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Our Lethal Air

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The Invisible Killer: The Rising Global Threat of Air Pollution—and How We Can Fight Back
by Gary Fuller
Melville House, 304 pp., $26.99

Choked: Life and Breath in the Age of Air Pollution
by Beth Gardiner
University of Chicago Press, 290 pp., $27.50

Clearing the Air: The Beginning and the End of Air Pollution
by Tim Smedley
Bloomsbury Sigma, 320 pp., $28.00

Integrated Science Assessment for Particulate Matter (External Review Draft, 2018)
United States Environmental Protection Agency

Letter to EPA Administrator on the EPA's Integrated Science Assessment for Particulate Matter, April 11, 2019
Review by the Chartered Clean Air Scientific Advisory Committee

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In December 1952 a dense, choking, particle-laden fog settled on London and didn't budge for four days. So many people suffered respiratory problems, heart attacks, and strokes that the city ran out of hospital beds. Coroners and undertakers could barely keep up with the flow of bodies. A government analysis in the immediate aftermath estimated that the atmospheric muck—mostly produced by the burning of low-quality coal to heat homes—caused nearly four thousand deaths. In 2002 a more thorough analysis

Bloomberg/Getty Images

Smog in Prayagraj, Uttar Pradesh, India, January 2019

concluded that the “Great Smog” had killed 12,000 people, most of them over forty-five or very young.

Gary Fuller dedicates *The Invisible Killer*, his new book about the persistent global scourge of air pollution, to the smog’s victims, who “have no memorial.” But, as his own book makes clear, one could argue that their memorial is the United Kingdom’s Clean Air Act. Passed in 1956, in direct response to what Fuller calls “the UK’s greatest peacetime disaster,” it restricted the use of dirty heating fuels and established “smoke-free” zones where only smokeless fuels could be burned. Despite its flaws and halting implementation, the law heralded a new era of government action to clean up outdoor air, driven by the growing recognition that air pollution was more pervasive, more deadly, and more human-caused than had been assumed.

During the same period, people across the United States, from Los Angeles to Pittsburgh to New York, were growing tired of chronic coughs, driving with headlights on during noontime haze, and perpetually dusting soot from their windowsills. Under public pressure, politicians passed a series of modest clean air laws in the 1950s and 1960s. These paved the way for the 1970 Clean Air Act, a sweeping piece of legislation that required the newly created Environmental Protection Agency to use the best available science to set and enforce limits on six major pollutants at levels that would allow “an adequate margin of safety…requisite to protect the public health.”

Slowly, power utilities, car manufacturers, and other polluters were compelled to meet these new limits. The law gave the EPA the authority to control vehicle tailpipe emissions and fuel additives, and to require new power plants and industrial facilities to use the best available pollution-control technology. States were responsible for enforcement, overseeing permitting and issuing fines—but if states failed to meet air quality standards, the federal government could take over with its own plan. Gradually, overall levels of particulate matter, ozone, and other pollutants in the air began to decline. By the 1990s, many people in the US and other wealthy countries thought that sun-blotting soot and smog were hazards safely surmounted in the onward march of progress, concerns of a past era like polio or cholera.

It turns out the threat had simply become less visible. Nearly half a century after the Clean Air Act instituted the world’s most stringent emissions controls, the problem of air pollution is far from being solved in the US or anywhere else. Pollution has proved much more persistent, and exposure to it much more damaging, than anyone expected. Today, 91 percent of people worldwide live in areas where air pollution levels exceed the World Health Organization’s recommended limits.

The result is a global health emergency, as three new books—Fuller’s *The Invisible Killer*, Beth Gardiner’s *Choked*, and Tim Smedley’s *Clearing the Air*—reveal in sobering detail.

Each recounts how decades of careful scientific study have brought the extent of air pollution's wreckage into clearer view. As Gardiner writes, "the science keeps moving on, and the list of maladies pegged to dirty air continues to grow."

