A SHORT HISTORY OF WOODSMOKE AND IMPLICATIONS FOR CHILE*

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Abstract: When living near forests, humans have always used wood fuel. Today its use across the world is a function mainly of wood availability with little relation in the

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amount used per capita across national incomes, although it constitutes a smaller fraction of total energy in wealthier countries as other energy sources become dominant. In poor countries, much of the use is for cooking while more is used for space heating and small industries as incomes rise. In simple household stoves, whether for cooking or heating, however, wood fuel produces significant health-damaging air pollution in the form of small particles as well as many other toxic components. In Chile and other countries in temperate areas of both hemispheres where wood is used for heating for a large portion of households in the winter, the levels of outdoor pollution can reach levels that are increasingly understood to produce significant health impacts. Heart disease, for example, may be increased as much as 50% by this pollution in some Chilean cities, particularly in the south. In Chile, cleaner burning fuels such as gas or high-combustion-efficiency woodstoves can thus be expected to have major benefits for health within a few years after successful programs to disseminate them widely.

Keywords: Household air pollution, space heating, wood fuel, PM2.5, particle air pollution, heart disease.

Introduction

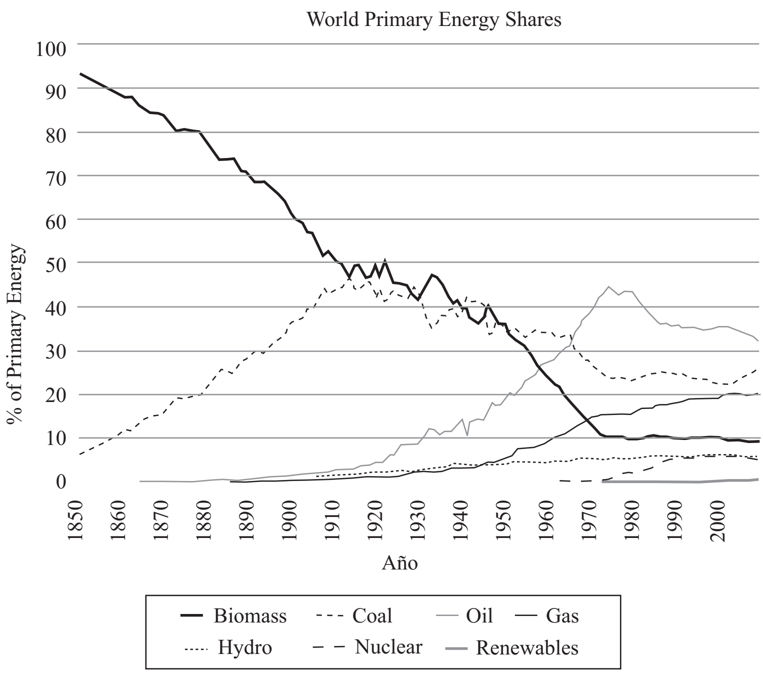
In his book *World Fire,* historian Stephen Pyne notes that throughout history wherever humans and forests live in proximity, the rate of wood burning increases (Pyne 1995). This is partly through accidental forest fires initiated by humans, through fire management of forest lands, and through human uses of forest wood for fuel. To some extent there is a trade-off —if less wood is harvested from the forest for fuel, the bigger the next forest fire will be. Some may rot, but most burns sometime. Forest fires are natural and needed to maintain the health of forest ecosystems (Pyne 2001). It might also be said that human use of wood fuel is, if not exactly natural, at least inevitable and needed to maintain the health of human societies. Indeed, the event that many archeologists use for defining the point at which humanity switched from pre-human to human conditions was learning to control fire (Lévi-Strauss 1969). Surprisingly, the rough date when the cooking hearth using wood became a routine part of human habitation has only recently been determined —about 350,000 years ago (Roebroeks and Villa 2011). We have been at it for a long time.

Wood use and development

Today, the use of wood and other biomass fuel in households is sometimes considered a condition of poverty —poor populations without access to modern fuels must resort to harvesting biomass for their household cooking and heating needs. Indeed, these activities that started a third of million years ago still occur daily in more than 40% of human households. This seems to be supported in that the fraction of national energy usage attributed to wood and other biomass tends to decline with development as other sources of energy become more prominent, as shown in Figure 1.

