GLOBAL HEART
VOL. 7, NO. 3, 2012

ISSN 2211-8160/$36.00
http://dx.doi.org/10.1016/j.gheart.2012.06.018

gOPINION

EDITORIAL COMMENT

# Reducing CVD Through Improvements in Household Energy

## Implications for Policy-Relevant Research

Jill Baumgartner *, Kirk R. Smith †, Arun Chockalingam ‡
*St. Paul, MN; Berkeley, CA; and Bethesda, MD, USA*

Much of this special journal issue focuses on the potential cardiovascular health impacts of household air pollution (HAP) from household use of solid fuels (i.e., biomass and coal). As discussed by several papers in this issue [1,2], there is growing evidence from integrated exposure-response models (i.e., models combining epidemiologic evidence from active and passive tobacco smoking and outdoor air pollution) that the cardiovascular risk of combustion pollution follows a highly supralinear exposure-response relationship [3,4]. That is, risk is very steep at pollution exposures typical of outdoor concentrations (<30 μg/m$^3$) and converges to a near flat relationship above ~100 μg/m$^3$ (Fig. 1). The latter is well below the average exposure levels among individuals using solid fuels, even with well-operating chimney stoves, implying that little cardiovascular benefit will accrue unless very clean interventions are introduced that bring total exposure in the range of the World Health Organization (WHO) Air Quality Guidelines <35 μg/m$^3$ [5].

Fortunately, numerous approaches exist for reducing HAP emissions to improve health, although their effectiveness, cost, and required level of behavioral change vary considerably. Indeed, over one-half of the world's population cooks using electricity or gaseous fuels, mostly piped natural gas or bottled liquefied petroleum gas, which, relative to solid fuels, emit very low levels of health-damaging pollutants. Ideally, all households will eventually transition away from solid fuels to clean-burning gas and electricity in order to fully protect health. The challenge is that gas and electricity are currently unaffordable and/or unavailable to most households currently using solid fuels and will remain so for decades to come. Thus, a key policy question becomes: How can total exposure levels be lowered into the low range of the WHO guidelines over time and achieve the greatest health benefits in the interim?

Here, we provide a brief summary of what is known about a range of housing, energy, and behavioral interventions to reduce HAP exposures. We also identify knowledge gaps and research questions that are important in successful design and delivery of these interventions. In many populations, the cookstove is the main source of combustion pollution, but it serves a range of energy needs. In high-elevation or temperate areas, space heating is another important source of pollution. Thus, we recommend investigating what combination, or "packages," of clean energy interventions (e.g., multistove, multifuel, fuel + stove, housing + stove + fuel) can address the multiple energy needs of households and reduce HAP to very low levels. Though our discussion focuses on policy and intervention recommendations in light of recent evidence on cardiovascular diseases (CVD), most are applicable to other diseases associated with HAP exposure as well.

### TECHNOLOGIES AND APPROACHES FOR REDUCING HAP

We begin by introducing the 4 major categories of fuels currently used by tens of millions of households that have been promoted as ways to reduce HAP exposures, though each has serious drawbacks.

Coal plays a small role in many countries, but is widely used in rural Chinese households for cooking

From the *Institute on the Environment, University of Minnesota, St. Paul, MN, USA; †School of Public Health, University of California—Berkeley, Berkeley, CA, USA; ‡Office of Global Health, National Heart, Lung, and Blood Institute, National Institutes of Health, Bethesda, MD, USA. Correspondence: J. Baumgartner (jbaumgartner@umn.edu).

GLOBAL HEART, VOL. 7, NO. 3, 2012
September 2012: 243–247

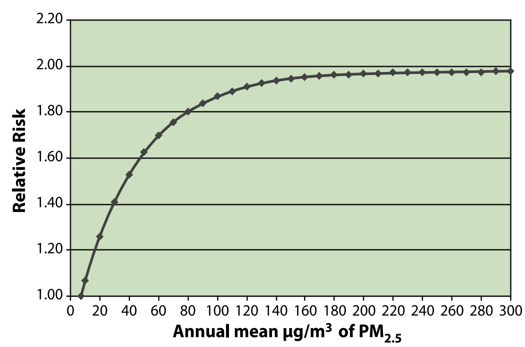


**Fig. 1. Ischemic heart disease risk versus average annual $PM_{2.5}$ exposure.** Integrated exposure-response relationship incorporating the results of studies on outdoor air pollution, secondhand tobacco smoke, and active tobacco smoking. Typical household air pollution exposures in solid fuel–using households seem to be above 200 μg/m$^3$. Here, 7 μg/m$^3$ is used as the counterfactual—what a gas stove with ventilation could achieve—and thus set at a relative risk of 1.0. Based on data in Pope et al. [4]. PM, particulate matter.