The Six Cities Study, a piece of decades-spanning research led by Harvard epidemiologist Douglas Dockery, is so foundational to modern air quality regulation that Fuller devotes an entire chapter to it. Starting in 1974, researchers followed over eight thousand people randomly selected from three more polluted and three less polluted US cities. They gathered information on height, weight, and health conditions via questionnaires and periodic interviews and tracked deaths over the years. When they analyzed the mountain of data, applying statistical methods to control for other variables, they found that adult residents of the dirtiest cities (e.g., Steubenville, Ohio) were dying two to three years earlier on average than those in the cleanest (e.g., Portage, Wisconsin). Among all the pollutants they studied, the relationship with premature death was most clear and pronounced for particulate matter less than 2.5 microns in diameter (PM2.5), a category that encompasses soot (black carbon), dust, sulphates and nitrates, and a wide range of other substances suspended in the air.[1]

Dockery and his colleagues were so surprised by the magnitude of the difference between cities that they re-checked their data, and then checked it again. Part of what shocked them was that, more than twenty years after the Clean Air Act was passed, air pollution was still killing people in significant numbers, even in cities that met federal air quality standards.

Their mortality findings, published in 1993, led directly to new ambient air pollution standards in 1997 that tightened limits on PM2.5 concentrations. "Dockery's revolutionary findings changed our perspective of air pollution even more profoundly than London's 1952 smog," Fuller writes. These studies have also yielded another bedrock finding: there is no safe level of exposure to fine particulate matter. Any amount of these tiny particles can harm you.

Air pollution cuts short the lives of far more people in the US each year—estimates range from 107,500 to over 200,000—than do traffic accidents. Together, indoor and outdoor air pollution caused one in every nine deaths globally in 2016—far more than the number felled by malnutrition, alcohol use, or malaria.

The bulk of all that damage, as Smedley explains in a dense but illuminating early chapter of *Clearing the Air*, can be traced to PM2.5. Most of these fine particles are a byproduct of our civilizational dependence on burning stuff: coal, gasoline, diesel, wood, trash, you name it. These particles can get past the defenses of our upper airways to penetrate deep into our lungs and reach the alveoli, the tiny air-filled sacs where oxygen is exchanged for carbon dioxide. From there, they cross into the bloodstream and spread throughout the

body. They can travel through the nose, up the olfactory nerve, and lodge themselves in the brain. They can form deposits on the lining of arteries, constricting blood vessels and raising the likelihood of blockages that lead to strokes and heart attacks. For decades, scientists have understood that they exacerbate respiratory illnesses like asthma and chronic obstructive pulmonary disease, but—as with tobacco smoking—the biological mechanisms have been elusive. It is now thought that much of the havoc PM2.5 wreaks is through systemic inflammation, caused by an overreaction by the immune system.

Scientists keep learning that there is no part of the body that these particles cannot reach, and no phase of life, from gestation to advanced age, they do not touch. Last year, researchers found inhaled soot particles in the placentas of five women who gave birth in London hospitals. In *Choked*, Gardiner interviews Beate Ritz, an epidemiologist at UCLA who has led groundbreaking studies of air pollution's links with adverse birth outcomes. When she first started analyzing data in the early 1990s, Ritz was motivated by her own experience giving birth to an underweight child while living next to a busy freeway. Since her early studies on the subject, a large body of literature has developed showing strong associations between air pollution exposure and a wide range of adverse pregnancy outcomes, including low birth weight and prematurity, as well as child cancers and even autism. There's also convincing evidence linking air pollution exposure to an increased risk of Alzheimer's and other forms of dementia.

These three books use very different vehicles to cover much of the same historical, geographic, and scientific ground. Smedley's *Clearing the Air* is light on narrative but stuffed with alarming data, a stitched-together collection of lightly edited mini-lectures from dozens of scientists, health experts, clean air advocates, and officials, punctuated by brief personal asides and vignettes. Gardiner's *Choked* is a more reader-friendly travelogue of the world's contemporary pollution hotspots, each chapter examining either a specific ingredient of the global air pollution stew (the San Joaquin Valley for agricultural pollution, Krakow for coal smoke, Los Angeles for ozone) or a particular set of solutions. Fuller, an air pollution scientist, writes with crisp, accessible authority on the evolution of awareness and knowledge of air pollution since medieval times. He is an excellent guide to the work of the ingenious and almost absurdly persistent scientists in the nineteenth and early twentieth centuries who invented the first devices to capture, count, and measure particles in the air, and to the efforts of twenty-first-century researchers to understand the complex chemistry of diesel exhaust on the streets of London and beyond.

