



Indoor Air Pollution

Technologies to Reduce Emissions Harmful to Health: Report of a Landscape Analysis of Evidence and Experience

Andrew Mitchell

USAID-TRAction Project

**University Research Co., LLC
Harvard School of Public Health**

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Table of Contents

Table of Contents	i
Acronym List	ii
Preface	iii
Executive Summary.....	iv
1 Introduction	1
2 Scientific Landscape: Evidence Bases on IAP Exposure, MNCH, and IAP Mitigation interventions.....	2
2.1 Evidence Base #1: IAP Exposure and MNCH	2
2.2 Evidence Base #2: IAP Mitigation Interventions, IAP Exposure and Health	3
2.3 Knowledge Gaps/Areas for Future Research	10
3 Scaling Up Landscape: IAP Mitigation Technologies and Interventions.....	10
3.1 Effectively Scaling Up	12
3.1.1 Getting the Product Right	14
3.1.2 Developing Effective financing Models	15
3.1.3 Having Effective Distribution Channels	18
3.1.4 Influencing User Behaviors Through Social Marketing.....	19
4 National and International Support Landscape: Enabling Environmental Factors for Scaling Up	20
4.1 Current Investments and Ongoing Efforts by U.S. Government Agencies, Multilaterals, Bilaterals, and NGOs	20
4.1.1 U.S. Government Agencies Involved in IAP Mitigation.....	20
4.1.2 International Institutions Involved in IAP Mitigation Technology Promotion	21
4.2 Sectoral Overlap.....	22
4.3 Current Technological Innovations	23
4.3.1 Cookstoves	23
4.3.2 IAP Monitoring.....	23
5 Existing or Potential Program Countries/Program Platforms To Conduct Research	24
5.1 Asia	25
5.1.1 India	25
5.1.2 Bangladesh.....	25
5.1.3 Nepal.....	26
5.1.4 Cambodia	26
5.2 Sub-Saharan Africa	26
5.2.1 Uganda	26
5.2.2 Ghana	27
6 Research pPriorities and Questions Within TRAction Mandate	27
7 Citations	29
Annex I — List of Persons cNsulted.....	34
Annex II — Evidence Base on Improved Cookstove Interventions and MNCH	35

Acronym List

Acronym	Definition
ALRI	Acute Lower Respiratory Infection
CDM	Clean Development Mechanism
CO	Carbon Monoxide
CO ₂	Carbon Dioxide
COPD	Chronic Obstructive Pulmonary Disease
DALY	Disability-Adjusted Life Year
GTZ	German Technical Assistance
IAP	Indoor Air Pollution
ITN	Insecticide-Treated Bed Nets
LPG	Liquid Petroleum Gas
MNCH	Maternal, Neonatal, and Child Health
NISP	Chinese National Improved Stove Program
NPIC	National Program for Improved Chulhas
PIC	Particulates of Incomplete Combustion
PM (PM _{2.5} , PM ₁₀)	Particulate Matter (PM _{2.5} /PM ₁₀ : PM with a diameter less than 2.5/10 microns)
PSI	PSI International, Inc.
SNV	Netherlands Development Organization
SSA	Sub-Saharan Africa

Preface

Acute respiratory infections annually kill an estimated 2 million children under age 5; 900,000 of those deaths are from indoor air pollution. An estimated 1.6 million people die each year from pneumonia, chronic respiratory diseases, and lung cancer as a result of indoor air pollution. The United States Agency for International Development (USAID) Bureau for Global Health is supporting research to accelerate and strengthen the implementation and scale-up of evidence-based tools, approaches, and interventions that may reduce exposure to indoor air pollution, and consequently help prevent severe pneumonia in young children and other potential negative health effects in the general population.

The USAID Translating Research into Action Project (TRAction), formerly named the Health Research Challenge for Delivery Project (HRCDD), solicits applications, and awards and manages sub-awards on research, evaluation, and introduction activities. TRAction will be soliciting Requests for Applications (RFAs) from organizations to conduct research in this area. This report is intended to identify areas within which research studies may be focused and provides a review of the following:

1. The association between existing improved stoves, as well as other technologies, and reductions in indoor air pollution (IAP) challenges and barriers to implementation.
2. Innovative methods, such as behavioral and health promotion strategies, to reduce exposure to indoor air pollution and technologies to improve indoor air quality.
3. Opportunities to leverage current investments by public and private sector entities engaged in activities related to indoor air pollution, climate change, and energy efficiency.

Recommendations from this review will be used to identify programmatic research that may better characterize evidence-based interventions to improve indoor air quality.

Executive Summary

Indoor air pollution resulting from household combustion of biomass energy is a serious impediment to improving maternal, neonatal, and child health (MNCH). International interest has grown in recent years in achieving large-scale reductions in IAP through improving combustion-related technologies — particularly biomass-burning cookstoves. However, a variety of knowledge gaps need to be filled to understand whether and how scaling up of IAP mitigation technologies, cookstoves and otherwise, can bring about desired improvements in MNCH. This document assesses the “landscape” of knowledge gaps related to past and current experiences with IAP reduction initiatives, how best to bring such interventions to scale, and the landscape of current international interest in supporting IAP mitigation efforts. The assessment is intended to inform future research into the scaling-up of IAP reduction initiatives.

Two main sets of knowledge gaps exist in relation to current and past experiences in IAP mitigation initiatives. The first set of knowledge gaps relates to the precise nature of links between IAP exposure and health. Despite epidemiological research focused on links between IAP and MNCH, as well as health more generally, little research has been able to precisely quantify relationships between exposure to IAP and health outcomes. The second set of knowledge gaps pertains to relationships between interventions and technologies aimed at mitigating IAP and actual exposure. Not only are there wide variations in the inherent quality and efficacy of IAP mitigation technologies on reducing exposure, but also a variety of environmental and behavioral factors intervene on pathways between IAP interventions and improved health. Although improved cookstoves have been the core technology of many (if not most) IAP mitigation interventions, specific cookstove technologies vary widely as do end user practices, which result in significant variation of field effectiveness in reducing IAP or improving health (to the extent that such bodies of evidence exist in the first place). Given the emphasis on improved cookstoves as a realistic strategy for reducing IAP among the world’s poorest populations, a better understanding is therefore needed on which cookstove design-fuel combinations are best positioned to bring about health improvements.

A third set of knowledge gaps relates to appropriate models for scaling up IAP mitigation technologies. Bringing the most appropriate IAP technology to scale will require finding successful models of product production, dissemination, and financing. Previous experience from large-scale improved cookstove programs, as well as from other health-related technologies with similarities to IAP mitigation (e.g., home water treatment systems and insecticide-treated bednets), suggests that a commercial-based model is best positioned to reduce IAP exposure on a large scale. Lessons learned from social marketing suggest that important factors that will affect the success of that approach include “getting the product right” (e.g., supply-side standards and demand-side product marketability), developing effective financing models (e.g., incorporating targeted subsidies and/or microfinancing, using carbon financing), effectively building or building on existing distribution channels, and influencing user behavior through social marketing.

Although significant knowledge gaps remain, there has been growing international interest and country-level efforts in disseminating IAP mitigation technologies (primarily improved cookstoves). At the international level, key organizations involved in IAP technology dissemination programs include multilateral donor agencies (e.g., GTZ-German Technical Assistance, SNV—Netherlands Development Organization, and multinational companies (e.g., Envirofit and StoveTec, both mass producers of improved cookstoves). At the national level, several USAID high-priority MNCH countries in Asia and Sub-Saharan Africa offer promising contexts in which to research IAP mitigation initiatives and technologies. These countries include Bangladesh, Cambodia, Ghana, India, Nepal, and Uganda.

The landscape assessment of knowledge gaps and current IAP mitigation efforts suggests that two broad research priorities and questions could be addressed within the TRAction project's research mandate:

1. Under which circumstances is it better to promote IAP technology packages with potentially lower, but less variable, expected health benefits compared to IAP technology packages with potentially greater, but more variable, expected health benefits?
 - 1.1. Which IAP mitigation technologies are least sensitive to user behaviors in terms of reducing exposure to IAP?
 - 1.2. Under which circumstances can the reliability of IAP mitigation technologies that are more sensitive to user behavior be improved?
2. What are the incremental benefits of each aspect of IAP interventions, including IAP technology features, complementary features, and behaviors?

Other research questions less directly related to the TRAction mandate but of potential interest include:

1. Given gaps between production costs and user willingness-to-pay for IAP mitigation technologies, are there ways in which cookstoves can be produced, marketed, and/or distributed that can serve as tipping points to propel users to adopt these technologies on a large scale?
2. Can carbon financing play a role in institutionalizing minimum emission standards for IAP mitigation technologies that are consistent with improved health?

1 Introduction

Approximately 2.4 billion people worldwide (around 34% of the global population) rely on combustion of biomass fuels for cooking and heating needs. In contrast to liquid or gaseous fuels, solid (biomass) fuels generally burn incompletely in typical household combustion devices such as cooking and heating stoves. As a result, a substantial portion (10% to 40%) of fuel carbon is converted to products of incomplete combustion (PICs) that include several compounds harmful to human health, such as particulate matter (PM), carbon monoxide (CO), nitrogen dioxide, sulfur dioxide (in coal-burning devices), and a variety of carcinogenic polycyclic aromatic hydrocarbons (Zhang & Smith, 2007).

Use of biomass and solid fuels is highest in the world's poorest regions, reaching 75% in Sub-Saharan Africa, Southeast Asia, and the Western Pacific regions (Rehfuess, Mehta, et al., 2006). In developing countries, indoor air pollution is estimated to account for 3.7% of the total burden of disease, making it the fourth most serious health risk factor after malnutrition, STDs, and inadequate water and sanitation (World Health Organization, 2007). Given connections between fuel use and poverty levels, the global distribution of ill health from IAP exposure closely tracks use of biomass fuels: over 89% of the deaths and over 87% of the Disability-Adjusted Life Years (DALYs) attributed to IAP exposure each year are in Sub-Saharan Africa, Southeast Asia, and the Western Pacific region (Smith, Mehta, et al., 2004). Further, women and children are disproportionately affected by indoor air pollution, with IAP-related acute respiratory infections resulting in around 900,000 deaths annually of children under 5 years of age (World Health Organization, 2007). A study in Bangladesh, for example, found IAP exposure among women 20 to 60 years of age to be twice as high as men of the same age group, with infant and children also exposed to high levels (Dasgupta, Huq, et al., 2006).

The following landscape analysis reports on evidence linking IAP to adverse health and experiences with technologies and interventions to mitigate IAP. It is organized into five sections. First, it reviews briefly the scientific landscape that links IAP exposure to health and IAP mitigation interventions to IAP exposure and adverse health outcomes, highlighting the knowledge gaps that remain. Second, the analysis reviews past and current experiences and challenges in bringing IAP mitigation technologies to scale. Third, it assesses the landscape of international donor support for bringing IAP mitigation technologies and interventions to scale. Fourth, it identifies six countries in Asia and Sub-Saharan Africa that may be well positioned to bring IAP mitigation technologies to scale and within which to conduct research related to TRAction's research mandate. Finally, it outlines four priority areas of research and study that could be addressed within TRAction's mandate.

