Chapter 13
Household Air Pollution from Cookstoves: Impacts on Health and Climate

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Abstract Household air pollution (HAP) is an exposure of poverty. The success in having a sustainable reduction in HAP requires an understanding of the traditions and culture of the family as well as the causes of poverty that place the family at the bottom of the energy ladder. An integrated approach to reducing HAP with efforts also aimed at correcting other poverty-related issues is challenging but offers the hope for addressing root causes of poverty in a community setting that provides a more comprehensive and sustainable approach to improving health, the environment, and, ultimately, the global climate. From one perspective, research that provides detailed exposure-responses to HAP may seem superfluous to the obvious need for poor families to breathe cleaner air at home. One can argue that we already have decades of information on the health risks from outdoor air pollution or the products of incomplete combustion from tobacco smoke and so further research is not needed. However, there is a compelling need to know how clean a stove or fuel must be to significantly reduce health risks, so that with proper use, major implementation of such new technology may reasonably provide the intended benefits for improved health, the regional environment, and the global climate. The alternative of providing electrification or use of clean fuels such as LPG may not be realistic for the

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world's poor for decades to come, if ever. Addressing the key scientific gaps related to HAP and its reduction will provide critical new information that can inform large scale implementation programs to provide sufficiently clean household air for families living in poverty, such that diseases are prevented, a healthier lifestyle is promoted, and a reduction in global warming trends buys more time for a planet in peril from climate change.

Keywords Biomass • Household air pollution • Climate change • Poverty and climate change

Household air pollution (HAP) from cooking fires in mostly low and middle income countries contributes to major health and environmental risks [1–3]. HAP is a result of incomplete combustion of solid fuels such as biomass and coal that is typically used for cooking, heating, and lighting in homes of those living at the bottom of the energy ladder. Biomass fuels consist of wood, crop residues, charcoal, or dung. Almost three billion people on the planet rely on use of solid fuels with the exposure to HAP contributing to almost four million deaths annually [3]. In addition, the consumption of these solid fuels causes regional environmental degradation through deforestation and the household emissions at scale represent a sizeable fraction of the outdoor air pollution in villages and cities [4]. Furthermore, some of these emissions such as black carbon are short-lived climate forcers that can contribute to global warming [5]. HAP is both a major health risk for the poorest people on the planet and a major risk for global climate change; thus, its remedies which are possible today offer the unique opportunity to improve the health and quality of life of the world's poor and, at the same time, provide hope that the global warming trends can be mitigated by reducing the impact of the short-lived climate forcers.

Cooking Fires and the Role of Women

Use of cooking fires goes back to the origins of our species and likely contributes to our evolutionary success as an intelligent species through improved nutrition [6]. Many of us harbor pleasant memories of camping fires and perceive cooking even in primitive sites as a warm and nurturing experience. Cooking fires in poor households reflect generations and centuries of traditions and cultural practices that reinforce patterns of behavior that often contribute to defining the role of women in a social and familial context. Cooking is not only a duty that falls almost exclusively to women, they are also responsible for the fuel gathering, a form of drudgery that occupies significant time in their daily routine and places the women and accompanying children at considerable personal risk, if they must walk miles from their villages to gather fuel [7]. Thus, because of the role of women in cooking and fuel gathering, women are at the center of this environmental issue. Therefore, women are additionally the key to the success of the proposed solutions to address HAP.

Proposed interventions to reduce HAP require the successful adoption and use of new stove or fuel technology, which can only be achieved through support from women. The ability of women to have a voice in the family decisions and to adopt the behavior changes necessary for reducing HAP requires fundamental changes in social and cultural practices. We emphasize this message early in this chapter lest the new and increasingly affordable technologies to reduce HAP suggest that the health and environmental risks are easily managed and implemented; they are not. Failure is always more likely than success. This is well demonstrated in a recent Ted Lecture by David Damberger, a member of engineers without borders, who articulates the need in any development enterprise to carefully evaluate the long-term outcome of any intervention, as most will fail [8]. Current efforts of large scale implementation of improved cookstove technology targeting the world's poor will require involvement of women in all levels of participation to achieve success. Implementation programs require constant evaluation and research to be certain that expected health, environmental, and climate benefits are in fact realized.

Cooking Using Solid Fuels and Possible Cooking Solutions

The three billion people who use solid fuels for cooking or heating typically use a variation of a three-stone fire with fuel being pushed into the fire gradually from the sides or, if affordable, use a primitive stove that provides the basic needs of cooking [9]. If a stove exists, it is often without a chimney or flue as they typically require detailed construction and maintenance to function properly. Over time, efforts for adequate removal of cookstove emissions are often not sustainable and emissions are simply released into the household [10]. This is how almost half the planet lives.

