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Current debates and future research needs in the clean cookstove sector

Gregory L. Simon [a,*], Rob Bailis [b], Jill Baumgartner [c], Jasmine Hyman [b], Arthur Laurent [d]

[a] University of Colorado Denver, Department of Geography and Environmental Sciences, P.O. Box 173364, Campus Box 172, Denver, CO 80217-3364, USA
[b] Yale School of Forestry & Environmental Studies, 195 Prospect St., New Haven, CT 06511, USA
[c] McGill University, Institute for Health and Social Policy, 1130 Pine Avenue West, Montreal, Quebec H3A 1A3, Canada
[d] Sciences Po, Centre for International Studies and Research, 56, rue Jacob, 75006 Paris, France

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ABSTRACT

The international clean cookstove sector has undergone considerable growth over the past decade. We use this critical juncture – where program priorities and strategies are formalized and converted into institutional norms and practices – to review current debates and areas for future research. We focus our review on four important areas and suggest industry participants expand and refine efforts to (i) balance technical stove performance with implementation needs and stove user compatibility; (ii) understand the trade-offs associated with local and imported production methods; (iii) determine a suitable role for direct subsidies for purchasing stoves and indirect subsidies for research, institutional development and distribution of stoves; and (iv) develop an appropriate finance strategy to support dissemination amidst carbon market uncertainties. Given the complex and interdisciplinary nature of the clean cookstove sector, we hope our appraisal of these four issues will inform innovation and invite new insights.

Introduction

The Global Alliance for Clean Cookstoves (Alliance) is a public–private partnership facilitating the creation of a thriving global market for clean and efficient household cooking solutions. Launched by the United Nations Foundation in 2010, the goals of the Alliance include promoting the adoption of 100 million substantially improved stoves globally by 2020 with hopes of universal adoption by 2030. In March 2013, the Alliance held its first Global Forum in Phnom Penh, Cambodia continuing a trend of biannual cookstove meetings initiated by the Partnership for Clean Indoor Air in 2003. The purpose was to convene various stakeholders in one location to review sector achievements, describe current challenges, detail emerging developments, and articulate pressing needs moving forward. This essay presents a description of significant debates that emerged at the Alliance Forum and outlines areas for future research.[1]

In many ways, the Forum's timing was appropriate. *The Lancet* õrecently published the updated Global Burden of Disease Report, which ranked household air pollution (HAP) as the fourth leading contributor to the global disease burden, behind only high blood pressure, alcohol and tobacco (Lim et al., 2013). Moreover, the *Journal of Geophysical Research* released a paper just before the Forum specifying black carbon (an HAP) as the second most important climate-forcing human emission behind carbon dioxide (Bond et al., 2013). These reports alongside other sobering trends – such as the persistent reliance on solid fuels (i.e., biomass and coal) by nearly 3 billion people (Bonjour et al., 2013) – underscored the gravity and urgency of the Forum.

While it would be easy to view the Forum as simply a response to mounting unpropitious news, the event was equally motivated by the Alliance's considerable achievements; particularly in the areas of awareness raising, technology innovations, sector investment growth, international partnership generation, mobilization of research funds, and market capacity development (GACC, 2012). The Forum thus provided Alliance members an opportunity to share accomplishments and establish collaborations across the sector. Participants included representatives from national governments, community-based organizations, cookstove designers and manufacturers, impact investors, corporations, and academic institutions, among others.

Signaling a clear shift in the cookstove community, Alliance Executive Director Radha Muthiah addressed the growing diversity of the Alliance by noting that,

> "Many of us have talked about the clean cooking sector being at a tipping point. Well everyone, we've tipped. And we've tipped in the right direction. There is no going back to what used to be a disparate sector of admirable and well-intentioned but non-scalable and

* Corresponding author. Tel.: +1 303 556 6393; fax: +1 303 556 6197.
E-mail address: gregory.simon@ucdenver.edu (G.L. Simon).

[1] Dr Simon and Dr Bailis have served as core advisors to the Alliance.

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insular efforts…. The state of the sector is that we are truly together in a way that we never have been before." (Radha Muthiah, March 18, 2013)

It is in the context of this sector transition that our paper intervenes. In the following pages we review the state of the industry as witnessed during and immediately following the Forum. We begin with a brief description of the household energy sector in the context of numerous programs and activities initiated by the Alliance. We then focus our review on several debates concerning how to (i) balance technical stove performance with implementation needs and stove user compatibility; (ii) understand the trade-offs associated with local and imported production methods; (iii) determine a suitable role for direct subsidies (for purchasing stoves) and indirect subsidies (for research, institutional development and distribution of stoves); and (iv) develop an appropriate finance strategy to support dissemination amidst carbon market uncertainties. In response to these developments we conclude with a brief description of future research needs that should assist sector activities over the next several years. We encourage others to continue this discussion in order to promote the widespread dissemination and adoption of low emission and household appropriate cooking technologies and fuels.

Clean stove sector under the Global Alliance for Clean Cookstoves

The contemporary international clean cookstove sector includes implementing programs, non-profit organizations, donor agencies, science institutions, investors and governments operating at local, national and global scales. Cookstove testing, certification, financing, marketing and distribution processes are increasingly coordinated between these diverse and international sector participants. The Alliance's diverse membership reflects the multifaceted appeal of clean cookstoves as a hub technology capable of confronting not only the problem of noxious household air pollution, but also a number of other development and environmental challenges (Table 1).