The landscape analysis is based on both desk review and interviews with key informants. The desk review has included reviews of literature from a variety of sources, including peer-reviewed journal articles, grey literature accessed through the Internet, and non-publicly-available literature provided by key informants. Interviews with key informants, which were unstructured and designed to obtain a wide range of perspectives, were conducted with both technical experts (primarily in health and/or the environment) and those working directly on

bringing IAP mitigation to scale (e.g., producers of IAP mitigation technologies). The preponderance of research was conducted between June and mid-September 2010.

2 Scientific Landscape: Evidence Bases on IAP Exposure, MNCH, and IAP Mitigation Interventions

2.1 Evidence Base #1: IAP Exposure and MNCH

Links between IAP and adverse Maternal, Neonatal and Child Health (MNCH) outcomes are backed by relatively strong evidence. The strongest body of evidence links IAP to acute lower respiratory infection (ALRI) in children and chronic obstructive pulmonary disease (COPD) in women (Bruce, Mehta, et al., 2006). Previous research suggests that children exposed to particulate matter from IAP are at two to three times greater risk of a serious episode of acute lower respiratory infection from exposure to particulate matter in smoke from biomass fuels (Ezzati & Kammen, 2001a, 2001b, 2002a, 2002b; Smith, Mehta, et al., 2004). A recent meta-analysis found that children under 5 in solid fuel-burning households had a 78% greater chance of contracting pneumonia than did children in households with cleaner-burning fuels (Dherani, Pope, et al., 2008). In other MNCH-related research, one study from Ecuador found over twice the odds of infant mortality among households using biomass fuels compared to those using liquid petroleum gas (LPG) and controlling for socioeconomic and household cooking characteristics (Rinne, Rodas, et al., 2007). There is also growing evidence that exposure to particulate matter from IAP is associated with low birth weight and poor pregnancy outcomes (Boy, Bruce, et al., 2002), and a recent meta-analysis found exposure to IAP to be associated with a 35% (53%) increase in the odds of low birth weight (still birth) (Pope, Mishra, et al., 2010). Other impacts on health outcomes from biomass combustion include burns and injuries, although much less research has studied these health outcomes.

However, little research has been able to precisely quantify relationships between PIC exposure and health. Determining exposure-response relationships and/or identifying threshold levels of IAP exposure (below which reductions result in significant reduction in the risk of important negative health outcomes) are crucial to understanding the possible impacts that interventions may have on improving health. Current understanding of the exposure-response relationships for any health outcomes—let alone MNCH-related outcomes—is limited at best. To date, only a handful of published studies have gathered data by which to estimate a dose-response relationship (Ezzati & Kammen, 2001a, 2001b, 2002a, 2002b; Bruce, McCracken, et al., 2004; Dionisio, Howie, et al., 2008). According to key informants, yet-to-be-published research from the Guatemala RESPIRE study suggests that reductions of 60% to 70% in PIC exposure may result in decreased pneumonia incidence by around 20%, while 85% to 90% reductions can halve rates of pneumonia. Although such ongoing analysis of data from the Guatemala RESPIRE study may improve knowledge in this area, assessing exposure-response relationships more generally will remain difficult. For cost and logistical reasons, most studies measure personal exposure through use of exposure proxies (e.g., fuel type, housing/stove characteristics, aggregate time spent near fires). Yet because variations in personal exposure in most countries depend on a variety of factors (e.g., fuel, stove, housing, behavioral), proxy indicators are severely limited in adequately capturing exposure variation (Dionisio, Howie, et al., 2008). This

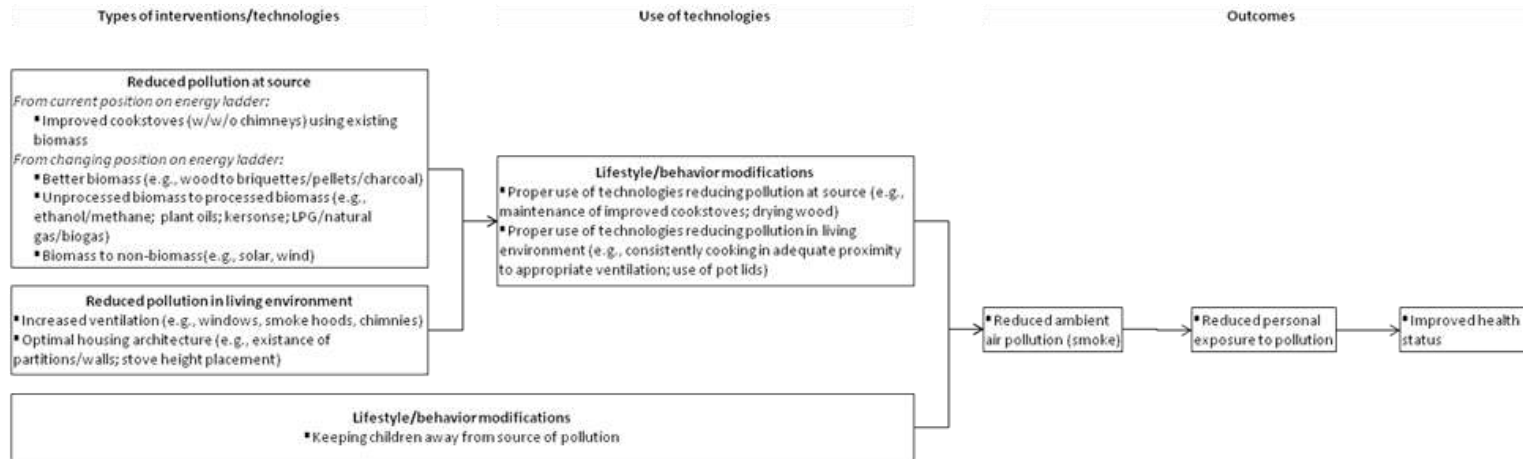
reality limits knowledge for estimating the potential health gains that might result from reducing exposure by different amounts. As pointed out by Ezzati, “little is learned [with indirect exposure proxies] about the details of the quantitative relationship between exposure and health risks” (Ezzati & Kammen, 2002a). Inability to quantify exposure and risk at even a basic level in relation to IAP severely limits ability to understand which IAP mitigation technologies are best placed to bring about health improvements when implemented on a large scale.

2.2 Evidence Base #2: IAP Mitigation Interventions, IAP Exposure, and Health

Despite decades of interventions focused on reducing indoor air pollution and mitigating adverse effects of IAP on health, wide knowledge gaps persist in the capacity of these interventions to reduce exposure to indoor air pollution in the real world (Ezzati & Kammen, 2002a, 2002b; World Bank, 2010). Although this knowledge gap is driven in part by substantial field variation in the inherent quality or efficacy of IAP mitigation technologies, part also likely relates to the many environmental and behavioral factors that intervene between interventions and improved health.

A conceptual framework of these factors is presented in Figure 1 and serves as a reference point for the following analysis. Although the range of IAP mitigation interventions can be classified into three broad categories — reducing pollution at the source, reducing pollution in the living environment, and modifying lifestyles/behaviors — this section focuses on the evidence base related to pollution at its source and incorporates evidence from the other two categories of interventions into the analysis. This approach is motivated by the observation that evidence from real-world interventions and programs are either directed solely or primarily at reducing pollution at the source (i.e., reducing pollution emissions through improving combustion devices) or at reducing pollution at the source in conjunction with living environment changes and/or behavioral modifications. Further, only a few studies attempt to isolate the effect of one or the other type of intervention on either PIC exposure or health. Exceptions include research conducted in South Africa focused primarily on linking behavior-related interventions to existing cookstove technologies to health outcomes (Barnes, Mathee, et al., 2004a, 2004b) and research by Zhou, Liu, et al. (2006) suggesting that behavioral interventions alone had no effect on PIC emission reductions in China. As such, this section does not seek to isolate evidence bases related to these three types of interventions — at pollution source, in living environment, and in behavior — but summarizes the evidence across these three broad intervention packages.

Figure 1. Conceptual Links between IAP Mitigation Technologies and Health<Q12>











Source: Authors

This analysis also concerns itself primarily with technologies focused on biomass users' current position on the energy ladder. While reducing reliance on combustion technologies with high PIC emissions can ultimately provide the largest health benefits, moving up the "energy ladder" (i.e., moving from relatively unprocessed to processed fuel sources¹) is either viable for much of the world's population only over the long term or encompasses technologies that are difficult to bring to scale. Liquid petroleum gas (LPG) and natural gas, for example, essentially eliminate the health risks associated with lower-rung combustion technologies but are out of reach for most of the world's population. Biogas is an example of a higher-rung combustion technology that provides health benefits and has gained some traction in certain Asian countries. A study carried out in Nepal, for example, found that biogas has concentrations of total suspended particles comparable to those of LPG (Acharya, Bajgain, et al., 2005). However, installing biogas "digesters" (i.e., the apparatus needed to generate biogas) incurs relatively large investment costs and infrastructure requirements, and can only be applied in certain contexts. Solar energy provides an example of a non-combustion-based energy source that entirely eliminates combustion-related health risks but that is likely to remain only a supplementary source of household energy in most contexts.

By far the most researched technologies with strong IAP mitigation connections are improved cookstoves, findings of which are summarized here (with additional detail on selected studies included in Annex II — Evidence Base on improved Cookstove interventions and MNCH). There are a variety of "improved cookstove" technologies that vary along three primary dimensions: combustion principle, energy source(s), and material(s) of construction. Table 1 provides a non-exhaustive list of both commonly used improved cookstove technologies and those that are newer to the scene (the latter examples are discussed further in Section 4.3).

¹ More precisely, fuels can be positioned on an energy ladder that relates to the amount of energy available in a given fuel, with lower rungs representing fuels with lower heating values (MJ/kg) and higher rungs representing fuels with greater heating values. For example, wet firewood (60% moisture content) is positioned on one of the lowest rungs at 8 MJ/kg; dried wood is higher at 15 – 20 MJ/kg; charcoal reaches 28 MJ/kg; and kerosene, biogas, and LPG are on the highest rungs at 45 – 46 MJ/kg (Rasmussen, E. , 2010). "Light introduction to energy scale and efficiency rate." Retrieved September 29, 2010, from <http://www.bioenergylists.org/fuels>).

