The Stoves Are Also Stacked: Evaluating the Energy Ladder, Cookstove Swap-Out Programs, and Social Adoption Preferences in the Cookstove Literature

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Abstract

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The distribution of fuel-efficient cookstoves, whether via aid, subsidies, carbon finance, or public programs, has undergone an international renaissance since the establishment of the "Global Alliance for Clean Cookstoves" (GACC) in September 2010, a high profile private-public partnership including the United Nations, the United States' Environmental Protection Agency, and the Shell Foundation. The dominant discourse within the GACC mission and project strategy is the conviction that cookstoves can attract sufficient carbon finance to completely offset project costs, resulting in highly leveraged returns on donor contributions. Much of the literature has focused on the many positive contributions of cookstove technology including improving public health, decreasing the burden on women, and reducing deforestation. Ample policy publications present recommendations for practitioners regarding cookstove design and project development, though these publications often underreport project failure. Cookstove technology is not a new intervention but with the entrance of innovative financing streams, it is essential to contextualize its past performance within the academic and policy literature. This survey of existing knowledge synthesizes current understanding of fuel-efficient cookstove interventions while also revealing literature gaps and potentially fruitful lines of inquiry for future scholarship.

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The distribution of fuel-efficient cookstoves, whether via aid, subsidies, carbon finance, or public programs, has undergone an international renaissance since the establishment of the "Global Alliance for Clean Cookstoves" (GACC) in September 2010, a high profile private-public partnership championed by United States Secretary of State Hilary Clinton, and which includes the United Nations, the United States' Environmental Protection Agency, and the Shell Foundation. The alliance aims to reduce black carbon (soot) from the atmosphere, improve family respiratory health, provide women with timesaving technologies, and reduce burns and injuries in the home. Yet beyond the public fanfare for the cookstove solution, previous attempts at distributing fuel-efficient cookstoves and liquid cooking fuels in rural communities in developing countries have achieved mixed results and are understudied. Today, there is a proliferation of gray literature on cherry-picked cookstove programs and a robust literature on the technicalities of cookstove performance in reducing indoor pollution and increasing the efficiency of fuel combustion. Yet after thirty years of international attempts at distributing fuel-efficient cookstoves to households in developing countries, adoption and implementation patterns remain enigmatic. The ability to determine project performance is further complicated by new factors—such as the proliferation of carbon finance projects.

This literature review draws upon scholarly and policy-papers from 1987 to the present to outline key debates in the production, dissemination, and continued utilization of efficient cookstove technologies in order to identify gaps in the research. The first section is a catalogue of the social and environmental benefits frequently attributed to improved cookstoves. In the second section, we investigate the spectrum of stove program types and financing models, from purely public to commercial distribution models in an effort to identify research gaps in terms of understanding adoption patterns in varying institutional contexts. In the third section we shift the examination to the household level to survey the landscape of theories and scholarly work responding to a question famously posed by Barnes et al. at the World Bank: *"Why, in the face of all the benefits, have so many potential beneficiaries of improved stoves decided not to purchase or use the stoves given the opportunity?"* (1994). The existing theories on fuel preferences, technology adoption, and gender dynamics in determining cookstove adoption rates are addressed, including a critical examination of the "energy ladder" model. In the fourth section we critically examine the vision of cookstove programs more broadly by synthesizing current debates on what "improved" cookstove technologies and fuel types include and by inviting scholars to more rigorously assess the advantages and disadvantages associated with locally produced or imported stove programs. Finally, the literature review concludes with key questions on the edge of the cookstove research frontier.

Meeting International Development Goals through Cookstoves: A Catalogue of Benefits

Cookstoves interest both policy-makers and development scholars given the relevance of improved energy access and modernized energy systems to the Millennium Development Goals (MDG), which have become a proxy for international development targets. While no specific MDG for energy exists, related issues, such as improving access to modern fuels, and reliable electricity and modernizing cooking methods, are required to achieve all eight goals (Foell et al. 2011; Modi et al. 2006). Additionally, growing interest in carbon finance as a mechanism to achieve climate compatible development has also refueled interest in cookstove interventions (Linacre et al. 2011).