Framing biomass use as a fraction of total energy use, however, hides a more pertinent point for this discussion, which is that the

FIGURE 1: CHANGES IN THE FRACTION OF TOTAL ENERGY BY FUEL/ENERGY TYPES SINCE 1850



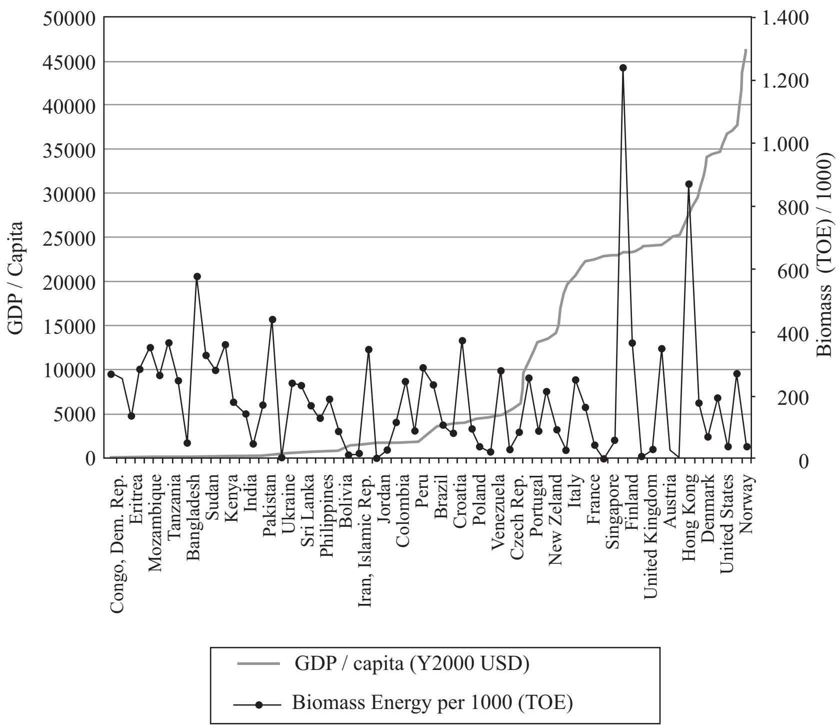
Note: By this measure, biomass has become much less important globally over time.

Data source: GEA 2012.

absolute use of woodfuel per capita has little relation with development. As shown in Figure 2, although there is much variation, there is no obvious trend with increasing income.

The observed variation seems to be explained simply by availability. Singapore and Finland are both wealthy countries, but the former has almost no forest and woodfuel use and the latter much of both. Of course, the ways woodfuel are used depends on income; for example, the fraction of households cooking with biomass drops substantially with income, but other uses of wood may remain or even rise —including fireplaces, boilers, small power plants, etc. If available, however, it is likely to be burned somewhere, even if in the next forest fire. There is also a parallel story with crop residues, which are collected and burned for household needs in poor countries, but otherwise often