Table 1. Selected Improved Wood- and Charcoal-Burning Improved Cookstove Designs

Combustion principle	Energy source(s)	Construction material(s)	Examples/notes	Appearance
Widespread cookstove technologies				
▪ "Rocket" elbow	▪ Wood	▪ Mud/clay/brick	▪ Built-in (mud) with chimney (e.g., Lorena)	
			▪ Built-in (brick) with chimney (e.g., Patsari, Inkawasi stoves)	
		▪ Metal	▪ Stand-alone (mud) without chimney	
			▪ Stand-alone without chimney (e.g., Ugastove)	
▪ Conical stove liner	▪ Charcoal ----- ▪ Wood / charcoal	▪ Metal stove body with ceramic liner	▪ Stand-alone stove and liner without chimney (e.g., Jiko stove [pictured to the right/above], New Lao stove [pictured to the right/below])	 
Newer/niche cookstove technologies				
▪ Gasifier	▪ Wood / charcoal	▪ Metal	▪ Philips wood stove	
			▪ Bio-Lite stove	
		▪ Biomass-based pellets		▪ First Energy (Oorja stove)

Previous studies suggest that improved cookstoves, by themselves or in conjunction with elevated cooking platforms and improved ventilation (e.g., flues/chimneys), can achieve reductions of 30% to 90% in the ambient concentrations of PICs (e.g., PM and CO) in households compared to traditional stoves. For example, a recently published review comparing 50 different cookstove-fuel combinations to traditional three-stone fires using standard protocols and under laboratory conditions found that rocket stoves can reduce CO emissions by 75% and PM emissions by 46%, well-operating gasifier stoves average 90% emissions reductions, and pot skirts can reduce emissions by an additional 25% to 30% (MacCarty, Still, et al., 2010). (See also Mason, 2010, for further detail on other studies.)

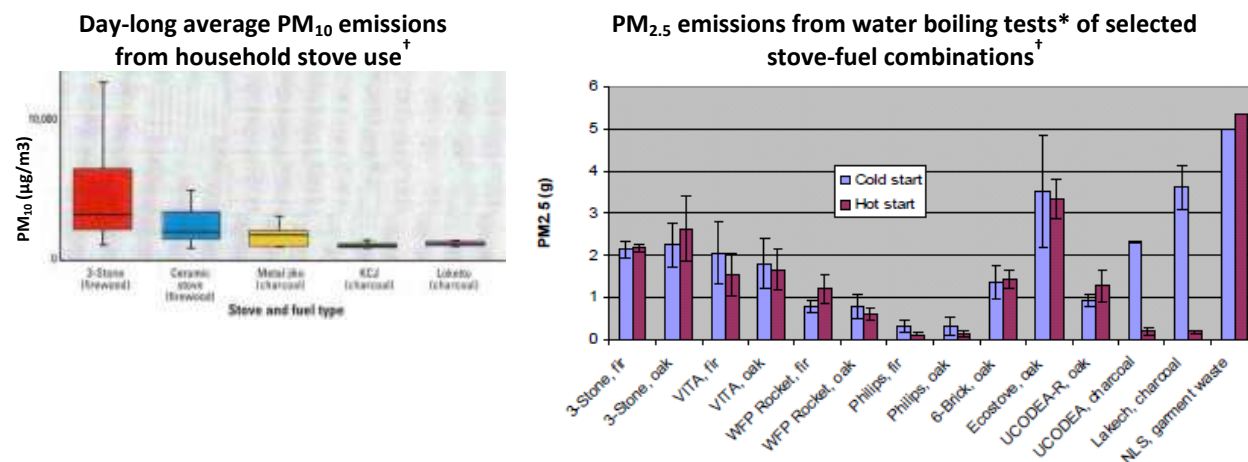
However, the body of evidence relating cookstove interventions to IAP reductions is limited on a number of fronts. Reductions in air pollution through cookstove (or other) interventions depend on a host of mediating environmental and behavioral variables including stove design features, longevity and life-course of the stove itself, the way in which the stove is used (e.g., stove placement/proximity to persons); whether lit frequently or infrequently each day; initial PM concentration levels/other sources of air pollution (independent of or caused by the cookstove itself); micro-environmental factors, which can significantly determine dispersion of (and therefore exposure to) pollutants; and environmental factors outside household living spaces that may determine exposure² (Ezzati & Kammen, 2002; Zhang & Smith, 2007). Some stoves may be relatively insensitive to use behavior in the context to which they are adapted, such as the Plancha and Patsari mud/clay/brick improved stoves (with chimneys) that are used in several Latin American Countries (LAC) countries and that have been shown to reliably reduce ambient pollutants by a 60% to 70% and up to 90% under the best working conditions (Bruce, Mehta, et al., 2006; Smith, McCracken, et al., 2010). Previous research suggests that among the contexts in which these stoves are used (e.g., Guatemala), the stove-fuel combination is by far the most important factor in PIC exposure, with several other physical housing characteristics not independently associated (Bruce, McCracken, et al. 2004). In many other contexts, however, existing stove technologies and use practices may result in much wider variation of field effectiveness in reducing PM concentrations. For instance, the popular rocket technology stoves — widely used in Sub-Saharan Africa and Asia — range in any number of characteristics, from choice of stove materials (e.g., clay or mud for locally produced models to forged metal for mass-produced models) and use in conjunction with other IAP mitigation technologies (e.g., chimneys or flues).

Along with wide variations in cookstove technologies and uses have been wide variations in field effectiveness of reducing IAP. At a country level, some studies (e.g., from India) have shown minimal or small reductions in PM while others (e.g., from Nepal) have shown reductions of around two-thirds from high initial baseline levels (Bruce, Mehta, et al., 2006). At a micro level, two studies comparing PIC emissions in widely used improved cookstoves highlight the high degree of variability. In a first study testing average day-long PM₁₀ emissions

² For example, previous research indicates that “neighborhood effects” may exist by which large numbers of households using solid fuels lead to significant reentry of pollution back into household living spaces independent of their personal use of biomass fuels (Smith, Apte, et al., 1994).

during household use of varying stove-fuel combinations, there was a high degree of variability among some stove-fuel combinations in addition to substantial variation across stove-fuel combinations (Ezzati & Kammen, 2002)(see left-hand side of Figure 2). Similarly, a recent study field-testing several different cookstove designs in conjunction with a range of biomass fuel sources found wide variations in measured PM_{2.5} concentrations emitted during a water standardized water-boiling protocol procedure (see right-hand side of Figure 2). Some cookstove-fuel combinations (e.g., gasifier wood-burning stove) reduced PM_{2.5} concentrations by 90% or more compared to traditional stoves, while others resulted in 50% higher concentrations or more (e.g., Ecostove). Further, PM_{2.5} concentrations with some stoves (e.g., two charcoal stoves) varied enormously depending on initial stove temperature — findings that relate directly back to some user behavior variables (Jetter & Kariher, 2009). Given the wide variability not only in technologies (i.e., stove design/fuel choice combinations) but surrounding conditions from setting to setting, it remains difficult to know what levels of IAP exposure reductions from a given technology may be reasonably expected.

Figure 2. Variability of PM Emissions



* Water boiling test: protocol consisting of three phases:

(1) “High power, cold start”—both stove and water start at room temperature, operated until reaching boiling temperature; (2) “High power, hot start”—conducted immediately after phase one with a hot stove and water at room temperature, operated until reaching boiling temperature; (3) “Low power”—conducted immediately after phase two with stove and water hot, operated to maintain temperature just below boiling point.

† Notes to stove descriptions:

- Unimproved traditional wood-burning: three-stone
- Improved (e.g., wind skirt, pot shield) traditional wood-burning: VITA
- Rocket wood-burning stoves: WFP, six-brick, Ecostove, UCODEA-R
- Gasifier wood-burning: Philips
- Charcoal (wood-based rather than compressed briquettes)-/non-wood-burning stoves: ceramic, Metal Jiko, KCI (Kenya ceramic jiko), UCODEA, Lackech, NLS

The evidence base linking cookstove interventions and/or use to improved health rests on even less evidence. The strongest body of evidence on health in general comes from the Guatemala RESPIRE study that has shown reductions in risk of respiratory symptoms (chest tightness, wheezing, cough, and reduced lung function), headache, and eye irritation. Additionally, the RESPIRE trial of improved stoves in Guatemala reported a 40% reduction in certain types of

high-mortality risk ALRI as a result of the reduction in IAP exposure (World Bank, 2010). In terms of maternal and child health, there is some evidence of higher ALRI prevalence among children and women and lower birthweight among wood vs. clean fuels users. Additionally, women using improved cookstoves in the RESPIRE trial experienced reduced blood pressure and were less likely to report eye soreness and headache (Diaz, Smith-Sivertsen, et al., 2007; McCracken, Smith, et al., 2007). However, other studies have found either no differences in health symptoms among improved and traditional stove users (Khushk, Fatmi, et al., 2005). Results from the Guatemala RESPIRE trial continue to be disseminated, holding the promise to substantially add to the evidence base linking improved stove use with health outcomes.

The weak evidence base that does exist suggests that fundamental changes in behavior or practices are important mediating factors between cookstove interventions and health. As suggested by Jin, Ma, et al. (2006), “a better understanding of the technology–behavior interface would allow designing technological interventions that account for, and are robust to, behavioral factors or to provide individuals and households with alternative behaviors that fulfill the original purpose of energy use while reducing exposure.” Studies of cookstove interventions on MNCH health outcomes support this contention. For example, two cookstove studies that included no behavioral component (in Mexico and Pakistan) found no significant health differences between households with improved cookstoves and those without (Khushk, Fatmi, et al., 2005; Romieu, Riojas-Rodriguez, et al., 2009). One of those studies provided a variety of behavioral reasons why this was the case, including dual use of technologies in which households keep their traditional stoves for specific cooking tasks or use multiple fuels and stoves depending on prices, seasons, and availability. The study authors concluded that stove intervention programs need to include not only the installation of the new stove but also reinforcement and further training over the following months (Romieu, Riojas-Rodriguez, et al., 2009).³

The importance of stove maintenance is also likely to be critical as well to health improvements — a factor which can be largely dependent on user behavior. As part of the design of the Guatemala RESPIRE study — for which there is some of the strongest evidence of reduced exposure/improved health — trial field workers monitored problems with the stove during weekly visits and conducted repairs as needed in order to maintain the stoves in good condition. While this action was done with the express intent of maximizing the potential effectiveness of the intervention, it also likely resulted in stoves that were in much better condition over their life-course and lasted longer than comparable non-trial improved stoves (indeed, authors of a different study in Mexico concluded that “adoption of an improved stove requires close long-term follow-up training in its use and maintenance” (Romieu, Riojas-Rodriguez, et al., 2009)). More generally, effective operation of lower emission woodstoves will almost certainly require training of users — at least initially and likely on an ongoing basis.

³ Zhou, Liu, et al. (2006) also found that the combination of introducing behavioral (health education) interventions along with improved cookstoves led to statistically significant declines in several measures of PICs. While that study suggested that the behavior-cookstove combination led to greater PIC reductions than behavioral interventions alone, it did not compare the behavior-cookstove combination to introduction of cookstoves alone.