For decades, nongovernmental organizations (NGOs), local and multinational manufacturers, development agencies, host country governments, and foundations have struggled with improving the quality of cookstoves in lower and middle income countries, which is where the majority of the world's poor live. Some of these efforts have had substantial success such as in China [11] or more limited success as in the case of India [12]. In the majority of implementation studies around the world, there has been little study of the impact of "improved cookstove" programs on health or environment. Most implementations are often conducted at such a small scale and in such different cultural settings, that benefits are assumed and comparisons across programs are difficult.

In the past several years, there are increasing efforts to develop better coordination of the efforts of implementation and to develop a common knowledge base about the principles of stove efficiencies, affordability, and successful implementation. The best example of this effort is the Partnership for Clean Indoor Air (PCIA) led by the US Environmental Protection Agency (EPA) that has more than 500 members including NGOs, manufacturers, governments, academic institutions, and others (http://www.pciaonline.org). Since there are many "improved" cookstoves on the world market, the PCIA has focused much its attention on improving the understanding of what is an efficient and clean burning stove.

There are two types of cookstove efficiencies that impact health and the environment: (1) fuel efficiency and (2) combustion efficiency [9, 13]. Fuel efficiency reflects the amount of fuel required to achieve a specific task, such as a controlled water boiling test [9, 13, 14]. Fuel efficiency is critically important to households as stoves with improved fuel efficiency save the family fuel costs and time lost in fuel gathering. Reductions in time required to gather fuel are important for both women and children because saved time could be redirected to enhance educational and economic growth. Improved fuel efficiency will reduce the quantity of solid fuel burned and, thus, the quantity of CO_2 released from cooking fires. The second type of efficiency relates to the efficiency of combustion itself, and is necessary for reducing particulate matter (PM) that impairs health. $PM_{2.5}$ is that fraction of aerosol particles that is smaller than 2.5 μm and poses special risks to human subjects due to its access to the lower respiratory tract and alveolar structures of the lung, where gas exchange occurs [15, 16]. Many outdoor air quality standards rely on $PM_{2.5}$ and $PM_{10.0}$ to reflect the risk of these air pollutant fractions to human health. Carbon monoxide (CO) is also a very dangerous pollutant, especially with the use of charcoal as a fuel [17]. Improving the combustion efficiency of a stove is key to reducing harmful emissions such as $PM_{2.5}$ and CO. Black carbon is part of the $PM_{2.5}$ fraction and is reflected as "soot" to the observer. Successful reduction of these pollutants will reduce human exposures and improve human health. There can be considerable differences in combustion and fuel efficiencies between stove testing sites and the household setting related to many factors including choice of fuel, ventilation, location of stoves, and human behavior. Therefore, demonstration of cookstove fuel and combustion efficiencies requires validation in the households of low to middle income countries to achieve desired benefits with implementation.

Another critical component to reducing exposures to household members is to understand how human behavior or cultural traditions may impact level of exposures. For example, the solid fuels collected (or purchased) for the stove must be sufficiently dry and combustible to perform the cooking task to achieve the reduced levels of emissions. Often, people will collect anything that burns easily such as leaves or crop residues which contain excessive moisture, and, when burned in even the most advanced stoves, will result in a very smoky indoor environment. In addition, there are special challenges during the transition from a traditional fire to use of an improved stove. Many families continue to use both types of stoves at the same time. In this common scenario, there may be some minor reduction in emissions with new cookstove technology. However, the reduction in indoor ambient pollution may be far less than that required to significantly improve human health. Often, the new improved stove or fuel is not properly designed to meet the complex cooking and cultural needs of the household including the absence of a traditional smoky flavor which makes it less desirable. Improving the efficiency of stoves or fuels offers the potential for multiple benefits to both households and the environment. However, implementation at large scale requires thoughtful interaction and participation with families and communities with a sensitivity to cultural traditions to ensure adoption of new technologies and realization of the co-benefits.

In an effort to bring together the diverse interests that surround HAP and its multiple adverse impacts, the United Nations Foundation launched the Global Alliance for Clean Cookstoves in September 2010 (http://cleancookstoves.org). The Global Alliance for Clean Cookstoves is a public–private partnership with a mission "to save lives, empower women, improve livelihoods, and combat climate change by creating a thriving global market for clean and efficient household cooking solutions." The Global Alliance has a stated goal to have 100 million homes adopt clean and efficient stoves and fuels by 2020. The US government is a key partner with a commitment of more than $50 million with almost half representing research and training efforts by the National Institutes of Health [1]. The Alliance has already developed hundreds of partners to help meet its mission and goals including other governments around the world, multinational companies, foundations, and NGOs. If successful, the Global Alliance will provide a forum for major implementation of new technology to reduce HAP and its health and atmospheric impacts that will use ongoing research and evaluation to validate whether such impacts occur at the scale expected. This ambitious effort is potentially a "game-changer" in bringing recognition and resources to address this global threat to human health and the environment.

