritime export trade to the Gulf and cities such as Ur in Mesopotamia, where objects inscribed with Indus signs have been discovered. Astonishingly, the culture has left no archaeological evidence of armies or warfare.

Most Indus settlements were villages; some were towns, and at least five were substantial cities (see 'Where unicorns roamed'). The two largest, Mohenjo-daro — a World Heritage Site listed by the United Nations — located near the Indus river, and Harappa, by one of the tributaries, boasted street planning and house drainage worthy of the twentieth century AD. They hosted the world's first known toilets, along with ▶