Participation in the trial and regular trial staff visits may very well also have affected user behaviors in ways that would not be observed under normal conditions (i.e., in the absence of a trial). To what degree observed improvements in health would be diluted with wider use of such stoves that are not part of a study is therefore impossible to know.

2.3 Knowledge Gaps/Areas for Future Research

The preceding analysis on evidence bases on IAP exposure, health, and IAP mitigation interventions suggests that there are two main knowledge gaps crucial to address when considering relative merits on MNCH of scaling up alternative IAP mitigation interventions. First, a better understanding is needed on the links/relationships between exposure to PIC and health risks. There is still little understanding of the dose-response relationship between personal exposure to PIC and adverse impacts on health. Relationships could be linear, concave/convex, or even discontinuous (from a clinical point of view) wherein only exposure reduction below a certain threshold level will incur health benefits. Such understanding is basic to the ability to prioritize or pursue one set of IAP mitigation interventions/technologies over another to improve MNCH on a large scale.

Second, given the emphasis on improved cookstoves as a realistic strategy for reducing IAP among the world's poorest populations, a better understanding is needed on which cookstove design-fuel combinations are best positioned to bring about health improvements. Part of answering this question revolves around the stove-fuel technology combination itself and which technologies can be best standardized, brought up to minimum levels in terms of PIC emissions, be readily equipped with complementary technologies to further reduce IAP (e.g., chimneys), and so forth. However, another major knowledge gap that informs knowledge revolves around an understanding of which stove-fuel combinations are more or less sensitive to user behavior and the living environment (again in terms of reducing PIC exposure). Findings from the preceding analysis suggest that there is significant (if not enormous) sensitivity of IAP reductions to user behavior for at least some stove-fuel combinations, especially when stoves are used for cooking.⁴ Indeed, a study of multiple stove-fuel combinations in Kenya found that differences in user behavior (i.e., inter-household variation) accounted for 18 times the variance in average emission concentrations than differences between stove-fuel combinations (Ezzati & Kammen, 2002). Scaling up improved cookstove technologies would benefit substantially from knowing which particular stove design-fuel combinations are more or less sensitive to user behavior so as to have a better idea of the magnitude of health improvements to be reasonably expected.

3 Scaling Up Landscape: IAP Mitigation Technologies and Interventions

There are a variety of ways along three dimensions — production, dissemination, and financing — by which IAP mitigation technologies and interventions can be scaled up. Models of production range from technologies produced locally based on local materials (such as clay

⁴ PIC emissions from stoves used for heating may be less susceptible to variations in user behaviors as combustion tends to be more stable and less intense than with cooking (Jin, Zhou, et al.,2005).

cookstoves built by local masons) to those mass-produced at the international level for export (such as improved cookstoves discussed in Section 4.1.2.2). Models of dissemination include those independent of markets (e.g., distribution by governments or donor agencies) and those completely reliant on market mechanisms. Financing models include subsidized approaches (whether fully or partially and whether backed with public or private financial support), those that partially support product supply or acquisition (e.g., microfinance) and those without any form of subsidization or support.

India's and China's diverging experiences in rolling out large-scale programs to disseminate improved cookstoves provide many insights into factors likely to facilitate or hinder future scaling up in other contexts. The National Program for Improved Chulhas (NPIC) in India, initiated in the 1980s, provided a subsidy of 50% or greater to households that adopted the improved stove. While approximately 35 million improved stoves (of various types) were distributed between 1983 and 2000, analysts suggest that a flawed top-down approach resulted in many shortcomings. Specifically, provision of Government subsidies directly to producers resulted in lack of attention to consumer preferences in terms of stove construction and marketing. Stove dissemination was slow to expand and the quality of stoves distributed was questionable. According to surveys, many users did not feel that the improved stoves saved energy, reduced smoke, or were even compatible with cooking habits (Smith, Apte, et al., 1994). The subsidy also had a dampening effect on stove development in the private sector (Bhattacharya & Cropper, 2010). The program was discontinued in 2002, although the Government of India has expressed renewed interest in a nationally sponsored cookstove program.

By contrast, the Chinese government's approach to its Chinese National Improved Stove Program (NISP), also introduced in the early 1980s, focused primarily on creating enabling policy and market conditions for cookstove adoption (e.g., improving Government coordination/lowering bureaucratic barriers; leading research and development and monitoring efforts; assisting sub-national jurisdictions in selecting pilot/target areas from which to scale up production). Not only was the overall Government contribution much smaller than India's in the 1990s (around 15%), it was channeled indirectly into cookstove markets through training, administration, and promotion activities (Smith, Shuha, et al., 1993). The Chinese NISP and subsequent support for cookstoves has been judged successful in a variety of ways. From the mid-1990s onwards, support for the stove industry was replaced with extension services and certification systems to standardize stoves. The development and dissemination of improved stoves is now left mainly to market actors, with some local Government oversight, and the Government claimed that, in 1998, 185 million (78%) of China's 236 million rural households had improved biomass or coal stoves (Xiliang & Smith, 2004).

Box 1. Features of Large Scale National Cookstove Programs in China and India Affecting Implementation Success

China	India
<ul style="list-style-type: none"> ▪ Initial focus on pilot counties with biomass fuel deficits concentrated efforts and targeted markets with highest user motivation. ▪ Direct central support to counties bypassed much bureaucracy and facilitated growth of rural, self-sustaining energy enterprises. ▪ Users paid full stove price; Government support was limited to supply-side technical assistance. 	<ul style="list-style-type: none"> ▪ Nationwide roll-out diluted resources and effort. ▪ Top-down structure resulted in cumbersome program administration and little local private program ownership. ▪ Stove price was subsidized 50% by the Government, reducing perceived value of the product to consumers and incentivizing producers to orient construction to Government preferences and criteria.

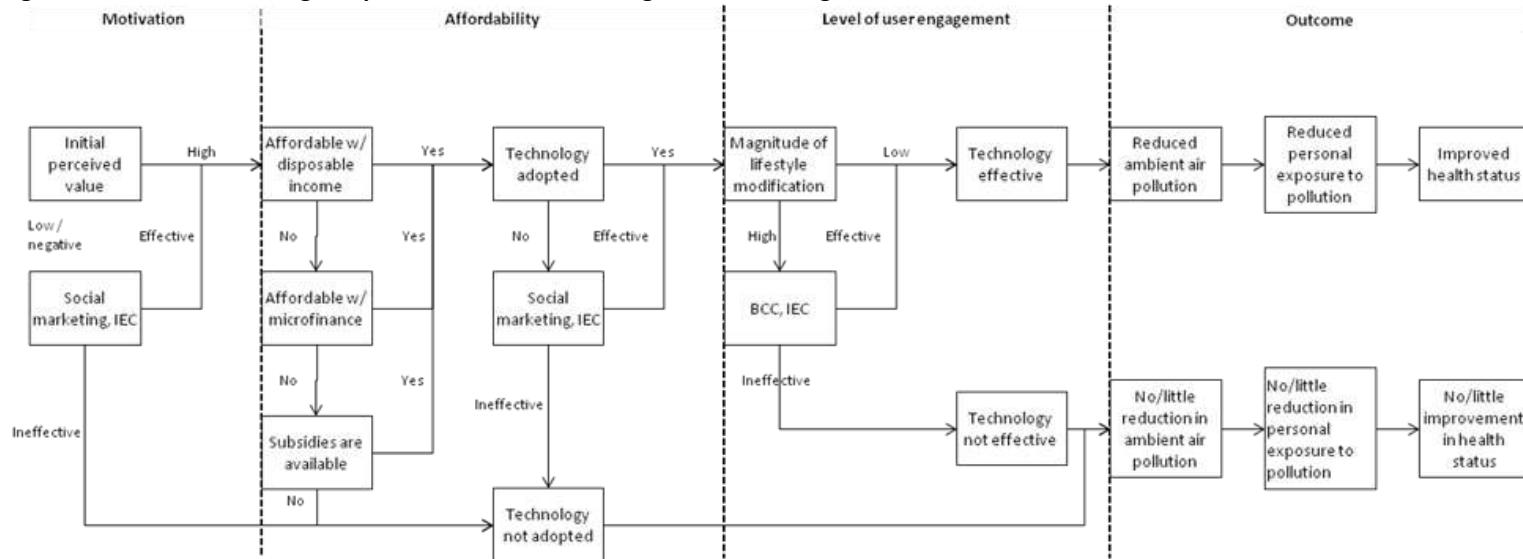
Source: Adapted from Barnes et al. (2004)

3.1 Effectively Scaling Up

Lessons learned both from IAP-related initiatives (e.g., improved cookstoves) and other health-related technologies with similarities to IAP mitigation (e.g., insecticide-treated bednets; safe water, sanitation) suggest that reducing IAP exposure on a large scale is not likely to be achieved through a fully subsidized (i.e., give away for free) approach. In a review of experiences in scaling up a broad range of home water treatment systems, for example, high “hardware” subsidies were identified as a common constraint to successful scaling-up of improved sanitation technologies (latrines) in Asia. More generally, the review concluded that commercial strategies to scaling up, while not a panacea, offered the “best hope for attaining scale” (Clasen, 2009).

There are, however, many inherent challenges in relying on a market-based approach to scaling up IAP mitigation technologies in a way that improves health. As illustrated in Figure 3, a variety of factors influence a given IAP mitigation technology’s uptake and use, including user motivation to adopt, affordability of the product, and level of user engagement required to adopt and use as intended. In many contexts, IAP mitigation technologies confront obstacles related to each factor. However, previous experience in use of a market-based approach to scaling up use of both IAP mitigation technologies and other health-related products suggest that addressing a number of issues may facilitate scaling up. These include “getting the product right,” using effective supply-side and demand-side financing models, availability of distribution channels, and social marketing to encourage product adoption (see Rai and McDonald, 2009, for a detailed synthesis of lessons learned in market-based approaches to scaling up improved cookstove dissemination). Considerations of each of these factors in relation to scaling up IAP mitigation technologies are now considered, in turn.

Figure 3. Factors Influencing Adoption and Use of IAP Mitigation Technologies



Source: Adapted from Slaski and Thurber, 2009.

3.1.1 Getting the Product Right

IAP mitigation technologies can only improve MNCH on a large scale if the technologies themselves are technically sound (from the perspective of reducing exposure to IAP) and consumers adopt and use them as intended. As such, “getting the product right” involves both supply-side standards and demand-side product marketability. Both sides may be particularly important in relation to improved cookstove technologies in which slight deviations from technically good designs can largely or completely eliminate capacity to reduce PICs.

There are two fundamental challenges to getting the product right in the context of IAP mitigation. First, there are likely to be higher demand-side barriers to overcome for encouraging adoption of better IAP mitigation technologies. To take the cookstove example, in many contexts the use of traditional wood-burning mud stoves is the norm, making improved mud stoves (or other locally crafted technology) the most readily accepted IAP mitigation technology on a variety of fronts. As highlighted by a cookstove pilot project in Bangladesh, materials for construction of improved mud stoves were already locally available and construction costs lower than those for improved stoves made with metal. This motivated the choice of a mud-based, locally produced model precisely because it represented “an easy transition for households, rather than a model that would require radical changes in cooking methods or maintenance” (Winrock, 2009).