and, in particular, space heating because its high energy density allows for overnight fueling. Although particle levels are typically less with coal than with uncontrolled biomass, coal quality and the subsequent emissions and toxicity vary by region and even by coal mine. Unlike biomass, coal often contains intrinsically toxic materials that cannot be eliminated by even the cleanest combustion, including sulfur, mercury, arsenic, and fluorine. Like biomass, however, it is difficult to obtain clean combustion in small, household stoves and the resulting smoke contains particulate matter (PM), carbon monoxide (CO), and complex cyclic compounds with toxic properties. Even the so-called clean coal, lightly processed briquettes to improve combustion characteristics and reduce sulfur, is not clean by most criteria. These concerns led most Western European nations to ban coal for household use last century as has been done recently for urban, but not rural, China.

Wood-charcoal is commonly used for cooking and space heating in many countries particularly in urban and periurban areas. Combustion emits lower levels of PM pollution than wood does, although it still produces health-relevant PM levels and particularly high CO concentrations. Stripping out the PM and associated irritating gases results in risk of overnight CO poisoning, which is not known to happen from wood smoke exposure. In traditional kilns, it is also highly polluting and a wasteful use of the wood resource.

Kerosene is widely subsidized in many countries to give the poor access to modern lighting and cooking fuel. It produces lower PM emissions per meal than traditional biomass fuels, though the quality of the kerosene fuel and stove affect emissions levels. Recent studies indicate that the remaining PM may have a disproportionately large health impact when compared with the impact of biomass smoke. In addition, storage of kerosene in small containers poses major poisoning risks to small children.

Biogas is a by-product of anaerobic digestion of animal dung in small tanks, often buried near households, that has gained some popularity in countries such as India and China. The resulting gas can be used for multiple applications including cooking and lighting (fuel constituent is methane), and the process retains the fertilizer value of the dung, which is recovered as digester sludge. Household units have serious limitations, however, being expensive to build and requiring substantial management. They also cannot operate below 10°C and require dung from at least 2 large animals, limiting potential coverage. Being cleanly burned as a gas, however, it is advantageous from a pollution perspective.

In the following section, we discuss a handful of other household energy approaches being pursued, though they have yet to achieve large market penetration.

Liquid biofuels like ethanol and plant oils seem to burn more cleanly, but share with all biofuels the problem of potentially competing with food crops.

Processed biomass in the form of pellets or briquettes can burn relatively cleanly because of its uniform size, moisture content, and other characteristics. It is promising for cooking and also for substituting out coal for space heating because self-feeding stoves are available. However, efficient processing cannot occur at the household level and thus a commercial market must be established to reach households, though village-level production has proven successful in several regions.

Solar devices have been successfully applied for water heating in some areas and had limited success for certain cooking tasks, but not as substitutes for cookstoves that can be used for most tasks at any time, due to the lack of viable energy storage for solar energy. Lower-cost solar lighting, water-heating, and space-heating collectors are currently being developed, giving promise of greater penetration in the future.

Although direct use of electricity for main cooking tasks is too expensive in most poor communities, even those connected to electricity supplies, availability of some electricity can pick off important cooking tasks to reduce the use of the main stove. The best examples are rice cookers and insulated hot water kettles, both highly efficient at what they do and together providing an important fraction of cooking energy in many parts of the world. Electrification, which is an important social welfare goal in itself, has been shown to eliminate use of kerosene lamps.

Improvements in housing stock and insulation have been promoted as ways to reduce the reliance on biomass and coal for space heating [6]. Improvements in housing thermal efficiency and conditions (i.e., insulation or reducing window and roof leakiness) present major opportunities for reduced reliance on space heating, particularly in the context of the fast-paced urbanization and housing growth in many low- and middle-income countries.

Chimney and advanced combustion biomass stoves refer to a broad category of technologies that reduces exposure through a chimney/hood to vent emissions from the kitchen or higher combustion efficiency or, most effective of all, both. These stoves are attractive because in principle they require no change in the fuel supply from traditional forms of biomass being used locally, although all truly clean stoves require some degree of processing (i.e., wood chopping, pellet production) and have moisture-content limits. In the past, "improved" biomass stoves referred to stoves with a wide variety of styles, materials, construction techniques, and performance. Sadly, experience has shown that most stoves promoted as "improved" provided little or no benefits in pollution emissions reduction, even if improving fuel efficiency. Current practice distinguishes advanced biomass stoves as those with better performance based on three major sets of criteria: 1) air pollution emissions/exposures; 2) fuel use; and 3) safety of the stove during usage. All of these factors need to be considered separately in both stove design and field assessments and are part of the new International Organization for Standardization standards for cookstoves being developed this year [7].

There is not space here to review the growing understandings and considerable remaining uncertainties about advanced biomass stoves, but two issues are important to the discussion here.