Stove Testing

There are multiple sites today where stoves can be tested for fuel and combustion efficiencies. The US EPA offers rigorous stove testing at its facility in Research Triangle Park, North Carolina, USA, to determine emission patterns under controlled conditions [18]. In addition, Aprovecho Research Center in Cottage Grove, Oregon, offers similar testing but also offers a portable stove testing lab that can be used anywhere in the world [14]. Similarly, Berkeley Air in Berkeley, California, offers state of the art testing of stoves that complement a number of technologies related to HAP and stove use including exposure monitoring devices [19]. The PCIA web site http://www.pciaonline.org keeps up to date information on available stove testing facilities around the world as this technology moves into the host countries where stove testing is so critical to assess the potential benefits of an "improved stove." Today, the standard practice is to test stoves both under laboratory conditions and in the field, where the testing more closely replicates family use and exposures.

Health Impacts of Household Air Pollution

HAP is the number one environmental cause of death in the world. These deaths are primarily from respiratory conditions including acute lower respiratory tract infection (ALRI) in children under age 5, chronic obstructive pulmonary disease (COPD), and lung cancer as reported in 2009 for the year 2004 [2] as well as from inclusion of cardiovascular diseases as reported in the recent update of the Global Burden of

Disease (GBD) 2010 [3]. The lung cancer risks are almost exclusively related to coal use for cooking and heating in China [20], although the GBD 2010 report now includes lung cancer from biomass HAP exposure [3].

Outdoor and HAP share many of the same products of incomplete combustion, although typically the household levels of these pollutants are of much higher concentration [21, 22]. Also, the same is true of emissions from burning of tobacco, the other “biomass.” Studies of health risks from HAP may well be informed from these related exposures, especially if exposure-response data are comparable across the different exposures.

A trans-US Government workshop held in May of 2011 addressed the state of the science of health impacts from HAP and offered a number of recommendations for future research related to health risks [23]. These findings relate to additional health risks from a small number of studies of HAP that may require replication but also include human health risks related to what we know from outdoor air pollution and tobacco smoke. Some of these putative risks will require further study in populations living with HAP, but the underlying rationale for these studies based on similar exposures is strong.

Examples of probable health risks attributable to HAP include cardiovascular disease, other respiratory diseases such as asthma or interstitial lung diseases, pregnancy outcomes such as birth weight, prematurity, or perinatal complications such as sepsis, infectious diseases such as acute pneumonia in older children or adults or tuberculosis, cancers related to HAP from non-coal sources such as biomass, and ocular disorders such as cataracts or trachoma. Of course, some health risks from indoor fires are unrelated to HAP. Burns and scalding are often under-reported and yet represent a life-changing risk for women and children that can include death [24]. Thus, stoves must not only be more efficient to promote health but also be tested for safety to reduce risk of burns.

Potential Host Risk Factors That Predict Adverse Health Effects Associated with Household Air Pollution

There are numerous studies supporting adverse health effects of chronic exposure to HAP related to use of cookstoves and exposure to incomplete combustion of solid fuels. The average of particulate exposure with use of indoor cookstoves is in the range of milligrams per cubic meter and peak levels can reach 10–30 mg/m^3 [25]. This level is orders of magnitude higher than current EPA regulatory standards for outdoor air pollution, which is currently a 24-h average of 35 μg/m^3 which is solely based on considerations for adverse health outcomes above this regulatory standard. There are limited studies of susceptible or vulnerable populations that are specifically associated with HAP related to solid fuel use. However, based on our fundamental understanding of the biological response to outdoor PM exposure and the extremely high levels of exposure encountered in homes with indoor fires, it is not unreasonable to consider that similar risk factors *may* contribute to adverse health outcomes associated with HAP. However, vulnerable and susceptible populations in the LMIC associated with this common environmental exposure have not yet been identified through rigorous scientific investigations.

There are specific groups that may be at increased risk of adverse health outcomes based on our current understanding of the biological response to particulate matter. Previous work with outdoor particulate matter exposure identifies that both life-stage (children and older adults) and low socio-economic status represent characteristics associated with increased health risk. This is highly relevant as individuals exposed to HAP include children of low socio-economic status. Studies consistently demonstrate an exposure–response relationship (duration of daily exposure and number of years of exposure with health risk). Additionally, because of the cultural role of women in many regions of the world, both women and children experience a highest level of daily exposure. Therefore, both women and children are at the highest risk of health-related complications from HAP. For example, strong associations between biomass exposure and COPD have been demonstrated in never-smoking women, but not in men [26]. These findings do not necessarily demonstrate sex-dependent differences in *intrinsic susceptibility*, but rather are more likely related to cumulative duration of exposure to HAP. Together these observations support that both women and children are likely at the highest risk of adverse health effects related to level of exposure to HAP.