Additionally, the same technologies that may be most readily accepted by users can be the ones that manifest the greatest supply-side variability in quality. While improved mud cookstoves have been crafted and promoted for years in countries around the world, these are, from a PM exposure standpoint, often not as effective as mass-produced and/or metal-based cookstoves, and significantly more variable in capacity to reduce PM concentrations (i.e., their ability to reduce health-related pollutants may depend almost entirely on skills of local masons). Thus although such technologies may work on a pilot basis, the quality control challenges to effectively scaling up grassroots technologies are many. As pointed out by a recent review of India’s new cookstove initiative, achieving long-term high stove performance requires advanced materials (e.g., ceramics, metal alloys) and component parts (e.g., blowers) that can only be reliably made by mass production (Venkataraman, Sagar, et al., 2010).

Second, once adopted, there are a host of behavior-related usage factors that can turn the right product into the wrong product in terms of reducing exposure to IAP. Experience from multiple countries suggests that users of IAP mitigation technologies make any number of technical modifications to products to adapt to personal preferences that adversely affect performance. In a rainfall area in India, for example, a study found that 60% of users modified wood-burning improved stoves within 6 months of adoption by increasing the firebox opening by removing the grate to accommodate larger pieces of wood, resulting in increased wood consumption and combustion (Dutta, Shields, et al., 2007). Ability to maintain these technologies can also negatively impact performance. For example, a pilot project of improved mud cookstoves in Bangladesh found a number of “problematic usage issues,” including excessive burning of fuel wood, modifications to cookstove design (e.g., placing the grate in a position lower than

required; increasing the diameter of the fuel inlet and ash outlet); and chimney cleaning practices that caused maintenance problems (e.g., decrease in diameter of chimney due to soot accumulation in the air passages, in large part because of mud and water used to clean stoves [Winrock, 2009]). In other contexts, households have been found to use traditional stoves in addition to improved stoves or stop using improved stoves when maintenance issues arose (e.g., chimney blockage), largely negating benefits of improved cookstoves (Dutta, Shields, et al., 2007; Edwards, Liu, et al., 2007).

A second behavioral issue relates to use of multiple fuel technologies. IAP reduction increases as users move up the energy ladder (e.g., from unprocessed fuel wood to coal to kerosene to liquid petroleum gas [LPG]). However, evidence suggests that as higher-rung fuel sources become available, many users do not entirely substitute those fuels for lower-rung ones but use them in a complementary (or targeted substitution) manner. From 1960 to 2000 in Mexico, for example, the total number of wood fuel users remained constant while the percentage of wood fuel users who also used LPG for certain tasks increased from 5% to almost 30% (Bailis, Cowan, et al., 2009). This suggests that “switching” to IAP mitigation technologies that incur fundamental fuel source changes can be a long-term process during which elevated IAP exposure may continue (Masera, Díaz, et al., 2005).

3.1.2 Developing Effective Financing Models

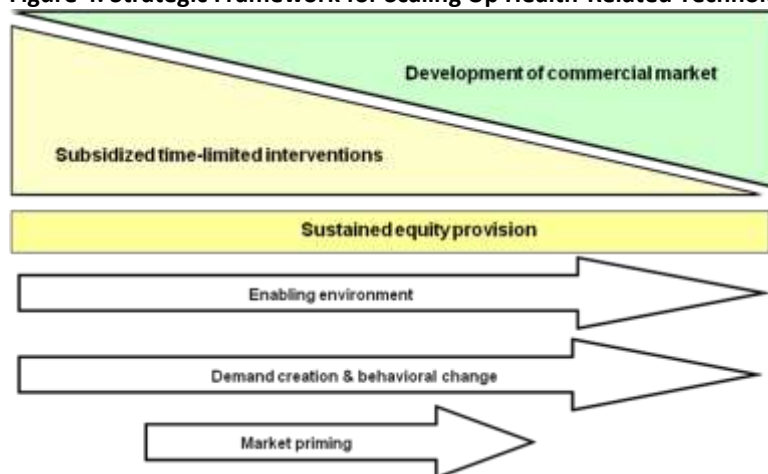
Although a commercial approach to scaling up IAP mitigation technologies is best positioned to improve MNCH at scale, these technologies are likely to continue to require some degree of subsidization and/or market segmentation to be widely adopted. In terms of improved cookstoves, anecdotal evidence and key informant interviews suggest that users are prepared to pay \$5 to \$15 for stoves that last 3 years or more. Study findings from Kenya, for example, suggest that 80% of sampled respondents would pay \$5 for two popular mass-produced improved rocket cookstoves (StoveTec and Envirofit), declining to around 60% at \$10 and less than 20% at \$17.50 (Wang, Tyler, et al., 2009). However, costs of mass-produced stoves that are both adaptable to many contexts and exhibit consistent PM/CO reductions on the order of 50% or greater (compared to traditional stoves) are likely to be \$25 to \$30 per unit. In terms of digester plants that produce biogas, costs run in the hundreds (sometimes thousands) of dollars, necessitating subsidies in conjunction with other financing models.

Two financing models are promising in relation to IAP mitigation technologies. First, and common to other socially marketed products, experience indicates that microfinancing can provide viable approaches to encouraging improved IAP mitigation technology adoption. For example, the Self-Employed Women’s Association Bank in India reportedly offers loans specifically for adoption of improved cookstoves while the Nirdhan Utthan Bank Limited in Nepal focuses solely on lending for the construction of biogas digesters (Morris, Winiecki, et al., 2007).

Lessons from other socially marketed health products suggest that targeted subsidies can be effectively used to overcome financial barriers for certain segments of the market or products. Figure 4 presents a strategic framework for scaling up socially marketed technologies (the

framework was developed for insecticide-treated bednets (ITNs) but is applicable more broadly). It emphasizes the role that time-limited and targeted subsidies may play in sustainably using a market-based financing (and delivery) model to scaling up, as well as enabling environmental conditions and creating demand/behavior change.

Figure 4. Strategic Framework for Scaling Up Health-Related Technologies



Source: Frandsen (undated).

Two types of targeted subsidies may be appropriate for scaling up IAP mitigation technologies: those targeted at certain market segments and those targeted at particular products. In terms of market segmented subsidies, a cross-country review of the PUR safe water social marketing campaign found a need to find solutions to the limited amount of water the product could treat and the need for additional materials to use PUR (e.g., two buckets). The report suggested that income-based targeted subsidies toward very poor communities, such as providing free scissors and buckets to households that want to use PUR, were effective.

Analogously, ITN experience highlights the potential importance of subsidies oriented at particular products that may be part of an overall technology. International experience in ITNs suggests that in contexts in which insecticide is sold for bednet retreatment, rates of insecticide retreatment have been characterized as “disappointingly low” — 20% or less. In China and Vietnam, by contrast, where the largest and longest sustained ITN programs in the world operate, the Government fully subsidized insecticide through a regular net-treatment service for bednets purchased on an unsubsidized basis. A key lesson is that the two basic components of an ITN — the net and the insecticide — are very different commodities, and require different models of financing support to influence behaviors in ways that are likely to result in large-scale health benefits (Roll Back Malaria, 2002).

Safe water and ITN lessons in using these two different types of subsidies — income- and product-based — may hold important lessons in scaling up IAP mitigation technologies. Given the connections between poverty and IAP exposure, it is likely that reaching the poorest market segments will require some degree of subsidized financial support to promote technology adoption (see Figure 3). As an example from an improved cookstove pilot project in Bangladesh, establishment of a revolving fund provided local entrepreneurs (in manufacturing,

installation, and retail) with capital necessary to start a business, with loans ranging from \$56 to \$700 (Winrock, 2009). Given the myriad ways in which behavior may mediate the ability of IAP mitigation technologies to reduce exposure and improve health, product-specific subsidies may be important in moving beyond scaling up of technology adoption to institutionalizing use of technologies that will improve health. For example, increasing technology adoption (i.e., initial purchase of an improved cookstove) may be most effective in a relatively unsubsidized financing model, with purchase of ancillary products or services that are likely to be crucial for reducing personal exposure to low enough levels to affect health (e.g., cookstove chimneys, costs of cookstove maintenance) done under a relatively more subsidized model.

A second example is supply-side carbon financing, a model that holds significant promise for buying-down end user stove prices or otherwise subsidizing production to achieve market scale. Carbon financing involves issuing producers of eligible technologies credits for each unit sold. Backed by purchasers in financial markets, credits essentially represent cash to producers. There are currently two avenues for carbon financing by which producers of technologies that reduce greenhouse gases can receive credits for pollution reductions: the Clean Development Mechanism (CDM) of the Kyoto Protocol and Voluntary Carbon Markets. The “Voluntary Gold Standard” methodology — eligible to renewable energy and energy efficiency projects — is one internationally- recognized mechanism for quantifying and therefore valuing greenhouse gas reductions of a given technology and level of sales production.⁵ Because of positive relationships between technologies that produce health-related IAP (e.g., CO and PM) and greenhouse gases (i.e., CO₂), carbon financing may be a viable business model under certain circumstances for large-scale production of some IAP mitigation technologies. (Having in place a “Methodology for Improved Cookstoves and Kitchen Regimes” approved by the Gold Standard mechanism is a further enabling factor).

As of 2009, three country-level cookstove projects — in Uganda, Ghana, and Mali — had been registered under the Voluntary Gold Standard methodology. The combination of achievable pollutant reduction (specifically carbon dioxide) and production scale will determine in large part the viability of the carbon financing model for any given IAP mitigation technologies. For improved cookstoves, one estimate suggests that a minimum production/sale of 15,000 stoves per year in Ghana would have to be achieved to make this financing model viable (Wurster, 2009).

While carbon financing is a promising model for sustainable financing to scale up IAP mitigation technologies, there are also several limitations. First, carbon financing credits reductions in pollutants focused on greenhouse gases (i.e., carbon dioxide) and not those that contribute most to adverse health consequences (i.e., PICs, including PM and CO). Certain IAP mitigation technologies with potentially high health benefits would not be able to benefit from this

⁵ The Voluntary Gold Standard methodology is a “best practice methodology and a high quality carbon credit label for both Kyoto and voluntary markets” used by the Gold Standard foundation — an international NGO that operates a certification scheme for Gold Standard carbon credits. Gold Standard Foundation, 2010, “Gold Standard,” retrieved September 15, 2010, from <http://www.cdmgoldstandard.org/>.

financing model. For example, while moving up the energy ladder from biomass to biogas could bring about health improvements, biogas has relatively high concentrations of greenhouse gases (e.g., 30% to 40% CO₂; 60% to 70% methane [Acharya, Bajgain, et al., 2005]), which are likely prevent it from being a viable carbon financing candidate.