Almost three billion people, equal to 40% of the world's population, lack access to modern cooking fuel and technology (IEA2010). Cooking fuel is a basic necessity required for cooking most staple foods, and the world's poor are disproportionately affected by the need to collect or purchase cooking fuel (Sagar 2005). Therefore, improving access to efficient fuel sources and reducing the amount of fuel needed for household heating and cooking is directly correlated with the eradication of extreme poverty and hunger. The majority of cookstove interventions therefore, focus on solid fuel use, although still only 27% of this population has access to fuel efficient cookstoves (Hosgood et al. 2010).

Much current scholarship on cookstoves focuses on specific benefit areas, such as health (Ezzati et al. 2004; Smith 2000), climate change (Bailis et al. 2005; Grieshop et al. 2011; Smith 1994), improved livelihoods for women and children (Parikh 2011), and development (McDade 2004; Sagar and Kartha 2007). Although there is empirical evidence demonstrating the positive impact of cookstoves in each of these areas, it cannot be assumed that cookstove interventions equally benefit each area. Certain projects may favor one benefit area over another, and no project includes a comprehensive benefit package.

Cookstoves and Gender

The burden of fuel collection is customarily a task reserved for women and children, and numerous studies document the work as time intensive (Oparaocha and Dutta 2011); potentially dangerous, particularly in politically unstable regions (Patrick 2007); physically treacherous and associated with a high rate of injury and soreness (Bryceson and Howe 1993; Parikh 2011). Furthermore, the time, risk and injury associated with fuel wood collection is not recognized in the price of wood fuel, rendering invisible both the energy expenditure and the true value of wood fuel within household budget calculations and many policy discussions (Parikh 2005).

It is common practice in rural communities to keep children, particularly girls, out of school for assistance with fuel wood collection and processing given the urgency of meeting household cooking and heating needs (Clancy 2002; Parikh 1995). Thus, while the relationship between cooking fuel options and cookstove options is clearly related to the livelihoods of woman and children, the dynamics of how improved cookstoves will actually improve the lives of women and children is complex, nuanced, and sensitive to social and cultural dynamics such as the woman's ability to authorize how she spends her time and how her work is socially valued.

Cookstoves and Health

The relationship between cookstoves and family health is dramatic. Coined the "killer in the kitchen," indoor smoke from traditional biomass, charcoal, and wood fuel cookstoves is highly correlated with pneumonia and chronic pulmonary disease and accounts for 3.3 million deaths (WHO 2006). By 2030, the number of premature deaths is estimated to reach 9.8 million, demonstrating the significant disease burden (Bailis et al. 2005). Following malnutrition, unsanitary water, and unsafe sex, indoor air pollution is the dominant cause of health risks in developing countries (WHO 2006). This health burden disproportionately impacts women and children, affecting child mortality rates and exacerbating the condition of the immuno-compromised. For children, research has shown that improvements in stove and fuel choices reduce acute respiratory infections equivalent to the delivery of antibiotics through primary health care systems (Ezzati et al. 2004). The potential health benefits of introducing fuel-efficient cookstoves into developing country households provides one of the fundamental justifications for international donor interest and support (Goldemberg et al. 2004; Smith 2010). While the correlation between increasing access to modern efficient fuels and health is well documented (WHO 2006), increasing health in the kitchen is not a simple technocratic task. Scholarship on the cost-effectiveness of fuel-switch interventions implies that cookstove interventions coupled with education on the importance of ventilation in the kitchen can reduce indoor air pollution 25% more effectively than fuel-switch interventions alone (Mehta and Shahpar 2004).

Cookstoves and the Environment

Initial attempts at fuel-efficient cookstove dissemination focused on ending deforestation, the underlying assumption being that wood fuel demand from the rural poor was driving the destruction of primary forests (Arnold et al. 2006, Foell et al. 2011). Further scholarship dismantled this development narrative, demonstrating that forest cover change is often driven by timber extraction or pasture and agricultural demand (G. Leach and Mearns 1988; M. Leach and Mearns 1996). Also, in some cases, village wood collection has actually been shown to stimulate forest cover growth (Forsyth 2003).

Currently, the debate has shifted to a focus on the local and global environmental impacts resulting from fuel-use emissions. Household fuel usage accounts for 18% of global black carbon emissions (Foell et al. 2011). Between 25% and 35% of black carbon in the atmosphere comes from China and India, emitted from the burning of wood and cow dung for household cooking and through the use of coal-based household heating systems (Ramanathan and Carmichael 2008). Notably, burning biomass results in a much higher global warming potential than more "modern" fossil fuels such as kerosene and liquefied petroleum gas (LPG) due to incomplete combustion and the release of other emissions such as methane and black carbon (WHO 2006).