The role of host genetics in the response to HAP has received little attention. However, we recognize that exposure to PM is associated with specific host genetics. Previous studies of PM have identified a potential role for genes associated with regulation of oxidative stress (GSTM1, GSTP1, GSTT1, HMOX1, CAT, MNSOD), detoxifying enzymes (NQO1, EPHX1), and inflammation (TNF, TGF) [27]. It remains unclear whether the response to HAP is dependent on similar host genetic factors as the specific components of HAP are different than those associated with outdoor PM. However, a major component of HAP is black carbon and recent evidence supports that exposure to black carbon is associated with adverse effects on blood pressure [28]. In addition to the role of host genetics in response to PM, it is now clear that exposure to PM can modify host DNA. Exposure to PM can result in both DNA damage [29, 30] and shortening of telomere length [31]. Future studies will be invaluable to better understand the role of host genetics in response to HAP and the potential impact of this exposure on damaging host genes.

Our current appreciation of the effect of ambient environment on disease susceptibility extends beyond classic genetics. We now appreciate that common environmental exposures can modify epigenetic marks that include DNA methylation, histone modification, chromatin structure, and short regulatory RNA. These nongenetic (*non-code*) heritable changes can impact genetic expression and can have a profound lasting impact on human health. For example, exposure to traffic-related PM can result in rapid changes in DNA methylation [32] and exposure to ambient PM can result in modified site-specific DNA methylation [33]. Exposure to black carbon is associated with specific changes in micro-RNAs (regulatory short fragments of RNA) [34] and DNA methylation [32, 35]. The implications of these observations are that exposure to air pollution could have immediate impact on disease risk in a manner independent of changes in genetic code.

Based on the current understanding of epigenetics, pregnancy likely represents a unique window of susceptibility in programming epigenetic marks [36]. We *speculate* that early life (in utero and childhood) may represent a vulnerable population to the effects of HAP. During this period of development, HAP exposures may have a lasting effect on health through modification of epigenetic marks. One example of this long-term impact of early life exposures is that HAP may represent a major contributor to risk for noncommunicable diseases later in life, even if subsequent years of childhood and adulthood are lived in an environment free of this hazard. The core principle of developmental origins of health and disease as initially proposed by David Barker is that these windows of susceptibility in early life impact lifelong risk of disease [37]. Future work should focus on the impact of HAP on modification of the epigenome and its role in long-term risk for health and disease.

Currently there are limited available studies that identify host risk factors for adverse health effects associated with exposure to HAP. There is strong evidence supporting an exposure–risk association with HAP, which identifies both women and children at the highest risk of adverse health consequences. We speculate that similar to outdoor particulate matter exposure, undefined host genetics likely contribute to the biological response to cookstove emissions. Ambient exposures can modify host epigenetic marks that could alter disease risk and should be considered in future studies of biomass exposure. Identification of both *susceptible* and *vulnerable* populations for the health effects of indoor biomass exposure will require multidisciplinary studies integrating quantification of environmental exposures, genetic/epigenetic marks, and social context.

Regional Environmental Degradation

Fuel gathering is necessary for most of the world's poor to maintain a supply of fuel for cooking, heating, and lighting within their homes. It may reflect a range from walking long distances to collect wood in areas that are deforested, to picking up burnable debris along the roadside to pilfering discarded chunks of coal, where available. As noted previously, fuel gathering long distances from the safety of the village places women and their accompanying children at risk from gender-based violence, as well as injuries from heavy lifting, animal attacks, and insect bites [7]. Progressive deforestation due to uncontrolled consumption of wood for fuel has enormous social, environmental, and climate consequences as the loss of trees directly impacts biodiversity with loss of habitats for animals as well as loss of plant life required for a balanced ecosystem [4, 7, 38–40]. This, in turn, begins a cascade which can impair effective water management that can result in pooling of water that exacerbates the environmental degradation as well as puts human subjects at risk for illness including infectious diarrhea and vector-borne disease such as malaria. As a "picture is worth a thousand words," there are several aerial photographs of national boundaries around the world that reflect differing environmental policies between countries that exist in nearly identical geographic circumstances.