Even in terms of biomass-based interventions, carbon financing might favor technologies with comparatively low health benefits. A study of multiple stove-fuel combinations found that if only gases included within the Kyoto protocol are considered in emissions from fuel combustion, burning of renewably harvested biomass (e.g., wheat) emits less of these gasses than higher rung energy sources such as kerosene and LPG, and emits amounts similar to (if not lower than) other fossil fuels (e.g., natural gas) (Edwards, Smith, et al., 2004). Renewably harvested biomass may therefore be better positioned for carbon financing even though it is much worse in relation to health because PIC emissions are elevated. Similarly, next-generation improved charcoal-burning cookstoves might be better than wood-burning stoves from a health standpoint but have no better carbon financing possibilities. For example, laboratory tests in 2006 found an elevated carbon monoxide to carbon dioxide ratio in Jiko-type charcoal-burning stoves (between 5% to 20%) and much lower ratios in charcoal-burning rocket stoves (between 0% and 10%). By comparison, the ratio for kerosene stoves should be 2% or less (Still, 2006). As carbon dioxide levels in the Jiko-type stove were lower than those in the rocket stove in absolute terms as well, these stove characteristics may position the Jiko-type stove better for carbon financing than the rocket stove. However, the better financing position may be at odds with desires for stoves with a higher capacity to reduce IAP pollutants that adversely affect health.

In addition, costs associated with certification — including upfront application costs, recurrent costs of monitoring, and time/opportunity costs of the lag between certification and receiving credit (which can be up to a year in length) — can be substantial and require subsidization. While “carbon developers” exist to manage the process on behalf of applicant organizations and cover these costs, receiving a percentage of profits from subsequent sales, some sort of outside assistance would almost certainly be necessary for in-country manufacturers of IAP mitigation technologies. Additionally, carbon credits are only applied after initial emissions tests determine the carbon offset quantity per unit and subsequent emissions tests confirm these offsets. According to one respondent interviewed for this analysis, this can mean a year passes before those credits are available for financing. Carbon financing therefore remains a complicated and lengthy process.

Further, the market for carbon credits is new and uncertain. Although carbon financing currently seems to be a promising model, longer term demand for credits by both producers of excess pollution and carbon financing intermediaries (i.e., investment banks) remains unknown, as does the viability of this financing mechanism in general.

3.1.3 Having Effective Distribution Channels

Improved cookstoves and other IAP mitigation technologies can likely benefit in many contexts from preexisting distribution channels that stock household energy products (other kinds of

stoves, fuel sources, etc.). In India, for example, the organization Prakti works with SELCO India, which uses a supply chain already established for their solar products. Similarly, Aprovecho and GTZ partnered in South Africa to promote highly efficient cookstoves produced in China (Rai & McDonald, 2009).

3.1.4 Influencing User Behaviors through Social Marketing

In addition to product affordability, two key aspects of improved cookstove adoption include user motivation and level of engagement required. Both user motivation to adopt and willingness to engage in stove practices that are likely to lead to PIC reductions may be open to influence. On the motivation side, users may be motivated to adopt improved cookstove technologies by both personal preferences and extrinsic attitudes in their communities (with the latter possibly influencing the former). For example, recent research from Bangladesh suggests that while personal preferences are by far the biggest determinants toward improved cookstove uptake, opinions of improved cookstoves by influential community leaders (particularly negative opinions) can affect adoption decisions (Miller & Mobarak, 2010). In terms of engagement, technologies that require a high degree of change in current practices may result in failure to use the technology (at all or in the intended way). Changing cooking practices is likely to entail a high degree of change, even require fundamental changes in lifestyles (Slaski & Thurber, 2009).

As has been found in social marketing initiatives for other health products — such as those related to water treatment and ITNs — concrete and observable benefits of a new product may be keys to facilitating motivation to adopt new technologies and sustaining the level of engagement required to bring about health benefits. A recent review of the water and sanitation product PUR (a household-based water treatment product) suggested that promotional efforts were best focused in areas with high water turbidity (and therefore murkier water) because the strong visual effect of post-treatment (clear) water could be used to increase awareness of water quality (Abt Associates, 2007). Given that IAP mitigation technologies mitigate highly visible smoke, social marketing efforts could focus on this aspect to also increase awareness of and demand for IAP mitigation technologies.

Box 2. Social Marketing Lessons from Safe Water Interventions

Programmatic experiences in social marketing of safe water products provide a number of lessons applicable to reducing IAP. These include:

- Long-term institutional commitment from all levels, including policies and leaders that will prioritize IAP reduction in agendas, civil society, and the private sector to identify technologies and resources that can make IAP mitigation technologies easy to practice, and institutions (e.g., clinics, schools) to drive messages home.
- A need to develop appealing and convincing messages outside the health perspective. IAP mitigation technologies in some contexts may be particularly well positioned for this approach because tangible benefits include not only smoke reduction but fuel savings and decreased time gathering biomass fuels.
- Focus program launch of rural-oriented IAP technologies in rural sites. A cross-country analysis of PSI International (PSI) programs promoting safe water products found that the traditional product/program launch setting (a formal setting with highly placed Government officials and media coverage) was not particularly useful in reaching out to low-income groups/beneficiaries, especially mothers in peri-urban and rural communities. Programs that shifted the focus of launch activities to rural areas and brought senior Government officials out to communities enhanced product prestige in the eyes of community members and fostered involvement and ownership of the product launch activities at all levels of public and civil society. This lesson is particularly

relevant for improved wood-burning cookstoves whose markets tend to be located in rural areas and are focused on women and children.

- **Timing of program launch can matter.** Both safe water and bednet social marketing strategies can benefit from launch just before the start of countries' rainy seasons because disease vectors are at their highest or most infectious (e.g., cholera in terms of safe water; mosquitoes in terms of bednets). Similar considerations may be important for launch of IAP mitigation technologies in some settings, such as climates that experience cold seasons during which personal exposure to smoke and IAP may be higher than at other times.

Sources: Abt Associates, 2007; Global Development Alliance and Safe Drinking Water Alliance, 2008

4 National and International Support Landscape: Enabling Environmental Factors for Scaling Up

In addition to longstanding engagement in IAP mitigation technologies at both the national and international levels, in September, 2010, U.S. Secretary of State Hilary Clinton pronounced major international support for adoption and use of improved cookstoves in launching the Global Alliance for Clean Cookstoves — a public-private partnership sponsored by the UN Foundation with the goal of adoption of improved cookstoves in 100 million households worldwide by 2020 (“100 by 20”). With significant financial backing from the UN Foundation among others, Alliance partners have pledged to commit \$60 million to cookstove dissemination, with hopes of raising up to \$250 million. With membership including foundations, nonprofit organizations, academic institutions, private enterprises, Governments, and UN agencies, the Alliance builds on the Partnership for Clean Indoor Air (PCIA), a diverse international body established in 2002 that joins together a variety of private and public partners, including research institutes, multilateral and bilateral institutions, Government agencies, nongovernmental organizations, and cookstove producers.

The Alliance will focus investments on six strategic areas: developing a strategic plan and governance framework; advocacy; strengthening empirical bases between IAP and health/climate change; mapping current cookstove engagement and programs; establishing benchmarks for clean cookstoves through development of standards and labels; and exploring financing options (Global Alliance for Clean Cookstoves, 2010). At a recent announcement launching this alliance, U.S. Secretary of State Hilary Clinton implied that a market-based approach to stove dissemination would be part of the effort, stating that the cookstoves “must not be given away” (The Economist, 2010). This was supported by a spokesperson for the United Nations Foundation who said that the Alliance seeks to create a market for stoves and that “you're not going to solve this problem with aid alone. You're going to have to create a thriving cookstove industry that can supply both stoves and fuels that people want and need” (Mason, 2010).

4.1 Current Investments and Ongoing Efforts by U.S. Government Agencies, Multilaterals, Bilaterals, and NGOs

4.1.1 U.S. Government Agencies Involved in IAP Mitigation

The National Institutes of Health (NIH) has committed about \$25 million over 5 years to improving the health of cookstove users. Specific activities of divisions (institutes, centers, and

offices) within the NIH include the Fogarty International Center (FIC) — support for research training programs; National Cancer Institute (NCI) — investigation of air pollution and respiratory health in China (e.g., impact of chimney installation on lung cancer and COPD); National Heart, Lung, and Blood Institute (NHLBI) — funding of epidemiological studies on cookstove-related effects on pulmonary and cardiac diseases (e.g., hypertension, atherothrombosis, asthma, chronic lung diseases, and co-contaminant effects) and instrumentation/measurement devices; National Institute of Environmental Health Studies (NIEHS) — support for new and ongoing studies evaluating effectiveness of interventions (e.g., in Guatemala, India, Nepal, and the Gambia), evaluation of an expanded array of health endpoints including children’s neurobehavioral development, and developing and evaluating innovative technologies for monitoring cookstove use and human exposures; Office of Behavioral and Social Sciences Research (OBSSR) — studies of ways to introduce and educate users on safety and proper use of cookstoves; and the Office of Research of Women’s Health (ORWH) — would like to support research on the impact of cookstoves on women’s health and safety.

4.1.2 International Institutions Involved in IAP Mitigation Technology Promotion

According to key informants and information posted on the Internet, there are a handful of bilateral and multilateral agencies actively involved in programs and interventions that relate to IAP mitigation, including GTZ, SNV (Netherlands Development Organization), and the World Bank. There are also a few multinational companies that support mass production of improved cookstoves, including Envirofit and StoveTec. A brief summary of the involvement and potential for leveraging funding of these agencies and companies follows.

4.1.2.1 Donor Agencies

GTZ (German Technical Assistance)

GTZ has been particularly active in developing markets for improved cookstoves, with a strong presence in several countries of Sub-Saharan Africa as well as Asia and Latin America. In Sub-Saharan Africa, for instance, GTZ has supported dissemination efforts across the continent, including Malawi, Kenya, Uganda, Burkina Faso, Mali, and Ethiopia. Under the Kenyan Private Sector Development in Agriculture project, in which entrepreneurs/small businesses were supported to produce and disseminate locally made improved cookstoves, around 420,000 households adopted improved stoves (e.g., Jiko-type and rocket stoves) between 2006 and 2008 (Djédjé, Ingwe, et al., 2009). Under the Energy Advisory Project in Uganda, over 200,000 rocket stoves were disseminated in Uganda (Habermehl, 2007). The majority, if not all of GTZ projects in Sub-Saharan Africa appear to promote local production of cookstoves using locally available materials (e.g., mud, clay).