Each author recounts the requisite famous, acute events—London's Great Smog, the recurring haze that plagued Los Angeles in the 1940s, Beijing's terrifying two-week-long smog in January 2013 (dubbed the "Airpocalypse"), the recent Volkswagen diesel emissions cheating scandal—that sparked wider awareness and political action. It should come as no surprise that Gardiner, Smedley, and Fuller are all Londoners. The city has

some of the worst nitrogen dioxide pollution in Europe, mostly coughed out by the diesel vehicles that ply its streets, and its air quality battles figure prominently in each book.

A crucial lesson in each of these books is that, just when officials think they've solved the problem, it rears its head again. London tackled coal burning and relocated industry after the Great Smog, only to have its air fouled by noxious diesel vehicle exhaust decades later. The 1956 law gave Londoners smokeless zones; last April, Mayor Sadiq Khan, who in his 2016 campaign declared that the city faced a "public health emergency" from air pollution, announced a new "ultra low emission zone for central London."[2]

Another common theme is that polluting industries simply do not accept *any* limit on how much waste they can pour into the air without a vicious fight. In 1952, the same year of London's killer smog, the chemist Arie Haagen-Smit published his research solving the mystery of another infamous species of smog: the yellow-brown haze that regularly blanketed Los Angeles. The culprit was ozone, produced by hydrocarbons from cars and the region's refineries reacting in the California sun. He was immediately attacked and ridiculed by the oil and automobile industries, and by scientists they funded. Haagen-Smit prevailed, but that battle created the playbook by which influential industry lobbies have sought to forestall pollution limits, and discredit the peer-reviewed science underpinning them, over the past half-century. When the EPA relaxed ozone standards in 1979 in response to relentless industry pressure, the American Petroleum Institute (API) thanked it by suing to overturn the entire standard, saying it was "far more stringent than medical evidence shows is necessary to protect public health." After President Obama's EPA proposed a modest tightening of the ozone standard in 2014, the API, along with other industry groups, sued again. Just last month, the D.C. Circuit issued its ruling, rejecting the API's arguments. This pattern plays out over and over in these pollution tales.

One of the best chapters in *Choked* tells the unlikely story of how the Clean Air Act (CAA) of 1970 was forged by two determined senators, Edmund Muskie, a Democrat, and Howard Baker, a Republican. Their two senior aides, Leon Billings and Tom Jorling, took the lead in crafting the legislation and became lifelong friends during the process. It's a tale about farsighted, enlightened governance that seems like it takes place in another universe, far from today's hyperpolarized and paralyzed Washington.

Gardiner argues that the "radical achievement" of those architects—the "beating heart" of the CAA—was its prioritization of Americans' health over the costs to be borne by polluting industries. Counterintuitively, this feature has made it a staggeringly cost-effective piece of legislation. According to a 1997 EPA analysis, from 1970 to 1990, the law had prevented 184,000 premature deaths each year; the illness and mortality avoided was valued at $22 trillion. The EPA's peer-reviewed report estimated the ratio of total economic benefits to costs to be greater than 40:1, with an upper range estimate of more

than 90:1.[3] A 2011 report found that, by 2020, amendments made to the CAA in 1990 will have avoided another 4.2 million deaths, with the monetized value of benefits exceeding costs 30:1.[4] Even Trump's EPA likes to crow, as it did in a 2018 press release, about the CAA's achievements and feathery touch on GDP: "between 1970 and 2017, the combined emissions of six key pollutants dropped by 73 percent, while the US economy grew more than three times."