To generate these mutually supported benefits at a large scale, the Alliance has developed a 10-year, three-phase, strategic business plan. Phase 1 began in late 2012 when the Alliance identified six nations – Bangladesh, China, Kenya, Ghana, Nigeria and Uganda – for priority intervention. The Alliance works with stakeholders in these countries to facilitate a range of enabling activities, including collecting and disseminating information on market dynamics, working with governments to create favorable regulatory environments, and generating increased supply chain capacities by improving market access to finance. Meanwhile, the Alliance is collaborating with other national governments, non-profits and community stakeholders to develop country action plans (CAPs) for market scale-up.

Phase 2 will extend these activities by encouraging investments that will bring operations to scale, while Phase 3 aims to establish a self-sustaining clean cookstove market. Fig. 1 illustrates how each phase coincides with several transformational strategies that are expected to facilitate the distribution of improved stoves to 100 million households by 2020. As dissemination continues to scale-up and a trajectory towards global stove distribution takes hold, influential decisions are being made that will affect how (and what) stoves are disseminated to millions of households. The following section examines several important debates currently facing this fast growing sector.

Emerging issue and debates

Given this critical juncture – where program priorities, goals and strategies are formalized and converted into institutional norms and practices – we discuss four significant and interrelated issues that emerged during the 2013 Alliance Forum.

Issue area 1: stove emissions and efficiency standards

Background

Hundreds if not thousands of cookstoves and stove related innovations promote improved efficiency and are commercially available around the world. Unfortunately, many of these stoves provide little or no reduction in harmful pollution emissions or human exposures. Some performed well in controlled settings or immediately after installation, but failed to realize measurable and sustained improvements in homes (World Bank, 2011). Chimney stoves have successfully moved some pollution outside the kitchen and improved household air quality (Armendáriz Arnez et al., 2008). However, without improved combustion efficiency, traditional stoves may do little for climate and, in high-density settlements, shift pollution into neighbors' homes. New epidemiologic evidence indicates a supra-linear relationship between HAP exposure and health outcomes including blood pressure and acute lower respiratory infection in young children (Baumgartner et al., 2012; Smith et al., 2011). This suggests that transitioning away from highly-polluting traditional stoves to cleaner-burning alternatives provides few health benefits unless the very cleanest stoves (e.g., gas or electric models) are used and the household is not 'stove stacking' (i.e., using multiple stove models).

Participants at the Alliance Forum discussed the need to develop and manufacture a new generation of very efficient, low-polluting stoves — referred to here as "advanced combustion stoves." Among these, for example, are gasifier stoves, which convert biomass into a combustible gas using a two-stage combustion process whereby the biomass fuel is heated and converted into a combustible gas in the first-stage pre-combustion (or gasification) chamber and the gas is then completely oxidized in the second-stage combustion chamber (Roth, 2011). Though the combustion process and fuels are quite different, most gasifier stoves contain powerful and adjustable flames akin to liquefied petroleum gas (LPG) stoves, which are viewed by many solid fuel users as an aspirational fuel due to its aesthetic appeal and associated status increase (Smith and Dutta, 2011). Decreasing exposures with low-

Table 1
Major issues associated with inefficient and high emitting traditional cooking methods (Adapted from GACC, 2012).

Issue	Description
Gender and development	–Women and girls spend up to 20 hours per week searching for fuelwood in areas with diminishing resources, leaving less time for other tasks and income generating activities. –Fuelwood collection can put women and girls in dangerous and isolated environments far away from home.
Human health	–Inefficient solid fuel combustion produces pollutants that affect health including childhood pneumonia, lung cancer, obstructive pulmonary disease, cataracts and blood pressure. –Traditional stoves with uncontained flames can cause burn injuries, disfigurements, infections and even death.
Forest protection	–Reliance on wood and charcoal for cooking and heating can place pressure on local forests. –Unsustainable harvests can contribute to mudslides, watershed damage, desertification and decreased food security.
Outdoor air pollution	–Solid fuel stoves are significant contributors to, and exacerbate, poor outdoor air quality.
Climate Change	–Inefficient combustion of solid carbon-based fuels contributes to climate change through the release of gases including methane, carbon monoxide and nitrous oxide. –The emission of black carbon aerosols contributes to the net climate-forcing impacts of biomass burning stoves.