SNV (Netherlands Development Organization)

SNV focuses on development of domestic biogas sectors in Asia (Nepal, Vietnam, Bangladesh, Laos and Cambodia), assisting clients to develop commercial, market-oriented biogas sectors. SNV reports to have reached 244,672 households through its programs and is expanding its scope in Asia to include Pakistan and in East Africa (Rwanda, Ethiopia, and Tanzania). SNV is also currently supporting a study on “Opportunities on Improved Cookstove Dissemination in

Asia” (carried out in Cambodia, Laos, Bhutan, Nepal, and Bangladesh) although content of this study has not yet been made publicly accessible.

World Bank

While the World Bank does not appear to widely incorporate promotion of IAP mitigation technologies into its loans, it has directed modest resources toward implementation research kinds of activities. This has included commissioning of two reviews of cookstove programs in the 1990s and more recently (Barnes, Openshaw, et al., 1994; World Bank, 2010). Additionally, the World Bank’s Carbon Finance Unit offers a possible institution for exploring ways to leverage funds to scale up IPA mitigation technologies.

4.1.2.2 Commercial Enterprises

There are a number of international commercial businesses that have made significant inroads into markets for improved cookstoves (selected national-level businesses are also discussed in Section 5). Efforts of two such companies are as follows.

Envirofit

Envirofit, with financing support from the Shell Foundation, mass produces lines of wood- and charcoal-burning improved rocket cookstoves for commercial consumption globally. Since 2008, Envirofit has sold approximately 150,000 stoves in 30 countries worldwide, primarily in India (which accounted for 80,000 of its sales by the end of 2009 (Rai & McDonald, 2009) and increasingly in Sub-Saharan Africa. Envirofit wood-burning stoves reduce PM emissions by up to 60 percent compared to traditional three-stone stoves. It is a leading mass-produced stove in India and was ranked favorably by users sampled in a three-country study in Sub-Saharan Africa (Uganda, Tanzania, and Malawi) on a number of dimensions compared to locally made improved cookstoves (Wang, Tyler, et al., 2009).

StoveTec

Owned by Aprovecho Research Center (a leading institution for improved cookstove research, development, and standards testing), StoveTec has sold over 70,000 wood- and charcoal-burning rocket stoves internationally over the past 2 years to countries including India, South Africa, Uganda, Tanzania, and Madagascar. StoveTec stoves are mass-produced in China in partnership with the Shengzhou Stove Manufacturing Company. Along with Envirofit, it was ranked favorably by users sampled in the three-country study in Sub-Saharan Africa on a number of dimensions compared to locally made improved cookstoves (Wang, Tyler, et al., 2009).

4.2 Sectoral Overlap

IAP mitigation directly overlaps three main sectors: energy, climate change, and agriculture. It also has potential links with microfinance and community/women’s empowerment programs and offers an avenue for research into IAP mitigation technologies. An example of how resources channeled into these sectors can be leveraged for research on scaling up IAP mitigation technologies comes from the World Bank-supported Energy Sector Management Assistance Program (ESMAP) in Cambodia. ESMAP is working with the Cambodian organization GERES (an NGO with extensive experience in cookstove production and dissemination; see Section 5.1.4) to pilot test dissemination of cookstoves in rural areas. ESMAP is also analyzing

the cookstove supply chain from a gender perspective to ensure that women's economic empowerment be incorporated in the scaling up of the pilot activities (RECambodia, 2007; Steele, 2010).

4.3 Current Technological Innovations

4.3.1 Cookstoves

Two cleaner biomass combustion technologies are making inroads, although they may remain limited in terms of future scalability. First, pellet-fueled cookstoves may offer a way for certain households to reduce PICs (see last row of Table 1, Selected Improved Wood- and Charcoal-Burning Improved Cookstove Designs, in section 2.2). The Oorja stove manufactured by First Energy of India (formally by British Petroleum Energy India Limited) is an example of a cookstove fueled by pellets (produced from agricultural waste) that, at a retail price of around \$15, has gained some traction in urban markets of India, and as of 2009, it was reported that Oorja stoves had been sold to over 400,000 households in four States of India (Sundar, 2007; Winrock International India, 2010). However, bringing such a technology to scale will abut several challenges, particularly as operation relies in part on access to higher rung energy sources (e.g., electricity).

Second, gasifier cookstove designs (see second-to-last last row of Table 1 in section 2.2) have the potential to significantly enhance PIC reduction capabilities (e.g., see MacCarty, Still, et al., 2010). Gasifier stoves (most of which currently use an underlying rocket technology) include internal fans that force air from below through the stove, improving cooking in a number of ways (e.g., shorter time to reach temperature; more controllable heat output). Importantly, thermoelectric energy at full combustion that is generated from the fans can be used to power chargers. In the Philips version, the charger is used to recharge the cookstove's fan battery. Current research and development efforts are exploring alternative uses of the thermoelectric power generated in ways that may be relevant to scaling up improved cookstoves. For instance, the U.S.-based company Bio-lite has been working with the Aprovecho Research Center to incorporate into its gasifier cookstove (which is a modified StoveTec rocket combustion chamber) a charger capable of recharging cell phone batteries and other small electronic devices (The Charcoal Project, 2010). Although gasifier cookstoves are a promising development, several challenges remain to their scaling up. These include a number of design features requiring extra effort,⁶ such as the need for external electricity supply and additional fuel for preparation for several gasifier models, as well as generally higher cost.

4.3.2 IAP monitoring

As illustrated in Figure 5, there are a range of methodologies commonly used to monitor IAP⁷. In general, greater methodological accuracy incurs higher resource requirements, both financially and in terms of time required to take measurements. While this analysis does not focus on specifics of technologies used to monitor IAP, a number of recent advances in IAP monitoring technologies are

⁶ See, for example, Dhoble and Bairiganjan, 2009.

⁷ For an overview of different IAP monitoring methodologies, see Naumoff, 2005.

worth noting. Indirect exposure assessment (the third most accurate methodology listed on Figure 5) of some PICs can now be achieved relatively reliably at moderate cost (Engineers for a Sustainable World at Stanford, 2008). For example, the UCB Particle Monitor (UCB), developed in the U.S. by the University of California at Berkeley (UC Berkeley) and costing around \$600 to use (less software requirements), stores minute-by-minute data over the measurement period in its electronic memory and has been field-tested in monitoring PM_{2.5} (Smith, Dutta, et al., 2007). The Stove Use Monitoring System (SUMS), also developed by UC Berkeley, offers a standardized way to measure PIC emissions (and other outputs of stove use) and may be able to leverage wireless electronic technologies to facilitate data collection in the future (UC Berkeley School of Public Health, 2010).



Figure 5. Indoor Air Pollution Measurement Options
 Source: World Health Organization (2005).

5 Existing or Potential Program Countries/Program Platforms to Conduct Research

Six priority MNCH countries in Asia and Sub-Saharan Africa are identified as well positioned for future research on scaling up IAP mitigation interventions. In Asia, these include India, Bangladesh, Cambodia, and Nepal. In Sub-Saharan Africa, these include Uganda and Ghana.

Table 2. Potential Countries in Asia and Sub-Saharan Africa To Conduct Future IAP Implementation Research

Country	Biomass usage	Pertinent characteristics
India	<ul style="list-style-type: none"> 94% (74% wood, 20% dung) 	<ul style="list-style-type: none"> Has/is attempting large-scale Government-backed improved cookstoves initiatives Presence of domestic and international producers and suppliers of improved cookstoves Potential research leveraging platform via Indian Council on Medical Research
Bangladesh	<ul style="list-style-type: none"> 96% (44% wood, 21% residues, 17% dung, 15% tree leaves) 	<ul style="list-style-type: none"> History of attempts to disseminate improved cookstoves with modest/little uptake
Cambodia	<ul style="list-style-type: none"> 95% 	<ul style="list-style-type: none"> Widespread commercial-based adoption of locally manufactured improved cookstoves (over 1 million sold) that also use carbon financing model Sizable biogas digester presence
Nepal	<ul style="list-style-type: none"> 85% (76% wood, 6% waste, 3% residue) 	<ul style="list-style-type: none"> History of Government/donor-supported initiatives for (relatively) large-scale biogas digester dissemination
Ghana	<ul style="list-style-type: none"> 92% (56% wood, 36% charcoal) 	<ul style="list-style-type: none"> Largest per-capita consumer of charcoal in the West

Country	Biomass usage	Pertinent characteristics
		Africa sub-region; current attempts at widespread urban commercial dissemination of improved charcoal cookstoves
		<ul style="list-style-type: none"> ▪ One of few Sub-Saharan Africa countries with in-country suppliers using carbon financing model
Uganda	▪ 95%	<ul style="list-style-type: none"> ▪ Presence of in-country manufacturer (Ugastove) of improved metal rocket cookstoves ▪ One of few Sub-Saharan Africa countries with in-country suppliers using carbon financing model

5.1 Asia

5.1.1 India

India's context is attractive from a research perspective on a number of fronts as it is one of two countries worldwide that has experience with large scale, Government-backed improved cookstove initiatives: the National Program on Improved Chullahs (NPIC) (see Section 3) and current efforts to revive a national improved cookstove initiative through the National Biomass Cookstoves Initiative (NCI). NCI has a goal of selling 150 million stoves within 10 years (Adler, 2010). Although the NPIC was in many ways a failure, this relatively long experience provides India with a well-developed supply-side presence from producers (e.g., see Section 4.3.1) to distribution channels and demand-side presence. Examples of the latter include self-help groups prevalent across States of India and existing demand for IAP mitigation technologies. However, one notable institutional gap is a lack of any country-level stove testing facility to assure quality standards. Other IAP mitigation programs have included:

- National Project on Biogas Development (NPBD): Over 350,000 household biogas plants were installed from 1981 to 2003, although a study in the early 1990s found only 60% of plants were functional.
- Deepam Scheme (Andhra Pradesh): Over 1.5 million LPG connections were installed through this subsidization scheme from 1999 to 2002.

Additionally, key informants have indicated that the Indian Council on Medical Research is sponsoring four studies to assess various health outcomes (e.g., COPD, pneumonia) on pilot cookstove interventions.

5.1.2 Bangladesh

Bangladesh offers a context in which to study overcoming barriers to IAP mitigation technologies. Although significant resources have been devoted to IAP mitigation interventions in Bangladesh, there has not been widespread adoption of these technologies. A commercial approach to disseminating IAP mitigation technologies has been promoted in recent years by various donors. While thousands of improved cookstoves and biogas digesters were disseminated through Government-run programs in the 1980s and 1990s, agencies such as the Infrastructure Development Company Limited, GTZ, and NGOs (including the Village Education Resource Center - VERC) are now the main organizations promoting improved cookstoves, biogas, and solar home systems. However, only around 300,000 improved cookstoves and

26,000 biogas plants (out of a total population of 130 million) have been installed, and it is not clear how many of these systems remain operational (World Bank, 2010).