This is rather darkly ironic. The EPA's current leaders and scientific advisers—a cadre of former lobbyists, lawyers, and consultants for the coal, power, automotive, and oil industries—are taking a sledgehammer to the law's core protections. Their strategy is a familiar one: attack the robust scientific consensus that underpins and guides decision-making on environmental issues.[5]

Republicans in Congress have repeatedly introduced bills to limit the EPA's use of studies that rely on subjects' confidential medical and health data, in the name of "transparency." These "secret science" bills had never gone anywhere until the disgraced former EPA administrator Scott Pruitt took the plan and refashioned it into a proposed new agency rule that Gardiner describes as "a spurious argument intended to put many of the most important findings on air pollution's effects out of bounds."

The Clean Air Act stipulates that, every five years, the EPA must review and update the scientific assessment on which national ambient air quality standards are based. That process is currently underway for particulate matter. EPA staff have compiled a draft *Integrated Science Assessment for Particulate Matter* (*ISA*) and sent it for review to the Clean Air Scientific Advisory Committee (CASAC), an independent panel of experts, mandated by the CAA, that provides scientific guidance on how much pollution is safe for us to breathe.

The *ISA* scrutinizes an enormous body of scientific literature on the health effects of particulate matter. Researchers have developed a set of rigorous, quantitative tools with which to access and analyze the treasure trove of observational data assembled by the Six Cities and other long-term studies. In the decades since its publication, the Six Cities findings have been gone over with several fine-toothed statistical combs: in 2000 an extensive reanalysis of the data by an independent team at the Health Effects Institute confirmed the results; another analysis in 2012 confirmed them yet again. The PM–mortality relationship has been repeatedly confirmed by large cohort studies, including one by the American Cancer Society that surveyed air quality in 150 US cities. The result is one of the most robust points of consensus in modern public health research: breathing particulate matter shortens lives.

Yet for the first time in its history, the CASAC is questioning the scientific consensus that exposure to fine particles causes mortality. Not coincidentally, for the first time in its

history, the CASAC has no epidemiologists among its seven members—all of them appointed since 2017. Last year, Tony Cox Jr. was appointed its chair. A statistician and risk analyst with no training or background in health or medicine, Cox has consulted for the American Petroleum Institute, the Truck and Engine Manufacturers Association, mining companies, and the tobacco conglomerate Philip Morris.

The CASAC met on March 28, 2019, via teleconference to discuss the draft letter they were obligated to send to EPA Administrator Andrew Wheeler, reviewing the *ISA*. Cox spent a good portion of the meeting expounding on the nature of causality and hectoring fellow members into approving language that was strongly critical of the methodology and conclusions of the draft *ISA*. Some of that hostile language was removed, but much was preserved in the final version CASAC sent on April 11. "Overall, the CASAC finds that the Draft *ISA* does not provide a sufficiently comprehensive, systematic assessment of the available science relevant to understanding the health impacts of exposure to particulate matter," it reads.[6]

The letter is a breathtakingly confused, self-refuting document. The CASAC critiques the *ISA* on a number of points, and then admits that it lacks the expertise to do so. ("The breadth and diversity of evidence to be considered exceeds the expertise of the statutory CASAC members, or indeed of any seven individuals," the letter reads.) It casts doubt on the *ISA*'s determination that PM2.5 causes premature death, and then goes on to describe the huge body of peer-reviewed evidence buttressing that determination.

This incoherence is partly due to a divide among its members, including between Cox and Dr. Mark Frampton, a pulmonologist and the lone medical professional on the CASAC. But it's also partly due to a willful blindness to the 1,879 pages of carefully assessed evidence—citing over 2,800 references—placed before them.

Cox argues that the epidemiological studies cited in the ISA don't adjust for confounding variables such as income levels, daily weather conditions, or existing health conditions. This is, on its face, incorrect. Taking into account such variables and searching for the clear signal amid all the statistical noise is at the heart of what epidemiologists do. In a February letter responding to similar criticisms that Cox made in December, John Vandenberg, a research director at the EPA who oversees the development of the ISA, patiently tried to explain this to him: "as I'm sure you are aware, epidemiologic studies go to great pains to identify these factors and to ensure they are controlled for through study design and advanced statistical models." Vandenberg also categorized the "multiple lines" of peer-reviewed evidence—dosimetry, controlled human exposure and animal toxicological studies, and more—considered by the EPA to inform its determination of causality.