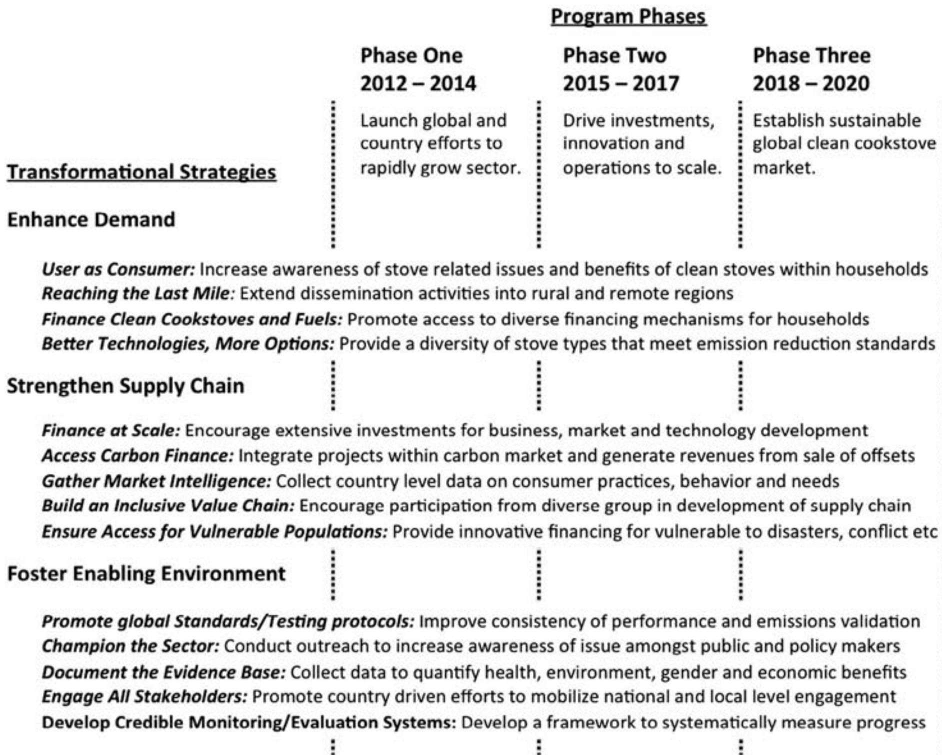

Fig. 1. Outline of the GACC industry growth business plan and dissemination strategy (Adapted from GACC, 2012).

polluting gasifier stoves is still contingent on successful stove adoption, sustained use, and reduced use of other polluting stoves (Lewis and Pattanayak 2012). However, they could serve as a more affordable and readily accessible alternative to LPG (Table 2).

A major obstacle to wide-scale implementation of advanced combustion stoves is the lack of universally accepted stove performance standards and testing protocols. This was a frequently discussed topic at the Forum and is a major area of activity within the Alliance. At present, consumers cannot evaluate or compare their cookstove's performance or safety with other models. Stove manufacturers are not required to meet any performance standards and stove developers, in turn, are insufficiently incentivized to innovate. Also, stoves must be compatible with household needs and regional housing, cultural and environmental conditions. Otherwise, users may reject them (Dupas, 2010; Lewis and Pattanayak 2012; Whittington, 2012).

The ongoing development of cookstove standards and testing metrics is critical to implementing better stoves. Yet defining and verifying high quality cookstoves amidst such a decentralized and diverse market presents challenges. A number of different protocols and metrics are already used for cookstove performance testing, including the Water

Table 2
Arguments for and against advanced biomass stoves and LPG stoves (Adapted from Smith and Dutta, 2011).

	Advanced combustion cookstoves	Liquefied Petroleum Gas (LPG) stoves
Emissions	– Clean combustion; lower emissions than traditional stoves, but higher than LPG – Altered stove use may result in higher emissions	– Very clean combustion; lower emissions than current advanced, improved and traditional biomass stoves – Highly robust to user behavior
Safety	– Risk of burns and stove tipping	– Risk of canister explosion or leaks
Operation and maintenance	– Ash removal after cooking – Normal wear and tear	– Canister replacement – Normal wear and tear
Power controllability	– Able to control and adjust flame for high and medium power cooking – May cook and boil water faster – Low power (e.g., simmer) can be difficult to control	– Easy to control and adjust flame for high, medium and low power cooking – Depending on size, highest power capability less than some advanced biomass stoves
Learning	– Some; training needed on fuel preparation, lighting and stove operation	– Minimal; high familiarity in most places
Fuel	– Biomass is readily available in most places – Biomass preparation often needed — chopping or pelletizing – Fuel must be added between and during longer cooking events, complicating batch-loaded stove use	– Risk of fuel running out during cooking – Problems with availability and reliability of supply in some places – Facilitates less-attended cooking
User perceptions	– Unfamiliarity with these stoves – Limited empirical evidence on adoption and use – Cultural preference for food cooked with biomass in some regions	– Often viewed as "aspirational" – Fewer technological and socio-cultural barriers – Less time needed for cooking and cleaning pots and kitchen
Portability	– Safe and easy to transport – Pelletized fuel may require special transport	– Larger canisters are heavy and difficult to transport from vender to home
Cost	– Acquisition costs vary, typically more expensive than traditional stoves – Some require electricity to power a small fan – Replacement stoves likely needed at least every 10 years	– Cost of LPG may make more expensive than advanced combustion stoves – Some global users (e.g., India) must register before accessing subsidies

Boiling Test (WBT), Controlled Cooking Test (CCT), and Kitchen Performance Test (KPT). These and other protocols are unique in their measurement of stove performance. The CCT and KPT, for example, can be used to measure emissions during cooking while the WBT is used most often to quantify the energy transferred from fuel to cooking pot. Variations between testing protocols – such as how to account for weight variations between dry and wet wood when calculating pollution emissions per kilogram of wood combusted – create data comparability issues. Further complicating this process are known discrepancies between stove performance (and thus testing results) in controlled (CCT) versus field (KPT) settings and lab (WBT) and field settings (Bailis et al., 2007; Roden, et al. 2009).

The International Organization for Standardization (ISO) International Workshop Agreement (IWA 11:2012) interim cookstove guidelines use a five-tier system (with higher tiers indicating better performance) to rank cookstoves by their fuel efficiency, total emissions, indoor emissions, and safety. Building on the IWA, the Alliance Standards and Testing Working Group has used an ongoing 'consensus-building' process to further refine stove testing protocols and to develop additional indicators for evaluation such as field performance, durability, cost, and home compatibility. (At the Nairobi meeting in February of 2014 however, a new ISO TC 285 process will be implemented.) In Forum sessions on standards and testing, participants acknowledged the need to identify and define these metrics so that manufacturers have performance targets and that users can differentiate high- from low-quality stoves. They also stressed that urgency should be balanced with efforts to maintain transparency and participation in the standards process and to minimize conflicts of interest.