Fig. 13.1 Island of Hispaniola demonstrating impact of deforestation in Haiti compared with Dominican Republic (DR). Haiti is the poorest country in the Western Hemisphere and shares the Island of Hispaniola with its neighbor, the DR. The population of Haiti relies on household fuel principally in the form of charcoal. There has been virtually no formal governmental policy in Haiti to protect its forests as fuel needs have increased over the past decades. The resulting deforestation results in a marked visual difference apparent in this NASA satellite photograph of the island with Haiti appearing largely barren and the DR that has federal policies regarding forest management, demonstrating a significant retention of its forests and biodiversity. http://earthobservatory.nasa.gov/IOTD/view.php?id=5352

One such example is the island of Hispaniola in the Caribbean, that is home to both the Dominican Republic and Haiti (Fig. 13.1). Haiti relies almost entirely on charcoal as its primary energy source for residential use of solid fuels and the environmental consequences are self-evident, placing the country at major risk for repeated flooding and with a loss of its once rich biodiversity.

Contribution of Household Air Pollution to Outdoor Air Pollution

The contribution of HAP on the level and composition of outdoor air pollution remains poorly characterized. However, given the global prevalence of households that use solid fuels as the primary source of household energy needs and the extremely high level of HAP, it is highly probable that HAP significantly contributes to outdoor air pollution. For example, one remarkable historical event is the London smog of 1952 that resulted in 12,000 excess deaths and was attributed, in part, to HAP from the myriad homes that relied on residential burning of coal [41]. It is recognized that black carbon is an important component of HAP. The relative contribution of HAP as source of black carbon in outdoor air pollution, when compared to industrial emissions, remains unknown. Future studies should focus on the contribution of HAP on ambient outdoor air pollution. Current global efforts to replace traditional cookstoves provide an opportunity to better understand the contribution of household incomplete fuel combustion on external environment. The Surya project described later in this chapter offers the first such opportunity to address this issue. Interventions on household stoves on a large scale could have the potential co-benefits of improved indoor environment and reduce emissions that may impact outdoor air pollution.

Role of Black Carbon and Other Short-Lived Climate Forcers

Rapid and meaningful progress on slowing global warming is achievable if we recognize that global warming is caused by two different types of pollutants. The first is the long-lived carbon-dioxide released by fossil fuel combustion, which stays in the atmosphere for a century to thousand years. Most climate policies have focused on CO_2, but it will take decades and trillions of dollars to reduce emissions significantly. The world cannot afford to lose such decades. The planet has already warmed by more than 0.8 °C and the resulting symptoms are being perceived in rising sea levels, melting mountain glaciers including in the Himalayas and the Alps, large scale retreat of the Arctic sea ice and warming of the ocean waters penetrating to a depth of 1,000 m or more, and such extreme weather as droughts, floods, and heat waves. Worse, humans have already dumped enough greenhouse gases in the atmosphere to warm the planet by more than 2 °C [42]. Even if we were to replace half of all fossil fuel use with renewables, the warming will continue to increase for decades, because roughly half of the CO_2 molecules live for a century or more once released.

Fortunately, the world can get out of this seemingly hopeless predicament by broadening its focus to the *second* type of pollutants. Roughly half of total global warming is due to the release of four of these: dark soot particles called black carbon; and the gases methane, lower atmospheric ozone, and the halocarbons (CFCs, HCFCs, and HFCs). These pollutants (except CFCs, which are already banned and few other halocarbons) stay in the atmosphere for only weeks to a few decades and hence are referred to as short-lived climate forcers. Cutting these short-lived climate warming pollutant levels in half, which is feasible with current technologies—as UNEP's Report on black carbon and ozone has recently demonstrated [43]—would quickly reduce the warming trend by 50 % [44] and give the world 2–4 decades for the effects of CO_2 reductions to take hold. In addition such measures can save 0.7–4.7 million lives annually and protect more than 100 million tons of crops from air pollution-related damages [45]. The effects will also be quickly realized. For example, if we were to eliminate black carbon emissions by diesel vehicles today, their warming effect would disappear within weeks to a month. The cost of such reductions would not cripple economies; for example, between 1989 and 2007, California reduced its black carbon emissions by as much as 50 %.

Black carbon and ozone in the atmosphere have major regional climate effects, including melting the Himalayan glaciers and decreasing the monsoon rainfall over S. Asia [43, 46, 47]. In addition, both these climate warming agents lead to melting of Arctic sea ice [43]. China and India have a common interest in cutting the black carbon and ozone that is melting their shared glaciers, killing millions and destroying millions of tons of crops. The United States and Europe share common interest in the Arctic where black carbon and other short-lived pollutants are responsible for almost half of the melting ice. Modest steps that attack these short-lived climate forcers, with fast and measurable responses, are the best way to jump-start the stalled climate mitigation actions.