Fuel-efficient stoves are estimated to reduce greenhouse gas emissions by 1–3 tons of carbon equivalent per annum (Bailis and Hyman 2011). Therefore, expanding fuel-efficient cookstove dissemination programs to their full breadth could reduce global greenhouse gas emissions from 2.19 to 6.57 million tons of carbon dioxide equivalent per annum. In addition, an alternative stove system such as an efficient biodigester, a type of cookstove that introduces a localized, household-level biogas system utilizing animal waste for cooking fuel, emits 99% less methane than a rudimentary cookstove that heats with dung (WHO 2006). Envirofit, a lead stove manufacturer for the developing country market, has recently launched its CH-2200 stove model which promises a 50% reduction in charcoal consumption and 37.3% reduction in carbon emissions (Envirofit 2012).

The Spectrum of Stove Program Types, from Public to Private Institutions

Underlying the potential for a cookstove program to make a development impact is the issue of ensuring cookstove adoption and sustained use (Ruiz-Mercado et al. 2011). Open debates in the literature regarding successful and prolonged cookstove dissemination and acceptance center around the appropriate role of governments, the private sector, and NGOs in facilitating the production, dissemination, and adoption of new cookstoves (Gaul 2009; Goldemberg et al. 2004; Kees and Feldmann 2011; Shrimali et al. 2011).

The spectrum of cookstove financing options includes purely commercial models, such as venture financing, as well as soft loans and public grants. Cookstove programs typically rely on intermediate options that seek to leverage public support for the social benefits associated with stoves while attracting market actors to the developing country energy market (Cox 2011; Shrimali et al. 2011). Hybrid programs evaluated in the literature utilize public, NGO, or donor financing, at least at the outset of the initiative in order to support the development of technologies, the creation of research and testing centers, and to begin stove promotion and training (Kees and Feldmann 2011). Public support for start-up costs reflects the simultaneous public and private benefits associated with the new stoves (Bailis et al. 2009).

State-Driven Programs

The two largest cookstove programs, in India and China, have been state run. China's National Improved Stove Program (NISP), which introduced 200 million improved biomass cookstoves to rural households within 10 years, is often cited as the most successful national intervention (Smith et al. 1993). This far exceeds the penetration of other national cookstove programs, and China accounts for the largest number of efficient cookstove users in the world (Smith et al. 1993). Sustained government support was one of the key factors for the program's success, leading to widespread adoption, the development of local markets, and the dissemination of technical stove innovations (Edwards et al. 2004; Sinton et al. 2004; Smith et al. 1993). The utilization of "institutions stacking," or the phasing in and out of varying forms of support for the NISP has received praise from the cookstove epistemic community, though the literature is thin on comprehensive studies on local user preferences for improved biomass stoves or access to other fuel types. Meanwhile, the Chinese government is preparing for the second round of the program to disseminate new efficient stove technologies, given the improvements in the technology and rural energy infrastructure (Smith and Deng 2010).

India's program, the National Program on Improved Cookstoves (NPIC), was initiated during the same period as China's program. According to government estimates, the NPIC disseminated 28 million stoves (Kishore and Ramana 2002). In contrast to China's success, NPIC is characterized by low adoption rates due largely to a lack of maintenance and criticism that its "improved" stoves have high emissions and limited increases in efficiency rates (Kishore and Ramana 2002; Smith 1989). In 2009, India began the National Biomass Cookstove Initiative, which focuses on disseminating more advanced combustion technology stoves and has loftier goals to reduce pollution, rather than just transferring smoke outside the kitchen (Venkataraman et al. 2010).

Non-Governmental and Commercial Stove Programs

In areas with less proactive government intervention, NGOs have frequently initiated stove programs with mixed success due to internal fragmentation or sporadic funding; in particular, NGO-led programs have been less successful in scaling up (Barnes et al. 1994; Kees and Feldmann 2011; Uvin et al. 2000). Although NGOs have limited resources and reach, often they focus efforts on populations that lack financial capacity to purchase stoves or with insufficient energy demand to support market development (Bailis et al. 2009). These projects often target users who have no economic incentive to purchase new stoves because they gather fuel wood for household usage (Troncoso et al. 2011). It follows that the private sector has also taken an interest in cookstove substitution programs, though commercialization efforts by the private sector prior to the carbon market are understudied (Bailis et al. 2009). Private sector involvement, particularly in

Asia, reflects the large market potential for energy services among the poor (Barnes et al. 1994). The private sector may bring management, marketing, research and development, and sales skills to the cookstove market, in addition to the ability to raise capital at scale. Notably, there are few examples in the literature of self-sustaining commercial enterprises distributing improved cookstoves outside the carbon market (Shrimali et al. 2011).