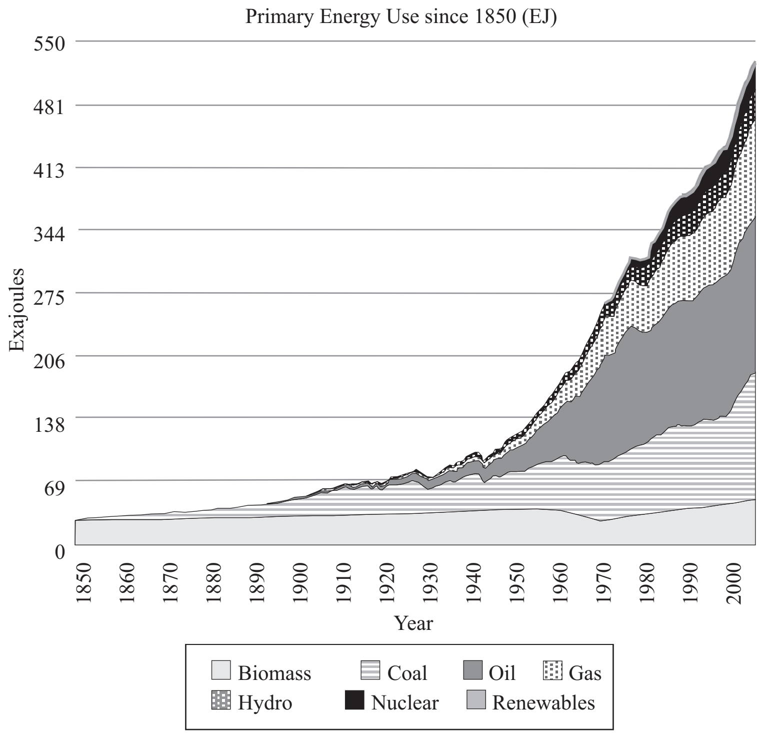
FIGURE 2: BIOMASS ENERGY PER CAPITA BY NATIONAL INCOME



Note: Note that although there is much variation, there is no clear trend.

Data source: World Resources Institute, Earthtrends (2007).

FIGURE 3: ENERGY USE SINCE 1850 BY MAJOR FUEL/ENERGY TYPES



Note: Note that there is no trend for total biomass fuel used over this period.
Data source: GEA, 2012.

burned in the field in even the richest countries. As with wood, the total amount burned is thus a function of availability —in this case the amount and type of crops grown locally.

Consequently, as shown in Figure 3, about the same absolute amount of biomass fuel has been used by humanity for hundreds of years and, correcting for population, probably much longer. When it is available, it is burned.

Woodsmoke

In recent decades, partly due to more sophisticated health science (epidemiology and toxicology) and partly due to changing expectations about health protection, combustion-generated small particles have come to be understood as major health risks in nearly all populations. The new Global Energy Assessment, for example, indicates that some 5 million people die prematurely each year as a result, even not accounting for active and passive smoking where the health effects are also due to biomass combustion pollutants. These impacts are due to the risks from household air pollution resulting from use of biomass and coal and from general outdoor fine particle air pollution —all due primarily to poor combustion of fuels.

Perhaps surprisingly, as described below, in the broad health view, there is little to distinguish the particles among different sources —whether from fossil fuels, woodfuel, or tobacco, for example. Unless accompanied by specific toxic contaminants, combustion particles are all similarly bad for you, of course adjusted by the dose received.

Human application of fire in the clearing of land has had profound impacts on the world environment, even when the human population was relatively small (Rambo 1982). When the human hearth developed, there were perhaps 1 million people on Earth, however, and household wood burning had relatively little impact on the environment even locally, although it probably led to health risks to the users. Now with 7 billion people, however, biomass burning in many hundreds of millions of households does have major impacts. The air pollution from biomass use for cooking, for example, is thought to kill some 2.5 million people annually in poor countries (IIASA 2012). Due to the plethora of climate-altering pollutants in biomass smoke, household biomass use has also been calculated to be one of the top sectors influencing climate change, rivaling ground transport, livestock production, power plants, etc. (Unger *et al*. 2010).

Biomass smoke is also a major contributor to ambient air pollution in many parts of the world. Purposely setting fires to clear land is still common in parts of Africa, Indonesia, and Brazil with major impacts on air quality. In other places, heavy pollution occurs due to episodic forest fires or seasonal burning of crop residues. In some poor populations, the daily use of biomass for cooking is a major source; for example in India and China, household fuel use is responsible for some 50 and 30%, respectively, of all outdoor combustion particle emissions (Chafe and Smith 2010). In a large part of the world, however, ambient pollution is heavily influenced by use of wood for space heating and thus is worse in the winter months.

Although there are no systematic world emission inventories that cover household wood burning for space heating, it seems clear it is responsible for more than half of all outdoor particle emissions in many countries, for example Canada, Finland, Norway, Denmark, New Zealand, and Chile. During the winter, it dominates in even more parts of the world, including much of the USA; Australia; Central, Eastern and Western Europe; and Russia. If heating with coal were included, household combustion would be responsible for the bulk of all particle emissions in Mongolia and, if not the majority, a large fraction of emissions in temperate China during the winter. Household use of coal for space heating in Ulaanbaatar, Mongolia, for example, causes some of the worst outdoor air pollution in the world during heating season.

These are striking conclusions given that all these countries have significant fossil fuel burning in their industrial, transport, and commercial sectors with consequent combustion particle emissions. In most cases, woodfuel is a relatively small portion of total energy but because of high and generally uncontrolled emissions per unit energy, household wood burning has a disproportionate impact on air quality.

What's the problem?