**The impact of user behavior.** Clean in practice means not only clean combustion performance, but also that people must adopt and use the new device as well as substantially reduce their use of the polluting alternatives. Empirical work in many countries shows that the transition from low- to high-quality fuels and energy technologies is often not a straight-line process. Rather than substituting one fuel for another as income increases, households instead add fuel/stove combinations in a process of "stacking" [8,9]. Modern energy forms are often used sparingly at first and for specific tasks (e.g., electricity for rice cookers or liquefied petroleum gas for boiling water) rather than entirely substituting an existing energy form that already meets household needs. Consequently, introduction of cleaner stove/fuel often, in practice, has less pollution benefit than would be estimated in advance unless an allowance is made for this stacking phenomenon. A corollary to this stacking phenomenon is that in addition to learning how to design and promote clean technologies, there is a need to understand how to discourage use of the older and often more polluting stoves and fuels in households—an area that is not yet well researched.

**How clean is clean enough?** Most biomass stoves being promoted today by nongovernmental organizations, government programs, and the new landscape of stove companies do in fact save fuel, which is important in making them attractive to households, but often do not appreciably reduce emission rates. Some have chimneys, but studies show that chimneys alone are not sufficient for achieving large exposure reductions relative to traditional stoves [10]. The few biomass stoves currently on the market with very low emissions have small electric blowers, increasing their cost and complexity. A new development, however, is a technology where the heat of the stove operates the blower, eliminating the need for electricity. Little field evidence, however, is yet available on households' acceptance, usage, and performance of such stoves over time. Through its air quality guidelines procedures, WHO is currently working to establish the limits to stove emissions that will allow household pollution levels to be below its official air quality guidelines for PM and CO [11].

## IMPLICATIONS FOR HOUSEHOLD ENERGY INTERVENTIONS AND POLICIES

The complex energy use practices of many households and nonlinear relationship between combustion particles and CVD risk has important implications for the implementation and evaluation of HAP interventions and policies. As discussed, the most efficient and lowest polluting fuels and

GLOBAL HEART, VOL. 7, NO. 3, 2012
September 2012: 243–247

stoves tend to also be the most expensive, posing a major challenge for poor households. However, if the greatest health benefit occurs at very low pollution exposures, then the higher priced, higher-quality interventions may also be the most cost-effective and could be promoted through a combination of programs and policies including user involvement, market-based approaches, and the promotion and availability of targeted subsidies or microcredit programs.

Second, because households in many areas operate with multiple fuel and energy sources (e.g., cooking, space heating, and lighting), a single intervention may not effectively reduce pollution levels to the levels that meet the WHO guidelines. Rather, it is a combination, or package, of clean energy technologies that might best achieve this goal. Cooking with solid fuels is estimated to be the largest overall contributor to global HAP exposures; however, studies in colder regions indicate that space heating plays a major, and in some cases equally large, role in determining pollution concentrations and exposures in these settings [12,13].

Consequently, in addition to continued work to develop and assess clean cooking technologies, there is a need to initiate research and development efforts to develop and assess clean energy packages that address multiple energy sources that may be necessary to reach sufficiently low exposures levels, factoring in technical performance and usage.

## FUTURE RESEARCH NEEDS ON HAP INTERVENTIONS AND CVD FROM A POLICY PERSPECTIVE

Thus, a key policy question becomes: How can total exposure levels be lowered into the low range of the WHO guidelines over time and achieve the greatest health benefits in the interim?

As discussed by McCracken et al. [2] in this issue, both epidemiological and toxicological evidence suggest that HAP affects the cardiovascular system in ways that likely increase CVD risk. Though the exact mechanisms driving this relationship are unclear, they argue that there is still a strong case for the promotion of improved energy interventions as cardiovascular interventions in low- and middle-income countries. Building an evidence base on the cardiovascular benefits of various HAP interventions is crucial to this effort. In general terms, we propose three research areas where answers are needed to understand the cardiovascular impacts of HAP exposure and inform appropriate interventions and policies to address them.

**Is there a clear relationship between heart disease and household solid fuel use?** Although cohort and intervention studies are the most powerful for determining effect size and estimating the potential health benefit of interventions, there is high value to conducting case-control studies of different types of heart disease. These can be done much faster and at lower cost, but still greatly inform both the design of more sophisticated studies and growing policy interest. To date, although the integrated exposure-response relationship between combustion pollution and CVD risk provide indirect evidence, having no direct evidence greatly limits the field. All other major disease endpoints now closely associated with HAP (e.g., chronic obstructive pulmonary disease, acute lower respiratory infections, lung cancer, cataracts, tuberculosis) started with such studies, which to our knowledge have not yet been conducted with CVD outcomes. A series of these studies in different areas of the world, perhaps done with common methods allowing for combined analyses, should have the highest priority.