Improved Cookstoves or Fuels as Interventions to Reduce Health Impacts

As the majority of HAP is from cooking fires, it is reasonable to pursue interventions with more efficient stoves and fuels that will result in dramatic reductions in emissions and in exposures to family members. The challenge to date has been that although many "improved stoves" have demonstrated improved fuel efficiency with expected savings in fuels from 30 to 50 %, exposure reductions have been more modest. The recently published RESPIRE study from Guatemala suggests that exposures may need to be reduced by 50 %, and perhaps as much as 90 %, to reduce the risk of pneumonia in young children [48]. These findings were the result of a controlled trial with improved built-in stoves with added chimneys that physically replaced the traditional stoves, thereby removing the risk that the families might continue to use the traditional stoves as well. Participants in the study were trained in the proper use and maintenance of the stoves and chimneys and community workers and investigators were available to monitor the intervention as well as the exposure assessments. Thus, multiple factors reinforced the correct use of the intervention to achieve the results of dramatic exposure reduction.

It is challenging to consider how to achieve similar results from implementation of cookstoves that are sold in local markets but will not have the support systems in place similar to that of a controlled trial that reinforces proper stove adoption and use. NGOs or government programs working closely with communities can develop village-level training and educational programs to provide many of the same support systems, if well planned and implemented. There are many, perhaps thousands, of cookstove types available at local markets in lower and middle income countries. Examples of many of these stoves have been tested for various performance measures including fuel and combustion efficiencies (Fig. 13.2) [9, 13, 14]. Typical

Fig. 13.2 Display of multiple cookstove types used around the world. This photograph shows the wide variety of cookstoves using solid fuels in LMIC including: Open "3-stone" fire, wood fuel, Berkeley Darfur, wood fuel, Envirofit G-3300, wood fuel, Onil, wood fuel, Philips HD4008, wood fuel, Philips HD4012, wood fuel, Sampada, wood fuel, StoveTec GreenFire, wood fuel, Upesi Portable, wood fuel, GERES, charcoal fuel, Gyapa, charcoal fuel, Jiko, ceramic, charcoal fuel, Jiko, metal, charcoal fuel, KCJ Standard, charcoal fuel, Kenya Uhai, charcoal fuel, StoveTec prototype, charcoal fuel, Belonio Rice Husk Gasifier, rice hull fuel, Mayon Turbo, rice hull fuel, Oorja, biomass pellet fuel, StoveTec TLUD prototype, wood pellet fuel, Jinqilin CKQ-80I, corn cob fuel, and Protos, plant oil fuel (Courtesy of James Jetter, U.S. EPA, National Risk Management Research Laboratory Air Pollution Prevention and Control Division, Stove Testing Center, Research Triangle Park, North Carolina, USA)

"rocket stoves" achieve reasonable fuel efficiency with reductions in fuel use of about 30 %, but the exposure reductions will be less than the 50–90 % noted in the RESPIRE trial to achieve risk reduction for acute pneumonia. Additions of fans to the rocket stoves, the so-called fan stoves, offer greater efficiencies for both fuel use and emissions [13, 14]. The Philips stove was one of the first examples of a successful commercially available fan stove produced at scale. And many of the liquid fuel-based stoves, such as LPG, propane, biogas, or alcohol, offer the opportunity for being ultraclean with exposure reductions greater than 90 % [13, 14, 49, 50]. There are also natural draft, "top loading updraft" (TLUD), and other gassifier stoves, all of which offer opportunity for marked reduction in emissions [13, 14]. And finally, solar-based stoves offer the advantage of zero emissions and no fuel costs [13]. However, there can be issues with solar stoves such as the timing of cooking (early morning and evening) when sunlight is not available, or during rainy seasons when alternatives are needed or, finally, the adoption of solar cooking from traditional cooking methods may be too great a change for some families. Nonetheless, solar cookers are a viable alternative as the primary means of cooking or as a supplement to an "improved" solid fuel stove. An additional strategy that can extend the cooking cycle without additional energy input is heat-retention cooking [9]. This method uses devices such as a "haybox" that is insulated and houses a cooking pot recently removed from a cookstove that limits loss of heat and permits the food to continue to cook. Such an integrated approach to cooking makes sense from both an energy usage perspective and a health and climate perspective. The diversity of cookstoves on the market in the absence of widespread testing creates confusion to consumers, NGOs, and governments that wish to address this problem. In 2012, there was an international working agreement for setting standards for cookstove performance from a meeting of stakeholders hosted by the International Organization for Standardization (ISO) in The Hague [13]. This is a major advance as both companies manufacturing stoves and consumers buying stoves can be guided by internationally accepted standards to ensure a "clean cookstove" is what it says it is.