5.1.3 Nepal

Nepal offers a context favorable to researching use of biogas as a scalable IAP mitigation technology. The country's Biogas Support Program in its current form began biogas installation in 1992. Supported by SNV (Netherlands Development Organization), from 1992 to 2005 over 200,000 biogas plants were installed for household use through the program. The program is currently overseen by an NGO in a public-private partnership. Program elements include support for and technical assistance in uniform technical designs/standards for biogas plants; financial support for end-users through a Government subsidy of US\$70 to US\$150 per plant; use of microcredit financing schemes; quality control and monitoring of production, installation and after-sales services; and outreach and awareness programs. Biogas construction companies are responsible for providing maintenance and after-sales services guarantees, and the program estimates that almost all plants installed since 1997 are still in use (Acharya, Bajgain, et al., 2005). As of 2003, there were 15 biogas manufacturers in country. There are a variety of hurdles to scalability (as with most biogas technologies) as the cost of each plant (over \$300) is high. However, the combination of in-kind payments, Government/carbon financing subsidies, and microfinancing has facilitated scaling up.

5.1.4 Cambodia

Cambodia offers a context in which to study successful large-scale commercial-based dissemination of the improved New Lao Stoves. Locally produced with production and distribution overseen by the national NGO GERES Cambodia, a reported 1 million New Lao Stoves (charcoal-burning stoves that rely on updraft combustion technologies) have been installed since 2003. While New Lao stoves cost around three times as much as traditional stoves, they are also reported to last two to three times longer (Nexus, 2010). New Lao cookstoves are also Voluntary-Credit-Reduction-accredited, providing carbon financing possibilities. GERES (2006) has documented its approach to reaching distribution scale.

Additionally, a sizable biogas sector exists, with around 20 producers/suppliers of biodigester plants and with an SNV-supported national biodigester program, a joint program with the Ministry of Agriculture, Forestry, and Fisheries that runs from 2005 to 2012 (see Bajgain & Shakya, 2005).

5.2 Sub-Saharan Africa

5.2.1 Uganda

Uganda offers a context in Sub-Saharan Africa in which to study locally produced and distributed improved cookstoves that have achieved modest scale. The Ugastove Company manufactures improved metal rocket cookstoves — primarily charcoal-burning for both residential and industrial use — with sales reaching around 40,000 since 2006. Ugastove sales focus on urban markets, and over 50% of the sales price is subsidized through carbon financing (Rai & McDonald, 2009). There are also biogas research possibilities because Uganda has a

technical potential of more than 200,000 household biogas digesters nationwide. Government policies are favorable for the large-scale dissemination of biogas in Uganda because the country's proposed Renewable Energy Policy has a target to install 100,000 biogas plants by 2016. Launching an initial 20,000 digester commercial household biogas program in Uganda is feasible (Pandey, Subedi, et al., 2007).

5.2.2 Ghana

Like Uganda, Ghana offers a context in which to research locally produced improved cookstoves that have reached some degree of urban scale. Ghana is the largest per capita consumer of charcoal in the West Africa sub-region, with about 30% percent of rural and urban households depending solely on charcoal for their chief cooking fuel (and around 10 % use it as a backup fuel source). Since 2002, EnterpriseWorks/VITA has been promoting adoption of the Gyapa jiko-type improved cookstoves through a commercial approach focused on urban markets. Estimated Gyapa sales are 150,000 to 200,000, with over 50 % of the sales price subsidized through carbon financing. In the past few years, the enterprise Toyola has become a significant distributor of Gyapa stoves (Atta-Owusu, 2009; EnergyAccess, 2010). Additionally, an improved rocket charcoal stove known as Ahibenso has been on the market since 1993, although sales volumes have been much more modest (30,000 as of 2009) (Atta-Owusu, 2009).

6 Research Priorities and Questions within the TRAction Mandate

The preceding landscape analysis suggests that two broad sets of questions could be usefully addressed within TRAction's health research mandate.

Set I: From the perspective of improving MNCH, under which circumstances is it better to promote IAP technology packages with potentially lower, but less variable, expected health benefits compared to IAP technology packages with potentially higher, but more variable, expected health benefits? To borrow from a microeconomics framework, this is essentially determining indifference points for technology effectiveness-variability combinations.

Answering this question involves addressing two sub-questions:

- Which IAP mitigation technologies are least sensitive to user behaviors in terms of reducing exposure to IAP? This is essentially a reliability issue. Answering this question can help determine which technologies are most likely to provide consistent results in terms of reduced exposure to IAP regardless of the degree to which they actually reduce exposure.
- Under which contextual circumstances can the reliability of IAP mitigation technologies that are more sensitive to user behavior (in terms of reducing IAP exposure) be improved? Are there certain environmental contexts and cultural practices that attenuate sensitivity of certain IAP mitigation technologies to user behavior and therefore increase reliability in expected IAP exposure reductions?

Examples of research activities that address these questions include:

- Comparing outcomes (either in PIC reduction or indicators of MNCH) from interventions promoting use of improved cookstoves compared to biogas production

- Comparing cost-effectiveness (with effectiveness measured either in PIC reduction or indicators of MNCH) of any intervention focused on improving biomass combustion to moving up the energy ladder.

Set 2: What are the incremental benefits of each aspect of IAP interventions, including IAP technology features (e.g., cookstove design), complementary features (e.g., use of cookstoves in conjunction with housing structural changes), and behaviors? This line of research would seek to isolate the effects of each type of intervention (those focused on the source of pollution, those in the living environment and behavior-related interventions) to understand which combinations are best positioned to bring about large-scale MNCH improvements (e.g., is it possible to increase the 50% to 70% PIC reductions commonly achieved in mass-produced rocket stoves to 85% to 90% (levels that might be required to significantly reduce pneumonia) through the right combination of technologies and behaviors?).

Additional research questions of interest for scaling up IAP interventions (but less directly related to the TRAction mandate) include the following

1. Given gaps between production costs and user willingness-to-pay for IAP mitigation technologies, are there ways in which cookstoves can be produced, marketed, and/or distributed that can serve as tipping points to propel users to adopt these technologies on a large scale? Illustrative research activities might relate to
 - Using subsidies for cookstove components to encourage users to adopt the underlying technology
 - Exploring add-on cookstove features. For example, recent thermo-electricity developments have made household power generation a possibility on some types of improved cookstoves (e.g., gasifiers). While power generated is typically channeled into fans to increase efficiencies, are there other applications of energy generation that might be used to encourage adoption, such as power chargers for cell phones and/or lighting for rooms?
 - Exploring possibilities for joint packaging and retailing of cookstoves with other products to encourage adoption.
2. Can carbon financing play a role in institutionalizing minimum emission standards for IAP mitigation technologies that are consistent with improved health? Sub-questions that may be involved include:
 - How viable is carbon financing as a financing mechanism across country/market contexts?
 - Are relationships between greenhouse gas emissions measured through carbon financing (e.g., CO₂) and those that play primary roles in MNCH (i.e., PIC such as PM and CO) strong enough that reducing greenhouse gas emissions will result in strong enough reductions in PM/CO emissions to positively impact MNCH?

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Annex I — List of persons Consulted

Name	Organization
Sameer Akbar	World Bank
Ron Bills	Envirofit
Elisa Derby	Winrock, International
Majid Ezzati	Harvard School of Public Health
Michael Greenstone	Massachusetts Institute of Technology
Evan Haigler	Impact Carbon
William Martin	National Institutes for Health
John Mitchell	Environmental Protection Agency
Jacob Moss	Environmental Protection Agency
Charles Rodes	Research Triangle Institute
Jim Tielsch	Johns Hopkins University

Annex II — Evidence Base on improved Cookstove interventions and MNCH

Country	Study characteristics			Technology	Health impact	Intervention			Source
	Design	Duration	N			Primary	Other	Notes	
Guatemala	RCT	1 year	504 (169 intervention; 335 control)	Plancha wood burning stove vs. open fire	Lower prevalence of chronic respiratory symptoms (e.g., wheeze) among plancha group women; no difference in lung function	Intervention HHs received new Plancha stove at RCT baseline; control HHs received new Plancha stove at RCT endline	Intervention HHs received basic training in use and maintenance of plancha; field workers monitored problems with the stove during weekly visits and conducted repairs as needed in order to maintain the stoves in good condition		Diaz, E., T. Smith-Sivertsen, et al. (2007); Smith-Sivertsen, Diaz et al. 2009
Guatemala	Observational	Cross-sectional	1717	Improved stoves (with chimneys) and cleaner fuels (LPG, gas)	Lower birth weight among open fire users compared to improved stove and clean fuel users; difference between improved stove and open fire users not statistically significant; difference between clean fuel users and all wood users statistically significant	None	None		Boy, E., N. Bruce, et al. (2002)
Kenya	Paired-observational	Cross-sectional	400 (200 with improved stoves; 200 with traditional)	Improved wood-burning stove	Lower ALRI prevalence among children and women in HHs using improved stoves	Improved stoves assigned to HHs 10 years prior to study as part of governmental energy project	None mentioned	No data presented about comparability of HHs using/not using improved stoves; no data to support text that:	Wafula, Kinyanjui et al. 2000

Country	Study characteristics			Technology	Health impact	Intervention			Source
	Design	Duration	N			Primary	Other	Notes	
			stoves)						"The effect of the type of stove on the prevalence of ARI among children and women and of conjunctivitis among children and women was maintained even after controlling for mother's level of education, socioeconomic status of the household, and the type of kitchen, using a logistic regression model"
Mexico	RCT	10 months	552 (282 intervention HHs; 270 control HHs)	Patsari (wood-burning) stove vs. open fire	No difference in symptoms/lung function decline between intervention and control group (i.e., intention-to-treat analysis); significantly reduced symptoms among Patsari stove users compared to non-users (i.e., effect of treatment-on-treated)	Intervention HHs received new Patsari stove at RCT baseline; control HHs received new Patsari stove at RCT endline	None	Dual use of technologies observed: "households frequently keep their traditional stoves for specific cooking tasks or use multiple fuels and stoves depending on prices, seasons, and availability"; "our study also indicates that stove intervention programs need to	Romieu, I., H. Riojas-Rodriguez, et al

Country	Study characteristics			Technology	Health impact	Intervention			Source
	Design	Duration	N			Primary	Other	Notes	
								include not only the installation of the new stove but also reinforcement and further training over the following months...adoption of an improved stove requires close long-term follow-up training in its use and maintenance"	
Pakistan	Paired observational	Cross-sectional	159 (45 with improved stoves; 114 with traditional stoves)	Improved ("smoke-free") wood-burning stove	Symptoms not significantly lower among HHs using improved stoves in adjusted regression analyses; 10 of 12 symptoms significantly lower in unadjusted analyses	Intervention HHs received new stove	None mentioned	Higher socio-economic status (education, income, housing infrastructure) among HHs using improved stoves; barriers to acceptance: improved stoves not considered sufficiently durable by many recipients, requires skilled help to install, continued guidance on installation/maintenance, no significant perceived economic efficiency vs. traditional stoves	Khushk, Fatmi et al. 2005