Current debates

Should cookstove scale up occur with current technologies or should we wait for technologies that can reduce exposures and improve population health with greater certainty?. The momentum of major initiatives aiming to disseminate hundreds of millions of more efficient, low polluting cookstoves over the next decade (GACC, 2012; Venkataraman et al., 2010) is encouraging and necessary. Yet there is much to be learned about stove performance and durability as well as suitability and affordability. A combination of cost, technology development/delivery infrastructure, and behavioral factors has limited the effectiveness of most stove technologies in reducing HAP under conditions of actual implementation (Ezzati, 2005; World Bank, 2011). For some members of the cookstove community, the magnitude of HAP-related health and climate impacts mandates immediate action and stove dissemination, even if current technologies fail to meet the highest IWA performance tiers and reduce air pollution emissions to very low levels. The Alliance mission, for example, emphasizes the number of clean cookstoves disseminated rather than target air pollution exposure or disease burden reductions. For other members of the cookstove community, cookstove scale up first requires greater confidence in the effectiveness of stove interventions to provide substantial reductions in air pollution exposures and related illness and deaths. A potential area of agreement between these two groups is that ongoing stove design and research activities should ideally coincide with broad market development efforts prior to larger scale implementation, as was recently done in India where a systematic assessment of stove performance, uptake, and sustained use preceded larger-scale implementation (Mukhopadhyay et al., 2012). This enables stove implementers to capitalize on current initiatives for stove implementation and address the need for clean energy without sacrificing the quality of interventions. Further, once high performing stoves are field tested and primed for market entry, the transformation of local and regional markets will be well underway.

Should we continue to focus on cookstoves or is a more comprehensive approach to household energy needed?. Much emphasis has been placed on "…clean and efficient household cooking solutions" (GACC, 2012) relative to other energy uses like space heating, water boiling, lighting, and cooking animal food. Indeed, cooking with solid fuels is a major health risk factor (Lim et al., 2013) and likely the largest overall contributor to HAP (Bonjour et al., 2013). However, empirical work shows that households typically operate with multiple fuels and stoves to meet their energy needs (Parikh, 2011; Ruiz-Mercado et al., 2011; van der Kroon et al., 2013). A more comprehensive household energy approach could achieve large gains in efficiency and exposure reductions, particularly since a stove's combustion pattern depends on its purpose — e.g., heating stoves must continuously generate and retain heat rather than direct it towards a pot during specific events. Thus, advances in cookstove technologies are unlikely to work for unattended, continuous space heating which is a large contributor to HAP in colder regions (Baumgartner et al., 2011; Edwards et al., 2007).

Should the clean energy sector primarily focus on promotion of clean biomass cookstoves or should the sector extend the focus to fuels such as LPG?. While biomass cookstoves have garnered much attention, the cleanest and most commercially successful HAP interventions to date are stoves that burn LPG. Despite their promise, biomass cookstoves remain largely unproven technologies for reducing HAP and improving health. LPG combustion, in contrast, produces less pollution than advanced biomass stoves (Zhang et al., 2000) and is very likely used by billions of people globally (Smith et al., 2005). At the Forum, a stated concern about LPG stoves was that the cost and continuity of fuel supply may limit LPG use among some families currently using solid fuels, particularly in more remote or poorer regions. Others argue that innovative business models combined with well-coordinated, targeted government action, including subsidies, could make LPG more readily available and affordable to poorer households, though previous subsidy programs have had mixed results (Kojima et al., 2011).

Issue area 2: local development

Background

The potential for cookstove programs to support local development is related to the manufacturing and distribution structure of the program. Local development is defined here as production activities that utilize and reflect the governing entities, resources and perspectives of areas targeted by programs. The relative advantages of local versus imported manufacturing on local development are active topics of debate. Discussion at the Forum largely focused on the benefits of imported cookstoves that are designed in engineering labs and industrially manufactured at low cost. In general, imported stoves offer better fuel efficiency and lower emissions than artisanal stoves (MacCarty et al., 2010). A recent technical assessment (Jetter et al., 2012) found that centrally produced stoves outranked artisanal stoves both in emissions and efficiency (Table 3). Imported stoves may also be perceived as holding higher prestige, leading to increased adoption rates despite their higher cost when compared with domestically produced stoves (Adkins et al., 2010).

Still, locally produced technologies offer other advantages, which merit consideration. Artisanal stoves are more likely to rely upon regionally available material and manufacturing capacities. Local manufacturing engenders community stove production networks (often trained by NGOs and aid organizations) which increases opportunities for skilled labor and faster rates of repair and maintenance services (Adkins et al., 2010). Linkages to localized networks can strengthen program durability though they cannot guarantee success — e.g., the Indian national cookstove program failed, in part, because its local production model did not disseminate stoves of sufficient quality (Kees and Feldmann, 2011). In addition, local production lends itself to "design drift", whereby stove producers diverge from the original stove model, a practice which can lead to

Table 3
Ranking artisanal and centrally produced stoves by performance (Jetter et al., 2012). Stoves were ranked on a scale of zero to four per the IWA, with zero representing an open fire and four representing best performance similar to that of a gas-burning stove. Scores reported here reflect overall performance. The original source includes a breakdown of individual stoves and sub-categories like high- and low-power performance.

	No. tested	Mean rank (emissions)	Mean rank (efficiency)
Artisanal woodstoves	3	0.3	0
Centrally produced woodstoves	9	1.4	1.9
Artisanal charcoal stoves	6	0	1.3
Centrally produced charcoal stoves	1	1.0	3.0
Centrally produced stoves using pellets and other fuels	6	0.5	0.5

sub-standard products that damage the reputation of the original stove (Bailis et al., 2009).