Commercial stove programs tend to incorporate more advanced tracking, monitoring, and certification schemes than public programs (Adler 2010; Gaul 2009; Kees and Feldmann 2011), particularly in the carbon market. While some productive imbrications can be expected between private sector actions and project performance (that is, market-based interventions often focus heavily on adoption and usage in order to guarantee that carbon credits will be generated), the private sector may be less attuned to the stoves' ability to promote health and improve the lives of women and children, and may target users not on the basis of need but on the basis of current fuel-use consumption in order to maximize the credits generated. Thus, private-sector driven cookstove projects provide both advantages and disadvantages to public-sector oriented interventions; whereas the private sector will likely monitor usage more accurately, the public sector may be more willing to invest in populations that are able to demand very limited energy services.

Understanding Adoption Patterns in Varying Institutional Contexts

Current studies on public and private institutional frameworks for cookstove dissemination are inconclusive, and it is unlikely that there is a single best model given the wide variation in local conditions within which cookstove programs are implemented. The launch of GACC is injecting ambition into cookstove distribution efforts, although it is too early to analyze its effectiveness (Goldemberg et al. 2004; Smith 2010). However, the literature does point to the need for a model that can offer sustained support to network building, production, education, and extension services over time, given the significant development efforts associated with technology deployment to poor urban and rural households. Further research would be instructive on how varying institutional models impact a program's ability to deliver some development goods over others. In particular, there is a research gap on the role that the public and private sector can play in building institutions that support cookstove production and dissemination over the long term.

Consumer Pricing, Microfinance, and Other Models

An early debate in the cookstove literature focused on whether and how households should contribute to the cost of cookstoves (Barnes et al. 1994). Experience indicated that households did not value free goods; and indeed, survey studies of cookstove dissemination failures suggested that giveaway cookstoves "soured" the intervention, resulting in families either not valuing the stove or expecting the stove to be free in perpetuity (Barnes et al. 1994; Krugman 1998). Thus, almost all cookstove programs today charge at least some of the cost of the stove to the household. In the Chinese NISP, county agencies covered the cost of cookstove design and dissemination while households covered the cost of their own installation (Sinton et al. 2004). In Cambodia, the "fixed subsidy" model utilized by the National Biodigester Program (NBP) provides an elegant solution to the question of public versus private cost burden, whereby all farmers seeking biodigester-cooking technologies are offered a flat rate subsidy from the government: for smallholders the flat rate covers a substantial portion of the biodigester cost, whereas for larger installations the subsidy is much less significant. In this way, poorer families benefit more from the subsidy while administrative processes are streamlined (van Mansvelt, 2010).

Other forms of assistance include microfinance and public contracts arranged through local commercial banks for soft loans for cookstove programs (van Mansvelt 2010; Rao et al. 2009). Integrating private sector-driven carbon finance with soft loan arrangements at the national level appears promising, as evidenced in the NBP, which uses both nationally sponsored support for lending facilities and external carbon finance to underwrite a national biodigester program that reaches over 10,645 families in twelve provinces (NBP 2012; Sundar and Shakya 2005).

Direct versus Indirect Subsidies and Their Usefulness

For a development intervention, cookstoves offer a considerable suite of development benefits for a low donor price tag. The cost of disseminating improved stoves to half of the three billion solid fuel users would cost US$34 billion per year while generating a return on the stoves themselves of US$105 billion per year in terms of fuel savings at the household level (WHO 2006). While the private sector offers an efficient means to distribute goods to paying populations, markets historically underserve the most indigent populations (Bailis et al. 2009), thus indicating a need for some subsidies or public assistance to reach development goals (Alvarez et al. 2004; Kremer and Miguel 2007; Shrimali et al. 2011).