Cox would like to toss this long-established "weight-of-evidence" approach aside and replace it with his own alternative framework, which would allow the EPA to consider only studies that pass a narrow test called "manipulative causality." Such studies would be designed to expose some people to pollution while others quit the habit, so to speak, and compare their health outcomes while holding all other specified variables fixed. But randomized control trials (which are used to clear new drugs for the market) and other manipulative study designs are inappropriate for studying the efficacy of "prescribing" clean air. For one, it simply isn't feasible to run a trial in which, say, an entire neighborhood of an American city stops breathing air pollution, and then wait for a few decades to see what happens.

It's also unethical, because the vast majority of scientists who study the issue are highly confident that air pollution is dangerous to people's health. They look at the enormous "forest" of collective evidence from epidemiology, toxicology, and natural experiments, rather than fixating on the "tree" of individual study design to demonstrate causality in the narrowest sense. They also look for ways to learn from what's already going on in the world, such as when a political event or regulatory action provides the opportunity to compare a treatment group to a control group. One of the most striking of these quasi-experiments in recent years is from China. Using the Huai River as a dividing line between colder and warmer parts of the country, from the 1950s to 1980 the Chinese government provided free coal for household heating north of the river and no subsidy to those living south of it. Researchers at the University of Chicago looked at mortality data in ninety Chinese cities and found a shocking result: those living in the north had their lives cut short by 5.5 years on average due to "cardiorespiratory mortality" from exposure to levels of particulate pollution that were 55 percent higher than in the air of the south. They estimated that the well-intentioned policy destroyed 2.5 billion life-years.

This debate over frameworks for causal inference may seem abstruse and arid, but the stakes are life and death. They will determine, in a very direct way, how many particles are permitted to enter Americans' lungs, merge into their bloodstreams, and travel up their olfactory nerves to their brains. Under Cox's proposed terms, it would never be possible to provide adequate evidence that fine particles cause illness and death. It's an impossible burden of proof. The way to read the CASAC's critique is as a weaponization of uncertainty, which is endemic to the

LA Daily News Negatives/UCLA

Highland Park Optimist Club members wearing smog gas masks at a banquet, Los Angeles, circa 1954

scientific enterprise.

This quietly made decision to exclude observational studies from policymaking would reverberate beyond the realm of air quality. Particulate matter reductions account for half of the total monetized benefits of all major regulations across the federal government.[7] (That sum encompasses the estimated dollar value of reduced mortality, avoided hospital admissions and lost days of work and schooling, and a host of other health, welfare, and ecological benefits.) An entire regulatory edifice—from mercury standards to the Obama-era Clean Power Plan that Trump's EPA has replaced with a much weaker rule for emissions from coal power plants—is constructed on the rationale that exposure to fine particles shortens and damages lives. If Cox's standard were applied, the Six Cities and other important studies would be disqualified from consideration. And the foundation for those life- and money-saving regulations would dissolve into quicksand.

Reading these three books and paging through the draft ISA gives one a dizzying sense of how many different ways air pollution can harm us. It would be hard to digest all this information and not arrive at the same two overarching conclusions as the three authors: (1) air pollution is severely under-regulated; (2) we need to get beyond combustion, as fast as we can. Burning stuff is burying us.

But these authors find hopeful signs that the slow-motion catastrophe of chronic air pollution is rising higher on the political agenda in at least some countries. Proven technological and policy solutions are both available and affordable, and there is renewed conviction that clean air is not a luxury to be secured at the expense of progress, but is itself one of the most meaningful measures and engines of true progress. Gardiner showcases Berlin as a city that has prioritized air quality by embracing low-emissions transportation and mobility solutions for its citizens and created a more pleasant place to live in the bargain. Smedley ends his book with a thirteen-point "blueprint" for clean air, the bumper-sticker version of which might read: *Ban internal combustion engine vehicles (especially diesels). Redesign cities for people instead of cars. Electrify everything.* (Not coincidentally, these same steps would also go a long way toward bending the curve of greenhouse gas emissions downward.)