As noted above, woodsmoke exposure has been with humanity since the very beginning. Considering this, sometimes people note that since it is "natural" it must be benign. This of course is nonsense —there is much that is natural that is quite nasty, from snake venom to botulism toxin to arsenic to malaria, not to mention typhoons, floods, and droughts. Indeed, most of humanity has spent most of human history protecting itself against natural hazards.

Smoke is a mixture of chemicals and thus a logical question might be whether any are proven hazards. Unfortunately, the answer is yes. Thousands of chemicals have been identified in woodsmoke, hundreds of which are known hazardous materials. Among these are many that have the reputation of being "industrial" chemicals such as benzene, formaldehyde, polyaromatic hydrocarbons, and dioxin. In addition, the levels found in heavy woodsmoke situations for these chemicals rival those found in factories and other modern polluted environments where health effects have been documented (Naeher *et al.* 2007; IARC 2010).

The most well-studied biomass smoke is that from tobacco combustion, which has all the same chemicals in woodsmoke, in somewhat different relative amounts, plus a few others due to its nicotine and the additives put in during manufacture of cigarettes. These are not thought to be the source of most health effects, however, but rather the products of incomplete combustion.

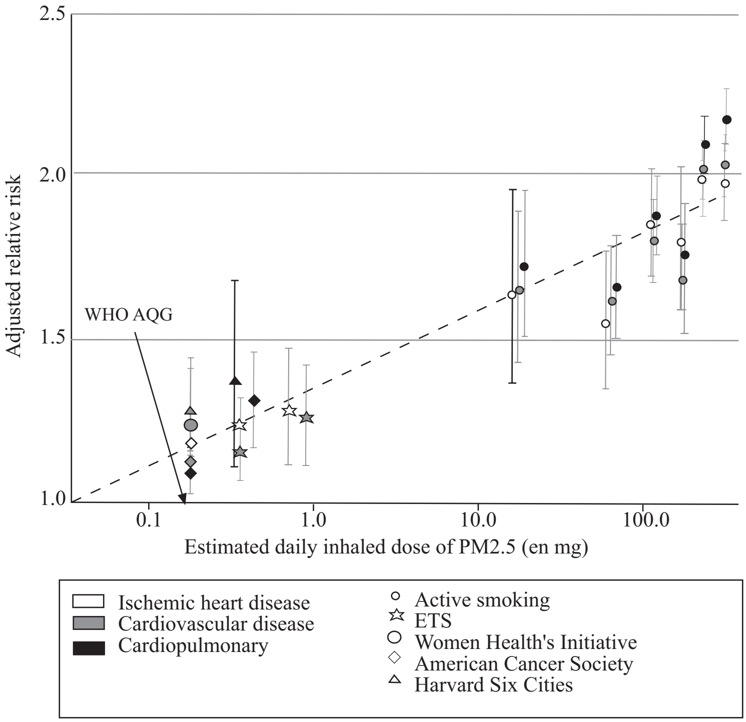
Although there are thousands of chemicals in combustion smokes, including those of wood and tobacco, it is not possible to measure them regularly due to technical and cost barriers. Nor is it needed, since a few indicator pollutants work well to link with most types of health risk. In cigarettes, for example, it is "tar", which is the term used to refer to what air pollution science refers to as respirable particles —those small enough to penetrate into the deep lung (best measured as PM2.5— particles smaller than 2.5 um in diameter). For air pollution, PM2.5 is the best single indicator of health risk from combustion pollutants, whether for outdoor or indoor air pollution.

The latest health research

Until recently, health research on air pollution health effects was done independently from that on tobacco smoking. In fact, of course, they are actually closely related, the difference being the high exposures from smoking compared to most air pollution situations. Recently, however, there is a growing literature that directly quantifies the relationship of particle air pollution across exposures ranging from the low end —ambient air pollution— to the extreme high end – active smoking (Pope —. 2011; Pope *et al.* 2009). This reveals not only that there is a smooth increase in risk from one type of particle exposure situation to the next, but some remarkable implications about the benefits of air pollution control measures at each level of exposure (Smith and Peel 2010).

Figure 4 illustrates a version of this relationship for several important diseases related to air pollution exposures, related to heart disease, perhaps the most important health outcome. Note that although the dose of particle inhaled per day ranges by about a factor of 1000 between heavy smokers and those living in polluted cities, the increase in risk of heart disease rises steadily.