Direct subsidies are usually required for imported stoves, given that the cost is prohibitive for rural households without some direct assistance from governments, NGOs, or microfinance institutions. Gaul (2009) argues that there is no clear answer to whether direct subsidies are useful and forwards the concept of "smart subsidies" that are appropriate for local conditions, while Barnes et al. (1994) conclude that subsidies are useless. Instead, Barnes et al. champion indirect subsidies, that is, subsidies that support cookstove dissemination infrastructure, stove production, and education. Regardless of subsidy type, there is consensus that subsidies cannot compete with other fuel and energy policies, such as putting improved biomass stoves in direct competition with subsidized LPG (Gaul 2009).

Innovative Subsidies: Carbon Finance

Since the launch of the carbon market in tandem with the ratification of the Kyoto Protocol in 2005, the private sector has been developing accounting methodologies to earn certified emissions reductions, or carbon credits. The Gold Standard Foundation, a certification scheme for both the international and voluntary carbon market, launched a methodology for cookstoves in 2008 that was revised in 2010. The Clean Development Mechanism (CDM) also introduced its own cookstove-appropriate methodology "AMS II.G" in 2008 and approved it in 2009 (Blunck 2011). The carbon finance model is a public-private partnership; the public sector sets a cap on global greenhouse gas emissions and the private sector creates emission-reducing projects that earn "credit" towards the cap. The subsidy aspect of the carbon market is that funds generated by selling credits can be used to reduce the cost of the stove or to cover program costs.

Carbon finance appears to be a powerful financing mechanism that effectively utilizes the strengths of the private sector, including the ability to attract capital at scale, use effective management techniques, create self-sustaining markets and support innovation. One benefit of carbon finance to the cookstove project is in helping it achieve long-term financial sustainability without relying on donor or government support. Indeed, the Kyoto Protocol's carbon market has been extended through 2020, as per the recent decision at the 17th Conference of the Parties to the United Nations Framework Convention on Climate Change in Durban in December 2012 (UNFCCC 2011). Prior to this decision, however, the European Union independently committed to honor the value of carbon credits sourced from Least Developed Countries (LDCs) through 2012–2020 (European Commission 2011).[1] Given the relevance of the technology for least developed populations, the EU's actions effectively stimulated private sector interest in developing methodologies for quantifying and monitoring the carbon reductions associated with cookstoves.

Carbon offsets from cookstove interventions now exist in both regulated and voluntary markets. The regulated markets are dominated by the CDM, which has a lengthy registration and credit issuance process that can pose barriers for project developers. The voluntary market presents an alternative to the CDM. Regulations vary in voluntary

[1] The definition of "LDC," according to the United Nations High Commissioner on Least Development and Land-locked States includes a low-income criterion, and low rankings on the human assets index and Economic Vulnerability Index. The LDCs comprise 12% of the world population but account for only 2% of world GDP. There are currently 48 LDCs: 33 in Africa, 14 in Asia, and one, Haiti, in Latin America (UNOHRLLS 2011). Given that the EU/ETS accounts for 80% of the demand for carbon offsets, the African cookstoves carbon market is expected to expand significantly in 2012. (European Commission 2011.)

markets: some market segments allow less burdensome verification processes than the CDM; others, like the NGO-created Gold Standard certification scheme, claim to be stricter (The Gold Standard 2011). While such claims may be contested, it appears that the Gold Standard offers the only carbon accounting methodology within the voluntary markets that specifically addresses cookstoves.

As this article was being written, 19 cookstove projects were in the CDM pipeline (Fenhann 2011), while 70 cookstove projects in 27 countries in CDM and voluntary markets were currently seeking carbon credits (Cox 2011). Another study that is currently underway estimates that 14 cookstove projects have been issued credits, 2 through the CDM and 12 through Gold Standard. There were another 24 projects that have been registered and 32 at the validation stage (Hill and Bailis 2012). A recent analysis from REN21 (2010) noted that 160 cookstove projects are currently active worldwide. If correct, this implies that roughly 30% of stove projects are engaged in carbon markets through the CDM or the Gold Standard.

Carbon finance differs from standard subsidies in that a formal monetization process transforms the cookstove project into a fungible asset representing climate change benefits. A number of criticisms have been raised about the merit of carbon markets in theoretical terms, questioning whether globally harmonized metrics can be relevant to local patterns of resource use (Robertson 2006) and whether decarbonization via geographically displaced offsetting is an ethical approach to carbon abatement (Bumpus and Cole 2010). There is also concern that the carbon market's dual goals of promoting sustainable development and achieving emission reductions for the lowest cost are incompatible (Schneider 2007). Others doubt the environmental integrity of the reductions themselves, claiming that many projects do not result in reduced emissions, nor are they cost effective (Wara and Victor 2008).