Gardiner and Smedley report on and applaud China's aggressive efforts to curb emissions from coal power plants, vehicles, and factories in urban areas. China still has a long way to go to meet WHO guidelines, but its leaders are now in the midst of their "Three-Year Action Plan for Winning the Blue Sky War," which mandates sharp reductions in PM2.5 levels in 338 cities. The authors also report from India, which is home to seven of the ten most polluted cities in the world, and describe its sluggish response to the crisis. Even so, in recent elections, India's major political parties jockeyed to best each other—rhetorically, at least—with their respective clean air battle plans.

Clearly, tackling air pollution must become a top political priority. Both Smedley and Fuller use the phrase “fight back”—it’s in Fuller’s subtitle and serves as the heading of the second half of Smedley’s book. But fight back against what—or whom? Against indifferent and triangulating politicians, who, as Fuller notes, “set aside the recommendations from health experts,” accept “air pollution as the norm,” and settle for half measures instead of truly healthy air? Against scheming companies like Volkswagen, or the science-denying regulators currently running the EPA? Perhaps the fight should be against our own complacency.

From the 1950s through the 1970s, New Yorkers complained loudly and regularly to their city’s officials about poor air quality and failures to enforce new controls on incinerating garbage and other sources of pollution. Meanwhile, citizens in Pittsburgh and Los Angeles formed activist groups like GASP (Group Against Smog and Pollution) and SOS (Stamp Out Smog), which conducted media-savvy public demonstrations and campaigns to pressure lawmakers, and even pursued litigation. These efforts launched from living rooms got results. “It is not the invisibility of air pollution that is the problem but its normalization and acceptance,” Fuller writes. And, in the US, there’s a new problem: the guardians who craft and enforce air pollution policy are busy dismantling the protections created by decades of careful science and study.

It’s a dark prospect, made darker still by the specter of a rapidly warming world. One wishes that these three authors more closely studied the haze on the horizon. None fully explores what climate change will mean for people breathing in 2030 or 2050, and how atmospheric warming is likely to erase hard-won gains in air quality from decades of regulatory protections. As air temperatures rise, smog events will last longer and expose people to higher concentrations of ozone. Residents of the American Southwest can expect to breathe more airborne dust and die in higher numbers as droughts become longer and more intense. Other parts of the country can expect sharp increases in airborne allergens. Wildfires will become more frequent and burn larger areas, unleashing carbon stored by forests along with a toxic stew of particles and gases.

This “climate penalty” is already being imposed. The fires that raged across Northern California last November briefly caused the Bay Area to have the worst air quality in the world, giving residents a bitter taste of what people in Delhi live with for much of the year. In May nearby wildfires forced Mexico City—which has fought valiantly for decades to clean up its own air by closing refineries and factories and limiting traffic-related emissions, despite its challenging topography—to declare a pollution emergency, closing schools and advising its more than 20 million residents to stay indoors. Levels of PM2.5 soared to more than six times the WHO limits.

On April 3, in its annual State of the Air report, the American Lung Association reported that 141 million Americans live with unhealthy levels of ozone and particle pollution, an increase of seven million from 2018. It attributed much of the rise to the effects of climate change. Even Trump's EPA acknowledges in a new report that "most of the northern half of the country will experience greater air pollution because of climate change."

New evidence seems to ratchet only in one direction: revising today's global death toll of air pollution upward, and widening the scope and variety of its damage. A recent study in the *European Heart Journal* concluded that ambient air pollution is responsible for 8.8 million premature deaths per year—more than double previous estimates, and 1.5 million more than smoking causes.[8]

Gardiner's chapter about London's ongoing air quality crisis is titled "9,416," a reference to the estimated number of residents who die each year from exposure to air pollution, according to analysis by researchers at King's College. Such numbers should be taken very seriously, but not too precisely, she argues. They "are intended to express risks to an entire population—a city, a country, millions of people—not an individual. They convey something urgent and vital, giving us a sense of a problem's scale so we can compare it with other dangers and decide whether to do something about it."