Hybrid approaches make use of local designs or materials while incorporating some parts that are produced in a central manufacturing facility. The “plancha” stoves popular in Central America follow this model: heavy steel grills, fireboxes, and chimneys are mass-produced while the rest of the stove is built on-site with locally procured bricks, sand, ashes, and cement (Bailis et al., 2009). Hybrid models are frequently favored in the literature. Barnes et al. (1994) describe successful local assembly techniques that mass produce critical stove components off-site and enable other stove parts to arrive at the household through local supply chains.

Current debates

Should local stove manufacturing be one variable for determining program success?. The merits of imported versus locally designed or hybrid produced stoves remain highly debated among practitioners and development scholars (Adkins et al., 2010; Bailis et al., 2009). In international policy circles where health benefits and fuel efficiency standards are paramount, preferences lean towards external manufacturing. Still, discrepancies between lab and field performance are well documented (Roden et al., 2009; Smith et al., 2007), rendering the performance gap between imported and locally-produced cookstoves less certain than lab tests may indicate. Complicating issues like “stove-stacking”, in which households adopt cleaner stoves and also continue to use their traditional stoves, raise concerns about the ability of a single intervention to achieve the benefits supported by lab-test results (Ruiz-Mercado et al., 2011). Furthermore, some cooking technologies, such as biogas-fueled stoves, rival the best performing stoves, but the fuel production system, such as a biodigester, must be constructed in situ.

Does current research support efforts to assess the benefits of local stove production on development and health outcomes?. Numerous potential corollary benefits associated with local development further complicate the local versus imported stove debate. In addition to improved fuel efficiency and reduced household air pollution, cookstove interventions may also improve employment and livelihood opportunities for the rural and peri-urban poor. For example, The New Laos Stove (NLS) program in Cambodia – a national cookstove distribution program that relies on local manufacturing and distribution networks – supports over 44 cottage enterprises (Geres, 2012). Based on testing by US EPA, the stove is less efficient than some comparable charcoal stoves and performs relatively poorly in emissions tests (Jetter et al., 2012). Yet local stove manufacturers cite program benefits ranging from increased entrepreneurship to reduced emigration pressures to locate viable work options. Cottage industries are often strategically located near village schools and other services, enabling women to watch their children during the workday while earning comparable wages to those acquired in more distant garment factories (Hyman, 2013). In addition, reliance on local manufacturing skills and materials increases the likelihood of success after external financing runs dry (Simon, 2009). There is a lack of consensus about how to assess the benefits of local development attributes in comparison to the emissions and efficiency performance benchmarks associated with programs that rely on imported stoves.

Can quality assurance and design standardization be sufficiently achieved when stoves are locally produced?. Quality assurance and control are more difficult in the local manufacturing model. Decentralized production increases the chance of design drift whereby local manufacturers modify the combustion chamber or other design features according to their own understanding of local needs (Sinton et al., 2004). This may involve producing stoves with wider fuelwood openings despite the fact that better-performing cookstoves frequently have narrow openings — a feature that could inconvenience users by forcing them to pre-cut fuelwood to smaller sizes than is necessary when using a traditional stove (Bailis and Hyman, 2011). A key challenge for the cookstove design community is to strike a viable balance between design that achieves health and environmental goals while also satisfying user preferences. Design drift may be troublesome for project implementers, but the phenomenon offers insight into user preferences that can assist future efforts to ramp up cookstove adoption rates. Empirically driven analysis of past and current stove programs will be needed to formulate an effective design, production and distribution framework that satisfies local user preferences.

Issue area 3: direct versus indirect subsidies

Background

Whether development interventions like clean cookstoves ought to be subsidized has been debated for decades (Barnes et al., 1994). As development interventions shifted from primarily aid-based dissemination models to more commercially oriented approaches in the 1990s, subsidized interventions were increasingly considered unsustainable because they failed to recover program costs (Bailis et al., 2009). Today, this debate continues as priorities like market competition and sustained demand (a feature of high-end stoves) are pitted against stove affordability for poor households. Further clarity is needed to distinguish how different kinds of subsidies and market economies actually perform in practice.

Subsidies can be direct or indirect and may be sourced through multiple channels. Direct subsidies include external financing (either through public, private or joint channels) of the partial or total cost of the cookstove itself. They can be critical to support a project's promotion of costly imported stoves, which typically offer higher efficiency and potentially greater health and environmental benefits (Gaul, 2009). Direct subsidies can also include external assistance to cover customs, taxes, or start up costs for cookstove dissemination programs. Indirect subsidies refer to external assistance used to support the fuel-efficient cookstove market in general. These may include payments to support public awareness campaigns and micro-finance institutions, cookstove research and design efforts, capacity building workshops for stove producers, and the creation of standards and certification schemes (Simon, 2009).

Current debates

How are stove subsidies different from other subsidized health products?. Evidence from other health product programs in developing nations shows that when subsidies are withdrawn, adoption rates of health-improving technology decline. Kremer and Miguel (2007), for example, argue that interventions reducing infectious and parasitic diseases, which deliver “large positive treatment externalities” will likely require ongoing subsidies (p. 1011). If subsidies are justified in other health interventions targeting poor communities – from bed nets to vaccines – why is there resistance to subsidies for cookstoves? For one, it remains unclear whether conclusions from other health sectors are transferable

Table 4
Arguments for and against direct and indirect subsidies. Descriptions of what constitutes a "smart" subsidy reflect each camp's varying development priorities for a cookstove intervention.