In addition to scholarly debate on the merits of the carbon finance idea per se*,* the impact of carbon finance on cookstove projects, specifically, merits more rigorous scholarship. Kyoto-type accounting does not capture the climate benefits associated with reducing black carbon (Grieshop et al. 2011) and as such may undervalue cookstove enterprises. While carbon finance projects are regularly monitored and third-party verified as part of the carbon offset accreditation process, there is little incentive to comprehensively assess whether or not full cookstove substitution is taking place given the negative impact such findings would have on credit issuance and the time constraints of the validators. Despite repeated efforts from market regulators to improve the quality of project validation, including the Gold Standard requirements that auditors walk into the homes of a random cross-section of users, project developers and buyers alike frequently cite inadequately trained and poorly informed validation as a primary bottleneck in the carbon market (Cosbey et al. 2006; Hyman 2009). Thus, while the carbon finance model simultaneously presents a rare opportunity for regular, annual monitoring of cookstove adoption and usage, this opportunity is hampered by a likely blindness towards the social and cultural preferences that might engender multiple stove-use strategies that are evidenced in academic research (Masera et al. 2000).

Despite considerable focus in the literature on the merits and drawbacks of direct and indirect subsidies, the relatively recent onset of carbon finance as an alternative subsidy model merits further query, particularly as the carbon market's own priorities predetermine and influence cookstove program design. In particular, the interface between user needs and the carbon market's priorities is underexplored.

Household Preferences, Social Adoption Literature

Households base their fuel use and cookstove technology preferences on highly personal, localized factors that are the key component to a public or private model's success. Several studies have attempted to explain adoption by using diffusion of innovation theory (Rogers 2003), technology adoption theories, and social-psychology based approaches, including the theory of planned behavior (Ajzen 1991). Although these theories allow for a better understanding of household energy decision making, the multifaceted behavioral, cognitive, and social processes applied in these decisions are still not well understood (Wilhite et al. 2003).

In practice, studies have demonstrated a range of barriers to transitioning from biomass fuel or to improved cookstove technology. The assessment by Barnes et al. (1994) finds that cookstoves are adopted when there are clear advantages for users, including fuel economy, durability, ease of use, low price, and cleanliness. Households are more likely to adopt stoves when there is a lack of access to fuel wood sources, which divides interventions based in rural and urban areas. Energy decision-making within the household is gendered and provides another dynamic that obfuscates decision-making. Often, financial decisions are within the realm of male household members, while women are in charge of the kitchen (El Tayeb Muneer et al. 2003). A stove purchase therefore requires both household heads to agree, which complicates marketing tactics. Women may not prioritize timesaving over traditional cooking practices, but this pattern often changes as women are earning income outside the home (Foell et al. 2011). Women are also aware that time savings in one area could bring more work in another area, providing less incentive for a timesaving technology transfer (Clancy 2002). Taste is also a significant cultural barrier since the ability to cook traditional foods on improved stoves can be difficult or impossible (Ruiz-Mercado et al. 2011; Taylor et al. 2011). A study in Mexico found that women did not like LPG stoves because they were not appropriate for making tortillas (Troncoso et al. 2007).

Although few studies have directly examined cognition bias within cookstove interventions, some studies seem to find that source agents, that is, the source of the recommendation to buy a new stove, matter (Bailis and Hyman 2011; Kishore and Ramana 2002). Therefore, the cultural and social barriers to introducing a new technology matter as much as the technology itself (Troncoso et al. 2011; Simon 2010). Finally, involving users—especially women who are the main cooks in the home (Ahmad 2001)—in the development and dissemination of cookstoves is also essential (El Tayeb Muneer et al. 2003).

The Energy Ladder and Energy Stacking

The energy ladder is a model of household fuel preference based on empirical evidence that households in urban areas and the wealthier households in rural areas prefer modern fuels, such as LPG and electricity (Masera et al. 2000). A defining feature of the energy ladder model is the assumption that *all good things go together*, that increased income paves a development path (Smith 1987, 452) to decreased wood fuel demand, increased fuel-use efficiency, decreased air particulate levels, and more modern energy consumption (Hosier and Dowd 1987). Critics of the energy ladder point to the complicated and unpredictable relationship between income and fuel choice, in large part because fuel choices are not perfect substitutes for one another (Masera and Navia 1997; Pachauri and Spreng 2004).