FIGURE 4: GENERALIZED EXPOSURE-RESPONSE RELATIONSHIP FOR FINE PARTICLE POLLUTION (PM2.5) FROM THREE MAJOR CATEGORIES OF COMBUSTION SOURCES —AMBIENT AIR POLLUTION, SECONDHAND TOBACCO SMOKE, AND ACTIVE SMOKING



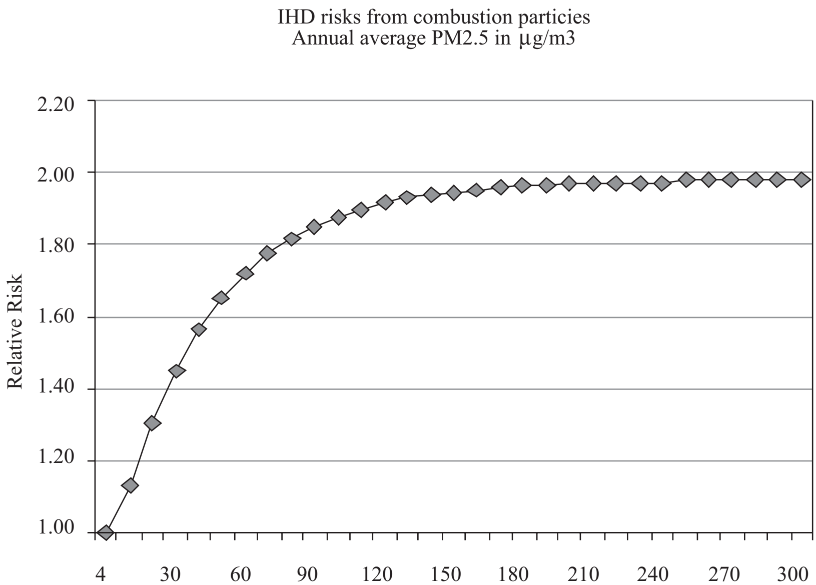
Note: The dose is expressed as inhaled combustion fine particles per day and risk in terms of multiples of background disease. Thus, a relative risk of 1.5 means that people at this exposure have 1.5x (50%) more disease than if they were not exposed. This figure, which is simplified from Pope *et al.* (2009), comes from Smith and Peel (2010).

Source: Reproduced with permission from *Environmental Health Perspectives*.

As Figure 4 has a log scale for exposure/dose and is in unfamiliar units (mg/m3-day), it is hard to interpret. Figure 5 puts the results into a figure with more familiar units, ug/m3 annual average, which is what outdoor air pollution measurements and standards use. It focuses on the most important of the heart-disease types, ischemic heart disease (IHD).

Available outdoor air pollution studies of heart disease range up to about 30 ug/m3 and secondhand tobacco smoke studies range up to 80 ug/m3 or so. On this graph, however, smokers are far to the right – 10,000 ug/m3 and higher.

FIGURE 5: HEART DISEASE RISK VERSUS ANNUAL AVERAGE EXPOSURE TO PM2.5



Note: Generalized exposure-response relationship incorporating the results of studies of outdoor air pollution, secondhand tobacco smoke, and active smoking.

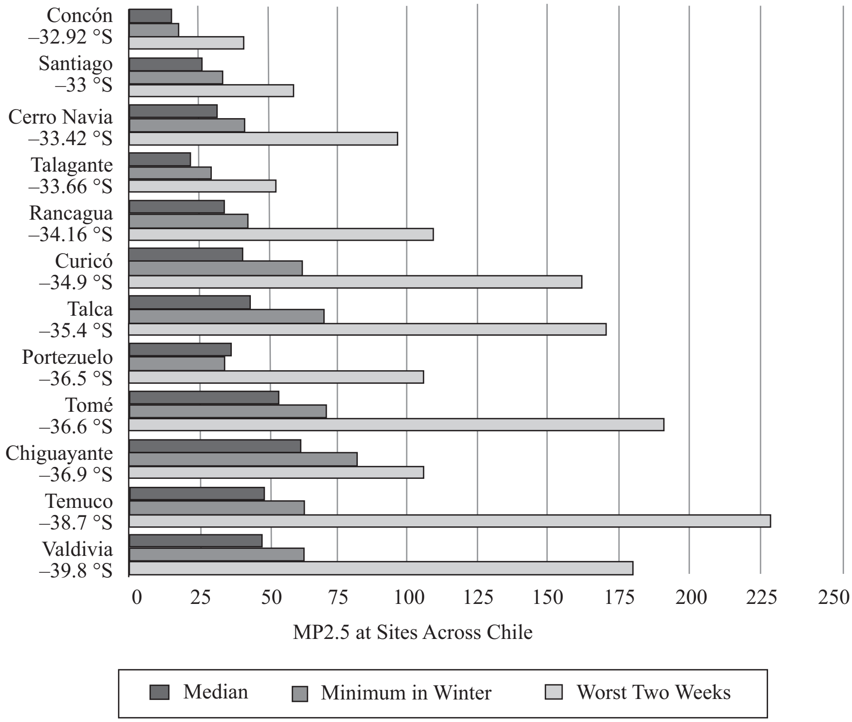
Data source: Based on data in Pope *et al*. (2011).