	Direct	Indirect
Pro	Reach poor households; increase access to aspirational technologies Support for public goods within "bottom of the pyramid" communities Correcting market failure (e.g. imperfect information, principal-agent problems, etc.)	Market development; capacity building Distributes gains along entire value chain Supports government engagement and oversight
Con	Inhibits market development and distorts market price structures Questions over long-term sustainability Increased opportunities for abuse; difficult to target Perceived value compromised, "entitlement effect"	May not meet the needs of the very poor/insufficient support for overcoming adoption barriers Micro-finance institutions and stove distribution groups may have conflicting priorities Local governments may be difficult to work with Difficult to calculate return on investment along diverse value chains

to stoves. Unlike vaccines, clean stoves do not present a near certain pathway towards disease resistance and prevention. Moreover, cookstoves are associated with different types of positive externalities, making the financial justification for subsidies difficult. Indeed, a defining characteristic of cookstove interventions is that they offer multiple benefits (Simon, 2010). Some stove benefits, including reduced health risks and fuel savings, are private in nature, and may be internalized in the cost of the stove. Other potential benefits affect public goods that might arguably warrant the use of subsidies. For example, fuel-efficient stoves can, in some instances, reduce pressure on forests and/or reduce carbon emissions. These benefits accrue to society at large and can be used as an argument in favor of programmatic subsidies.

What are the main arguments for and against the use of direct and indirect subsidies?. The topic of subsidies generated passionate discussion at the Global Forum (Table 4). A seminal World Bank study argues against direct subsidies, citing concerns that subsidies are vulnerable to misuse and difficult to phase-out (Barnes et al., 1994). Further, subsidies can generate an "entitlement effect" whereby consumers "anchor" around the subsidized price and refuse to pay more once the subsidy is reduced or removed (Dupas, 2010). Those in favor of subsidies argue that cookstove technologies are relatively inexpensive considering their range of potential development benefits. The World Health Organization estimates that distributing clean cookstoves to half of the solid fuel using population would cost only US$34 billion per year while generating US$105 billion in total fuel savings per year (WHO, 2006). A compelling case for subsidies is that traditional stove users may not internalize the potential benefits of improved stoves. People may be unaware of the health risks associated with current practices or determine that mitigating these risks is a low priority in comparison to other household needs (Mobarak et al., 2012). Health risks are not equally distributed within the household; people in charge of cooking or most exposed to HAP do not necessarily make expenditure decisions (Pritchett and Woolcock, 2004). Thus, gender-based power dynamics or risk-aversion within poor rural households may block a family's ability or willingness to invest in a better cookstove.

Is there a role for the market and government in delivering subsidies?. In addition to questions about the relative advantages of direct versus indirect subsidies, there is active debate about the level of need within the recipient population. Bailis et al. (2009) argue that the private sector is an efficient means of distributing goods to paying populations, but those market mechanisms historically underserve those most in need. Within very poor communities, a case could be made for direct subsidies or public assistance to reach development goals (Alverez et al., 2004; Shrimali et al., 2011). In a related study, Kolk (in press) identifies three types of business models for delivering goods to poor and remote areas based on local market-readiness (Table 5). Given the appropriateness of subsidies in certain contexts, this delineation usefully indicates how and where to apply subsidies. Therefore, in our view, debate over subsidies should hinge not on the choice of whether or not to subsidize, but rather, how to promote "smart subsidies" which effectively overcome barriers to adoption, avoid long-term dependence on external aid and utilize local market capacities.

Issue area 4: the role of carbon and impact finance

Background

Over the past 10 years, there has been a steady rise in carbon financed stove projects. As of May 2013, carbon finance supported approximately 75 cookstove clean development mechanism (CDM) projects and 63 Program of Activities (PoAs) including biogas.[2] Along with greenhouse gas emission reductions, researchers estimate that solid fuel cookstoves emit roughly 18% of global black carbon emissions, which were recently recognized as a major climate change contributor (Bond et al., 2013). Cookstove intervention programs therefore present an opportunity to generate significant climate forcing emission reductions (Bond et al., 2004; Ramanathan and Carmichael, 2008; Smith et al., 2000).

A substantial decline in the market rate of certified emission reduction (CER) credits has raised concerns about the long-term viability of carbon finance schemes within the sector. Market prices dropped from the already low level of US$3.40/CER in late 2012 to US$0.66/CER a year later (UNFCCC, 2012). Forum participants voiced concern about their capacity to sustain the carbon credit provision, agreeing that current credit prices are untenable as program costs increase due to stricter emissions monitoring and technical requirements.

The low pricing and volatility of carbon offsets and other administrative challenges are encouraging the development of alternative investment mechanisms. To be sure, no substantial opportunity for stove projects can emerge from the regulatory (as opposed to the voluntary) carbon credit market without ambitious government-initiated GHG emission reduction commitments that remain a major demand side driver. Yet despite these barriers, promising new market innovations are now emerging. For example, Nationally Appropriate Mitigation Actions (NAMAs) are expected to extend finance avenues opened by PoA schemes as they allow for greater flexibility of activities without a need for major methodological changes (Lee et al., 2013). PoAs allow for simplified inclusion of new activities over a long time period, thus avoiding the cumbersome process of developing accreditation for each new project. NAMAs are expected to use – and expand upon – a similar administrative architecture to those found within PoAs. Although support from developed nations is required, greater flexibility for developing nations emerges under NAMAs as countries have greater control over the development of a network of projects that comply with domestic technology, administrative, financial, ecological and social capacities.