Kowsari and Zerriffi (2011) propose that households use a combination of fuel types depending on three drivers, which they label a "Three Conceptual Framework" whereby fuel choice is determined by the energy services, devices, and carrier. The energy stacking model, forwarded by Elias and Victor (2005), adds nuance to the energy ladder by demonstrating how external factors such as fuel subsidies and accessibility, fluctuating budgets, and secondary-fuel-use benefits (for example, using wood fuel smoke to repel mosquitoes in tropical areas) often lead to multiple-fuel use patterns whereby households maintain both traditional and modern cookstoves. According to the energy-stacking model, increased income simply increases fuel use choice, but does not guarantee increased fuel-use efficiency.

While the linearity of the energy ladder has been robustly critiqued, energy-stacking models remain poorly defined and unable to predict household behavior in terms of fuel-efficient cookstove adoption. If households do not necessarily view fuel types as perfect substitutes or adopt "improved" cookstoves to the exclusion of the old models as research suggests, then it is also possible that cookstove users do not define success in the same way as policy designers define it. Further research is needed on the types of cookstoves that local communities prefer and the highly probable phenomenon of "cookstove stacking," whereby households maintain multiple stoves even as their income increases.

Thus, the final section of the review critically examines how "success" in cookstove program interventions is defined. What type of development results from introducing advanced biomass combustion stoves versus programs that leapfrog the poor from biomass to LPG models? How does the decision to import or locally produce stoves create and limit possibilities for local and climate compatible development? These questions often play a secondary role in the technical, health, and economic studies of cookstove programs, which is unfortunate given their salience for the global cookstove industry.

Are Cookstoves a Crutch or a Tool? How Far Can Cookstoves Really Take the Poor?

A key debate that is rarely discussed in the literature revolves around the definition of what an "improved" cookstove entails. Efforts to disseminate advanced biomass combustion stoves (Venkataraman et al. 2010) are critiqued by scholars who claim such programs should focus instead on elevating rural populations to more modern and efficient stoves that run on LPG (Smith 2002). Issues of access and availability limit the potential of the fuel-switch option, but underlying the discussion of feasibility is an ethical and development debate as to whether promoting petroleum products adheres to global development goals (Foell et al. 2011).

An inherent tension in discussions about climate compatible development derives from the simple fact that poor people emit very little greenhouse gas, and thus, interventions aimed at responding to their suppressed energy demand will almost always increase their contribution to global greenhouse emissions. Those that favor the distribution of LPG-based stoves point to the relatively small impact of their use in light of developed country petroleum use (Foell et al. 2011; McDade 2004; Smith 2002). According to an assessment by Smith, if the 2 billion biomass and wood fuel users switched to LPG, the additional impact would not even reach a 2% increase in global greenhouse gas emissions (2002), while the health and greenhouse gas benefit from reductions in black carbon would annul this already negligible environmental externality. The recent report of the International Energy Agency (IEA) comes to a similar conclusion, arguing that transitioning 1.2 billion people to LPG by 2030 would only increase global demand by 5% of the oil demand in the United States today (IEA 2010).

Furthermore, renewable biomass and the utilization of bioenergy—while avoiding the taboo of fossil fuel promotion—are not necessarily less harmful to the natural environment. Bioenergy and its production can positively contribute to climate goals and rural livelihoods; however, if not implemented carefully, they could exacerbate degradation of land, water bodies, and ecosystems; reduce food security; and increase greenhouse gas emissions (Sagar and Kartha 2007). Every fuel type has its deleterious impacts and potential advantages; thus greater attention is required to fully understand who defines "improved" in "improved cookstove" programs.