In other words, spread across populations, these numbers—40,000 dead in the UK, 1.2 million dead in India—are tools that permit rankings of risk and ordering of societal priorities. Smedley quotes a report from the UK Chief Medical Office that puts them in the proper context: "Life-years (or quality-adjusted life years) are more appropriate for analysing policies than numbers of deaths, as it is when people die rather than whether they die that matters."

Nine-year-old Ella Kissi-Debrah died way too soon, of an asthma attack in London in 2013. She had been admitted to the hospital twenty-seven times since 2010 for severe asthma symptoms. At her mother's urging, city health officials have reopened the inquest into her death, and are considering—with the support of expert testimony showing that pollution levels were quite high in her neighborhood on the day she died—listing air pollution as a cause of death on her death certificate.

It would be a profound statement, confirming the judgment of so many scientists: that air pollution acts in concert with other factors to tip human bodies over into crisis, illness, and death, and that behind the staggering statistics, air pollution curtails and corrodes individual lives. But whether or not officialdom puts it on a death certificate, the larger truth remains: these pollutants are robbing us of time, our most precious resource, on an unimaginable scale. A study in the *Lancet* found that 122 million years of lost life were due to exposure to PM2.5 in 2015. Children in sub-Saharan Africa and South Asia were its

primary victims, suffering nearly 20 percent of all those lost years.[9] They, too, have no memorial.

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1 Douglas W. Dockery et al., *The New England Journal of Medicine*, Vol. 329, No. 24 (December 9, 1993). ↩

2 Gardiner describes how California, which has been in the global vanguard of stringent, science-based air quality controls since 1947, is trapped on the same treadmill: "This is LA's paradox: Its assault on smog is sometimes described, rightfully, as one of history's great environmental achievements. But this city's air remains among the country's worst." ↩

3 US Environmental Protection Agency, Office of Air and Radiation and Office of Policy, Planning and Evaluation, *The Benefits and Costs of the Clean Air Act, 1970 to 1990*, October 1997. ↩

4 US Environmental Protection Agency, Office of Air and Radiation, *The Benefits and Costs of the Clean Air Act from 1990 to 2020*, March 2011. ↩

5 One newly appointed EPA adviser, Robert Phalen, has said previously that he believes "modern air is a little too clean for optimum health." His calls for *more* pollution echo the seventeenth- and eighteenth-century theorists who advocated burning more coal in London, as coal smoke was thought to cleanse the "miasma," airborne vapors from rotting organic matter that they assumed were responsible for all-too-common respiratory illness and fevers. ↩

6 The CASAC upbraids the *ISA* authors for ignoring "inconsistencies and discordant data." As examples of such data, Cox has offered several of his own published papers questioning the link between air pollution and adverse health effects—papers that have been little cited by other scholars. In his own published work, he has argued that temperature extremes, not levels of PM2.5, explain observed changes in mortality rates. His views are, as many former CASAC members have observed, far outside the mainstream of air pollution science. ↩

7 Office of Management and Budget report to Congress in 2013; see also Francesca Dominici, Michael Greenstone, and Cass R. Sunstein, "Particulate Matter Matters," *Science*, Vol. 344, No. 6,181 (April 18, 2014). ↩

8 Jos Lelieveld et al., "Cardiovascular Disease Burden from Ambient Air Pollution in Europe Reassessed Using Novel Hazard Ratio Functions," *European Heart Journal*, Vol. 40, No. 20 (May 21, 2019). ↩

9 Jos Lelieveld et al., "Age-Dependent Health Risk from Ambient Air Pollution: A Modelling and Data Analysis of Childhood Mortality in Middle-Income and Low-Income Countries," *The Lancet Planetary Health*, Vol. 2, No. 7 (July 1, 2018). ↩