A striking characteristic of the relationship shown is that the extra risk per unit extra exposure is quite different at different levels of exposure. After about 150 ug/m3, for example, the risk only rises slowly all the way up to the levels experienced by active smokers. This is found in the tobacco literature —heavy and light smokers have almost the same risk. This has potentially profound implications for policy (Smith and Peel 2010), which will be discussed in terms of the situation in Chile.

Lessons for Chile

Compared the rest of the world, the Western Hemisphere does not in general suffer from high levels of either household or outdoor air pollution (See Figure 6). Chile is an exception for outdoor air pollution, however, due to wood use for heating.

FIGURE 6: PM2.5 CONCENTRATIONS MEASURED IN CHILEAN CITIES



Note: Much of this pollution in winter is due to household wood burning for heating, particularly in the more heavily polluted cities, which are all in the south. Note also the high levels during the worst two weeks of the year, which occur during the winter heating season when meteorological conditions often prevent dispersion of the pollution.

Data source: Chile, Ministry of Environment, SINC (Sistema de Información de Calidad del Aire) 2011.

Although affecting any part of the country where space heating is used, this problem is most severe in the southern cities in valleys, which have long heating seasons, are near forests, and have limited air movement in winter. Figure 7 shows PM2.5 levels measured in a range of Chilean cities over the year along with the rough minimum in winter and the worst two weeks of the year. Note that those in the south have higher mean levels than essentially any major area of the Western Hemisphere or Europe, although not as high as places in Asia and Africa. This is due to household wood stoves.

Peak pollution for a few days a year creates unpleasant conditions for all and probably threatens the health of those already suffering from respiratory conditions. The most well understood health effects, however, relate to annual average levels. What might be expected in populations living in those several southern cities with annual means of around 50 ug/m3 PM2.5 based on the newest health evidence?

In Figure 5, it can be seen that 50 ug/m3 PM2.5 corresponds to a relative risk for heart disease of about 1.5, compared to living in a clean city at 10 ug/m3, which is what the WHO Air Quality Guidelines recommend (WHO 2006). This implies that people in these cities have about 50% more heart disease than those in clean cities or, conversely, that 33% of the heart disease in these southern cities could be eliminated if pollution levels were controlled.

This is a large impact, but a bit of good news is that 50 ug/m3 is on the steep part of the curve, which means that health improvements will start immediately with the first reduction of pollution. This is unlike the case, for example, in village households burning solid fuels for cooking in India where exposures are in the hundreds of micrograms/m3. In this case, as seen in Figure 5, rather great reductions in pollution are needed to achieve the first health benefits.

Summary

The worst thing you can do is stick burning stuff in your mouth, which is what millions do with tobacco. The next worst is having lots of stuff burning inside your house for cooking with an open fire. The third worst thing, however, is what happens in a number of Chilean cities where woodstoves with no combustion improvement are used during the winter for space heating. There is so much pollution produced by these stoves, which are found in a large majority of households, that it cannot disperse adequately and it builds up creating extreme peak levels outdoors, but also influences annual averages that significantly impact health.

Needed, therefore, are measures to promote cleaner fuels such as gas, better household energy management through insulation and other measures, and woodstoves that significantly reduce emissions from those common today. As these measures start to lower emissions and annual concentrations, health benefits should start immediately.

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