**By how much must we reduce people's HAP exposure to make a real difference in cardiovascular health (i.e., what is the exposure-response relationship)?** Data on both pollution exposures and health outcomes are needed to estimate exposure-response relationships and apply them to appropriate cost-effectiveness analyses. Given field limitations in these settings, understanding of the exposure response may be best achieved in the context of well-designed intervention studies that include rigorous measurement of pollution exposures, cardiovascular endpoints, and other important covariates.

**What are the impacts of viable HAP interventions in large-scale applications on exposure and cardiovascular health, and do these impacts change over time?** Few intervention studies haves included health outcomes and even less is known about the impact of combinations of interventions that may be used by any household, as well as what factors motivate households to adopt and continue using them. Intervention studies that integrate exposure assessment and health outcomes are crucial for drawing more clear-cut conclusions about which interventions are most effective. Further, these studies offer the unique vantage point of assessing the pollution and health benefits of interventions in both the short term (days to months) and longer term (months to years). Randomized trials can be used to assess the pollution and health impacts of a single intervention or limited combination while avoiding selection bias and confounding. Nonrandomized assessment of larger intervention studies can help facilitate evaluation of energy packages involving a range of solutions and also elucidate the health benefits for individuals who choose to obtain the intervention (i.e., the beneficiaries in practice).

## CONCLUSIONS

Household cooking and heating with biomass and coal in inefficient stoves are among the world's most common tasks. There is growing evidence of a wide range of health outcomes associated with HAP, including limited direct and indirect evidence of cardiovascular impacts where the largest change in relative risk seems to occur at the lower end of the exposure distribution. Reducing HAP emissions and exposures to levels that meet or exceed the WHO guidelines should be a high-priority task for the cardiovascular and public health communities. Other than the proven, but expensive alternatives of gas and electricity, there are a number of housing, energy, and behavioral interventions, ranging from improved insulation to ventilation to advanced combustion biomass stoves, but only a few at present show promise of reaching low pollution levels in large-scale dissemination still using solid fuels. Relatively little is known about their health benefits, particularly for cardiovascular outcomes, and even less is known about combinations of interventions that best meet the full energy needs of households. We hope that future investigations will provide greater insights into the cardiovascular effects of HAP and, perhaps more importantly, what interventions, singly or in packages, will most effectively reduce HAP exposures to low levels and spur large gains in global health.

## REFERENCES

1. Rajagopalan S, Brook R. Indoor-outdoor air pollution continuum and CVD burden: an opportunity for improving global health. Global Heart 2012;7:207–13.
2. McCracken JP, Wellenius GA, Bloomfield GS, et al. Household air pollution from solid fuel use: evidence for links to CVD. Global Heart 2012;7:223–34.
3. Smith KR, Peel J. Mind the gap. Environ Health Perspect 2010;118: 1643–5.
4. Pope CA 3rd, Burnett RT, Turner MC, et al. Lung cancer and cardiovascular disease mortality associated with ambient air pollution and cigarette smoke: shape of the exposure-response relationships. Environ Health Persepect 2011;119:1616–21.
5. World Health Organization. Air Quality Guidelines: Global Update for 2005. Copenhagen, Denmark: WHO Regional Office for Europe; 2006.
6. Yang XD, Jiang Y, Yang M, Shan M. Energy and environment in Chinese rural housing: current status and future perspective. Front Energy 2010;4:35–46.
7. The Partnership for Clean Indoor Air. ISO International Workshop on Clean and Efficient Cookstoves. Available at: http://www.pciaonline.org/proceedings/iso-international-workshop-clean-and-efficient-cookstoves. Accessed June 11, 2012.
8. Masera OR, Saatkamp BD, Kammen DM. From linear fuel switching to multiple cooking strategies: a critique and alternative to the energy ladder model. World Dev 2000;28:2083–103. Available at: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3226505/. Last accessed September 9, 2012.
9. Ruiz-Mercado I, Masera OR, Zamora H, Smith KR. Adoption and sustained use of improved cookstoves. Energy Policy 2011;39:7557–75.
10. Smith KR, McCracken JP, Thompson L, et al. Personal child and mother carbon monoxide exposures and kitchen levels: methods and results from a randomized trial of woodfired chimney cookstoves in Guatemala (RESPIRE). J Expo Sci Environ Epidemiol 2010;20: 406–16.
11. World Health Organization. Indoor Air Pollution. Available at: http://www.who.int/indoorair/en/. Accessed June 11, 2012.
12. Edwards R, Liu Y, He G, et al. Household CO and PM measured as a part of a review of China's National Improved Stove Program. Indoor Air 2007;17:189–203.
13. Baumgartner J, Schauer JJ, Ezzati M, et al. Patterns and predictors of personal exposure to indoor air pollution from biomass combustion among women and children in rural China. Indoor Air 2011;21: 479–88.