The challenge facing investigators and implementers (mostly NGOs, manufacturers, and governments) is to select cookstoves that are affordable and acceptable to households; and, yet, are sufficiently clean as to achieve dramatic reductions in both emissions and exposures. Exposure reduction of 50–90 % is critical to reducing health risks [48] and emission reduction is necessary for mitigating climate risks. Currently, the commercially available stoves most likely to provide both reduced emissions and exposures from use of solid fuels include fan stoves that use a predictable and reliable fuel source such as pellets or properly dried wood. As noted previously, there is a rapidly emerging class of stoves that are gassifiers, natural draft, or other stove types that are also available but not necessarily world-wide as yet. Commercially available charcoal stoves typically have lower PM emissions than rocket or traditional stoves but can create dangerous levels of CO as families are less aware of the dangers absent the higher PM emissions. As noted previously, liquid fuels such as LPG, propane, biogas, and alcohol offer very low emissions but ongoing cost of fuels can represent an unrealistic financial burden to a family in poverty. The key to any of these strategies is to develop a monitoring and evaluation system that documents stove use and, where possible, exposure levels in and around the household. The stove unit monitoring system (SUMS) developed by Berkeley Air offers one approach to quantitatively assess stove use for both improved and traditional stoves [51]. Personal and area exposure monitoring on a selected basis are also essential to determining whether improved stoves or fuels are delivering the impacts expected.

Surya Project as Model of Potential Interventions to Reduce Climate Impacts

Black carbon and ozone, two potent short-lived climate forcers, are also great targets for developing nations because they have other known consequences apart from their health effects. They contribute to global warming (about 25–50 % of the CO_2 warming

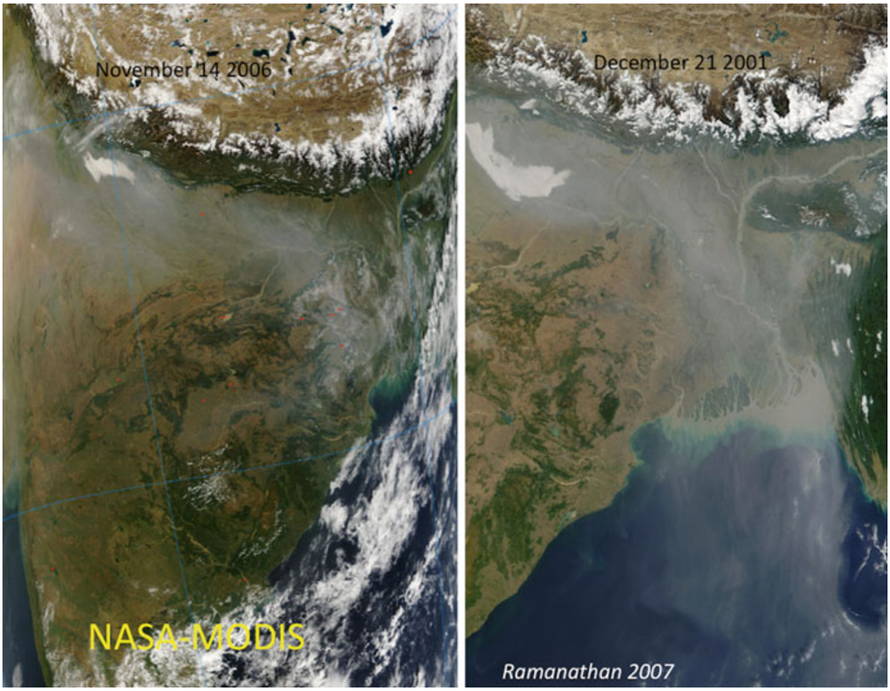

Fig. 13.3 Evidence of warming over the elevated Himalayan-Tibetan region comparing aerial photographs of 2001 with 2006. The interception of sunlight by black carbon leads to about 30–50 % of the warming effect of this region with evidence for deglaciation

as of 2005). In addition, they perturb regional climate in major ways. Interception of sunlight by black carbon leads to about 30–50 % of the warming over the elevated Himalayan-Tibetan region (Fig. 13.3) [43, 52, 53]. Black carbon interception of sunlight also weakens the monsoon circulation and reduces monsoon rainfall [43, 54, 55]. In addition both these pollutants lead to widespread destruction of crops, both directly [43] and indirectly through their effects on monsoon precipitation [56].