Among the 224 NAMAs listed in the registry of approved CDM projects dated May 1st 2013, at least 2 explicitly mentioned stoves as one technology diffusion option (UNEP Risoe Center, 2013). Further innovations are expected from the yet still vaguely defined 'New Market Mechanisms' (NMMs), which are expected to provide alternative

[2] These include 32 projects registered as Gold Standard but omit voluntary Gold Standard projects.

Table 5
Business models for delivering goods to poor populations (adapted from Kolk, in press).

Business model	Commercial viability	Relevant context
Company-funded	Fully viable	• Only in developed countries or emerging economies • Very difficult to start and sustain in LDCs
Co-funded or partially subsidized	Not yet viable	• Public–private partnerships, perhaps with NGO partners • Developed as a "Social Enterprise" or as part of a Corporate Social Responsibility campaign • Little or no requirement for internal return on investment
Fully subsidized via government or donor support	Unlikely to be viable in the foreseeable future	• Areas considered too high risk or low-return for commercialization (e.g. remote high-poverty regions, conflict zones, fragile states) • Philanthropic participation justified

approaches to incentivize and verify greenhouse gas (GHG) emission reductions. Given the diversity of methods and scales of intervention operating simultaneously, a Framework for Various Approaches (FVA) model has been discussed during international climate negotiation events (such as those organized by the United Nations) in order to coordinate and prevent duplication between different market mechanisms (Marcu, 2012).

Beyond carbon finance there is growing interest and demand for "impact investing" opportunities, which present investment possibilities based on health, development and ecological benefits associated with stove replacement programs. As Simon et al. (2012) note, the primary benefits of clean cookstoves are health, development and ecology related, with climate dividends a secondary program outcome. Impact investors evaluate various social and environmental benefits (e.g., ecosystem based metrics or disability adjusted life years) associated with cookstove programs beyond carbon reductions. Philanthropists, governments and other financiers determine their investment choices based on the ability of programs to generate sustainable and self-supporting benefits beyond the initial investment.

Current debates

Given recent price and demand changes, is there a future for regulatory carbon finance?. Given the complexity, pricing and volatility of carbon finance, there is great uncertainty about the role that carbon finance can play in supporting stove distribution under the Alliance. While Forum participants do not see carbon finance as a panacea for the sector, optimism remains about its utility in the diffusion of clean cookstoves, particularly in the voluntary market. Carbon market advocates will need to build bridges with public and private sector representatives to enhance demand, refine sector practices and promote market growth under a Framework for Various Approaches. Industry stakeholders should continue to develop and expand impact investment opportunities by articulating sector achievements to philanthropists and social entrepreneurs, while highlighting potential cost savings (from improved health, ecosystem services etc.) to governments. Avoiding double counting of carbon reductions amidst a plurality of funding streams will be necessary to promote sector credibility and growth.

Should carbon finance be considered a type of stove subsidy?. At the Alliance Forum, there was lack of clarity among practitioners, investors and governments alike over how (or whether) to differentiate carbon finance from subsidies. Carbon financed projects are similar to subsidized cookstove projects in that revenue from carbon credit sales is often used to directly reduce the price of the stove, or to indirectly support the cookstove market (Simon et al., 2012). Like subsidies, carbon finance attempts to compensate for market failures. Unlike subsidies, carbon finance adds layers of complexity for project implementers who must market themselves to prospective credit buyers and navigate a complicated accreditation process. Moreover, carbon finance – a results-based finance mechanism – is generated by the internal performance of the cookstove project itself. As such, the carbon investor holds responsibility for projected and/or unrealized results and thus has an incentive to improve stove adoption rates and ensure timely transactions. Research that compares the viability of carbon finance with traditional subsidies and other finance mechanisms would assist efforts to increase fuel-efficient cookstove dissemination.

Is carbon finance good for clean cookstove distribution?. Perhaps the most enduring critique of carbon finance is that it does not necessarily promote low-polluting stoves — projects can qualify for finance with stoves that reduce GHG emissions but do not improve (or may even worsen) harmful HAP emissions (Grieshop et al., 2011). Other concerns raised at the Alliance Forum included carbon credit prices and volatility (Newell and Bumpus, 2012) and technical challenges in calculating the percentage of fuel from non-renewable sources — known as 'fraction of nonrenewable biomass' (fNRB) which determines the magnitude of GHG emission reductions for cookstove projects (Arnold et al., 2006; Ghilardi et al., 2009; Johnson et al., 2010; Top et al., 2004). Carbon finance offers other benefits as well. In the case of upfront payments for credits, it provides project developers upstream investments to support outlay costs and develop supply chains, which may, in turn, reduce manufacturing and/or distribution costs and lower stove prices. It also generates opportunities for technology support and maintenance during periodic emissions monitoring activities (Bailis et al., 2009; GTZ, 2011; Troncoso et al., 2007) and provides opportunities for scale-up (Bumpus, 2011; Zerriffi, 2011). While there is general agreement that carbon finance can be leveraged, disagreement lies in how to construct and integrate diverse mechanisms in the most transparent, uncomplicated and equitable way. Table 6 distills the debate over carbon market inclusion.

Future research directions

Emissions and efficiency standards: conducting integrated research to evaluate and promote high performing, household suitable stoves

The Alliance Forum and past stove programs make clear that implementers cannot assume that improved cookstoves will significantly reduce emissions and exposures. Comprehensive vetting of stove interventions for their performance and desirability prior to scale-up is a crucial, and often overlooked, phase of many stove programs. Such vetting requires an integrated approach that evaluates both the technical (e.g., emissions and exposures) and socio-cultural (e.g., adoption and sustained use) determinants of stove performance. Efforts to introduce emission standards and testing protocols have grown since the Partnership for Clean Indoor Air Global Forum delivered the Lima Consensus in 2011. As international cookstove protocols are further developed and refined, future research could evaluate the relative benefits of stove interventions by identifying and testing a wide range of stoves that are highly efficient, low-polluting and safe in both controlled and field settings. Field performance assessments that are accompanied by evaluations of the stoves' ability to perform in ways that users expect

Table 6
Arguments for and against inclusion of carbon finance in cookstove projects.

	Carbon finance	
	Pro	Con
Price	Places value on environmental services from improved stoves. Generates project revenue, which may lower stove price.	Price of carbon is low and volatile in most cases. Black carbon not included. N_2O and CH_4 not included in CDM.
Eligibility	Stove projects are eligible, as are solar technologies in some cases. Carbon finance aids projects capable of scale up.	High transaction costs and associated risks direct investments to larger and financially secure projects. Many burning solid fuel other than fuelwood cannot access carbon finance.
Governance	Third party analysis, ongoing monitoring and transparent processes for most schemes.	Lower levels of transparent, consistent and impartial support exist in some voluntary market certification schemes.
Climate	An effective mechanism to reduce GHGs and black carbon emissions.	Presents uncertainties in complex calculations and questions over emissions enumeration accuracy.
Health	Can increase efforts to scale-up cookstove distribution resulting in wider delivery of health benefits.	Emissions of GHGs and health-damaging pollutants are not always correlated. Optimizing climate benefits may not result in health improvements.
Environment	Carbon GHG emission reductions tend to correlate with energy efficiency and reduced biomass consumption.	Estimating fNRB is difficult due to ambiguous methodologies and inherent uncertainties, which make it difficult to confirm cookstove impacts on forest cover.

and desire in the short- and longer-term will assist in the identification of a suite of high-performing, household suitable stove interventions.

Imported versus locally produced stoves: developing a framework for analyzing site-specific conditions that promote local production of high quality cooking technologies

A salient challenge facing efforts to promote and evaluate local development within cookstove interventions is determining how to compare diverse project benefits. Rather than generate a standardized metric of development success, efforts would be better directed towards describing the conditions and challenges associated with actuating a range of project benefits. Such efforts would enable policy makers to prioritize development outcomes. Discourse within the cookstove community often conflates local development and health outcomes as automatically complimentary when, in fact, the financial, environmental, and health benefits of a project may be unrelated or even conflicting. Project outcomes are generally informed by a suite of local conditions including labor capacity, resource availability, administrative leadership, business acumen and community outreach abilities (Dupas, 2010; Lewis and Pattanayak 2012; Whittington, 2012). Empirical clarity is needed to assess how imported stoves can remain reliably accessible and appropriate for the poor (with or without carbon finance). This research should also generate guidelines for determining how locally produced stove enterprises can achieve an equivalent level of stove quality and market adaptability.

The role of direct versus indirect subsidies: further evidence-based research on the influence of diverse subsidies on market sustainability and household usage

There is a need for further research exploring the relationship between direct and indirect subsidy interventions on adoption rates over time, including repurchase rates and continued use after the subsidy desists (Whittington et al., 2012). Most research has commented on the consequences of stove subsidies ex post facto without actually conducting comprehensive household research at the moment of subsidy application (e.g., NCAER, 2002; Rehman and Malhotra, 2004). One major issue still requiring systematic evaluation is the relationship between subsidy application, stove adoption and sustained usage by households. Moreover, evidence-based field research will help practitioners better articulate conditions under which direct and indirect subsidies are appropriate.[3] Are subsidies supposed to promote the creation of a viable local stove industry or the diffusion of highly modernized technologies into a developing country setting — or both objectives at once? Further work will be required to both determine the purpose of subsidies and to measure their effectiveness in achieving the varied goals associated with cookstove intervention.

Carbon and impact financing: investigation of sector conditions that attract investors and integrate diverse (carbon and non-carbon) finance mechanisms

Waning demand and plummeting prices for carbon offsets have raised doubts about the long-term influence of regulatory (CDM) carbon finance within the cookstove sector. These developments notwithstanding, considerable carbon investment and administrative capital still remain to assist the growth of global stove markets. As such, the general sentiment among Alliance Forum participants was not to move away from carbon finance, but rather to adapt to market changes and diversify financing approaches. If indeed the primary objective of the sector is to bring clean and efficient cookstoves into millions of new homes (Freeman and Zerriffi, 2012), then a suite of effective and complementary financing options are needed. Evidence-based research will be needed to determine accurate, transparent and efficient approaches for integrating CDM, Voluntary Market, NAMA, NMM, targeted subsidies and other mechanisms. Furthermore, there is a need for better empirical data illuminating the financial benefits of stove distribution so that impact-financing methods begin to attract investors in both public and private sectors. These research pathways will be needed to help program managers evaluate the optimal mix of funding applications (i.e., Framework of Various Activities) for a given project so that technology accessibility and performance are optimized.

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[3] Evidence based research is premised on the collection of empirical data that reflect verifiable findings, real world conditions and actual human perspectives. The benefits of this research are two-fold. First, these data can be used to inform model projections and increase their accuracy and predictive power. Second, empirical observation can be useful for increasing our understanding of site-specific conditions and important, local social–ecological processes.

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