The world has an unprecedented opportunity to mitigate some of the disastrous effects of black carbon and ozone on climate, agriculture, water, and health with a simple act: replacing traditional cookstoves with energy-efficient and pollution-free cooking technologies. This work has already begun with international initiatives like the Global Alliance for Cookstoves, but challenges remain. The numerous cookstove initiatives that have taken place all over the world have demonstrated time and again that catalyzing widespread adoption of such clean cooking technologies will require innovative and affordable solutions.

This is where Project Surya, an internationally recognized cookstove project sponsored by the United Nations Environment Programme, comes in [52, 57]. Its goal is to demonstrate scientifically the environmental and health benefits of introducing clean cooking technologies and, ultimately, provide a rigorous evidence base for large scale action. It aims to deploy improved cooking technologies in a contiguous region with a population of approximately 50,000, thus creating a "black carbon hole" in the otherwise omnipresent pollution cloud which will be measured across space and time to quantify the multi-sector impacts of better cooking technologies. Project Surya will use cell phones, instrument towers, and satellites, and will empower village youth to work with world-class experts in documenting the impacts.

A pilot phase was successfully completed in 2010 in a village in one of the poorest and most polluted regions in the Indo-Gangetic plains. It has already achieved some ambitious and measurable outcomes including documenting the connection between indoor air pollution from cooking and ambient outdoor pollution levels [58]; identifying improved cooking technologies that reduce pollution significantly [59]; deploying improved cookstoves in all the 500 or so households in the pilot village; and verifying that we will be able to measure the impacts of a larger-scale intervention using cell phones [60]. Another, parallel pilot test has been started in Nairobi, Kenya.

Our recent data has also shown that the measured black carbon concentrations are three to five times higher than the concentrations simulated by climate models, making it all the more urgent to take action now to target it and other short-lived climate forcers [61]. Fortunately, there is a great success story to draw upon. The enormous greenhouse effect of CFC-11 and CFC-12 was discovered only in 1975 [62]. CFCs were regulated by the 1987 Montreal Protocol, because of their negative effects on stratospheric ozone, but if this had not happened they would have added enough heat energy to warm the planet by about 1 °C or more.

Value of Co-benefits for Human Health and Climate

Improved and more efficient stoves or fuels can significantly reduce stove emissions that reduce HAP but also reduce outdoor air pollution that contributes to atmospheric changes that influence the climate. Simply displacing stove emissions through a chimney or flue without improving stove or fuel efficiencies not only continues to place a family or village at risk for HAP as the pollution reenters the home from the outside, its contribution to atmospheric change remains unabated. There are additional strategies needed to augment household exposure reduction. Obviously, the technology used to reduce HAP in any intervention being studied is critical to the impact on health and climate outcomes. However, the new technology must be acceptable to the user as significant reductions in HAP require exclusive use of the new stoves or fuels by the user, as opposed to shared use with the traditional means of cooking that can generate emissions that overwhelm the benefits of a new stove or fuel. There has been too little focus on the importance that human behavior and cultural traditions play in household approaches to energy use. When large scale implementation programs with improved stoves or fuels are being conducted, there is a need to measure the impact on household and outdoor exposures either directly or indirectly that reflect the impact of the improved stove or fuel. In the absence of such measurements, the impact on human health, environment, and climate remains unknown and speculative. It is the responsibility of investigators, implementers, communities, and governments to work together to validate that major implementation programs with improved cooking solutions have the intended effects, and, if not, make the necessary changes in the implementation to ensure that the health of human subjects in poverty and the health of the planet are finally realized as true co-benefits.

Summary

HAP is an exposure of poverty. The success in having a sustainable reduction in HAP requires an understanding of the traditions and culture of the family as well as the causes of poverty that place the family at the bottom of the energy ladder. An integrated approach to reducing HAP with efforts also aimed at correcting other poverty-related issues is challenging but offers the hope for addressing root causes of poverty in a community setting that provides a more comprehensive and sustainable approach to improving health, the environment, and, ultimately, the global climate [63]. From one perspective, research that provides detailed exposure-responses to HAP may seem superfluous to the obvious need for poor families to breathe cleaner air at home. One can argue that we already have decades of information on the health risks from outdoor air pollution [64] or the products of incomplete combustion from tobacco smoke [65] and so further research is not needed. However, there is a compelling need to know how clean a stove or fuel must be to significantly reduce health risks, so that with proper use, major implementation of such new technology may reasonably provide the intended benefits for improved health, the regional environment, and the global climate. The alternative of providing electrification or use of clean fuels such as LPG may not be realistic for the world's poor for decades to come, if ever. Addressing the key scientific gaps related to HAP and its reduction will provide critical new information that can inform large scale implementation programs to provide sufficiently clean household air for families living in poverty, such that diseases are prevented, a healthier lifestyle is promoted, and a reduction in global warming trends buys more time for a planet in peril from climate change.

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