Beyond the distributional justice arguments for bringing modern fuels to developing country kitchens, and the cultural preferences already outlined in the "energy stacking" discussion, practical debates on fuel costs and access also underpin the literature. Depending on geographical region and local policies, LPG may be prohibitively expensive (Venkataraman et al. 2010) or highly feasible (Bazilian et al. 2011). Frequently, the barriers to LPG are related to the infrastructure surrounding fuel access, such as the delivery of LPG in large canisters (high upfront costs versus the small incremental costs associated with charcoal and wood collection or purchases) and access to the fuel. Barnes et al. (1994) propose that improved biomass stoves should be a "stepping stone" between traditional biomass stoves and modern cooking fuel technologies. This compromise, however, is also subject to the criticism that incremental improvements are just as costly as the leap to modern fuel, and thus beg the question, why delay access for the poor? (McDade 2004).

Imported versus Locally Produced Stoves

The development potential of cookstove programs is significantly interrelated with their reliance on imported or locally produced technologies. The merits of imported versus locally designed or hybrid produced stoves are highly debated (Adkins et al. 2010; Adler 2010; Bailis et al. 2009). Locally manufactured stoves, while less vulnerable to accessibility issues associated with interrupted subsidies or public funding and cross border taxation and controls, are more vulnerable to "design drift" wherein local manufacturers adapt the cookstove design, possibly resulting in less efficient combustion chambers and lower performing stoves (Sinton et al. 2004). Hybrid models are frequently favored in the literature: Barnes et al. 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 (1994).

The Possibility of Imported or Locally Produced Enterprises

Issues of material availability determine whether or not stoves can be produced by artisans or whether they must be manufactured abroad (Adkins et al. 2010). Stoves are usually based on clay, metal, or concrete and masonry and can employ a suite of fuels from biomass and charcoal to LPG (Sagar and Kartha 2007).

Dissemination practices also determine whether or not stoves can be imported or locally produced. The prevalence of ox-cart transportation for household goods in LDCs such as Cambodia, favors locally produced clay stoves that are easily stackable and can withstand long journeys on rough roads unlike their higher efficiency counterparts. Other cookstove interventions are only available through in-situ construction, such as the Dutch-supported biodigester programs throughout Asia, where the biodigester itself must be built in-situ, but specialized parts such as the gas measurement valve are sourced from abroad (van Mansvelt, 2010). Other hybrid approaches to technology transfer include importing the stove, but relying on only local engineers to maintain and monitor their performance (van Mansvelt, 2010).

Imported stoves are more expensive and may also be associated with higher performance levels in terms of combustion efficiency and reductions in particulate matter in the home (MacCarty et al. 2010). According to a survey of stove users in Uganda and Tanzania, the imported stoves were preferred because of their improved performance and because they brought greater social status (Adkins et al. 2010). The merits of locally produced stoves include the stove production networks (often trained by NGOs and aid organizations) whereby local artisans become fuel-efficient cookstove builders, able to supply and repair the stoves on demand (Kees and Feldmann 2011). Despite the assumption that local networks strengthen a program's durability, it is noteworthy that the Indian national cookstove program failed, in part, because its local production model did not produce stoves of high enough quality (Adler 2010).

The implications of locally producing, importing, or hybrid-producing cookstoves for local development are significant for the formation and long-term viability of projects. To illustrate, carbon finance projects that use revenues from the credits to subsidize imported stoves are dependent on the carbon market for the viability of the program, whereas projects that utilize carbon finance for local capacity building and the monitoring of artisan stove performance merely rely on the carbon market to grease the wheels of a new enterprise. There is no denying, however, that stove performance is paramount to a cookstove program's ability to forward development goals. Further research and empirical clarity is needed to assess how imported stoves can remain reliably accessible for the poor, as well as the conditions within which locally produced stove enterprises can perform at par and adjust to changing market conditions.

Conclusions

The Global Alliance for Clean Cookstoves is tasked with disseminating 100 million stoves to developing countries by 2020 in an attempt to increase energy access for the poor, and with calling on public-private partnerships for the production and distribution of the stoves. Given the potential benefits surveyed in the literature, the goal is worthy of international focus. However, in order to successfully design, distribute, and sustain fuel-efficient cookstove adoption in developing countries, significant advances are required in research fields. Progress could include a closer look at areas ranging from the social dynamics of household preferences to more nuanced findings on technology adoption, as well as a clearer understanding of how and under what conditions subsidies and innovative finance tools, such as the carbon market, can distribute benefits to the poor. Our synthetic literature review from 1987 to the present identifies key findings in the cookstove field to date. In addition, our landscape assessment of the field clarifies its frontier, pointing to areas for future scholarship and experimentation. Each bullet, below, synthesizes a key finding as well as a knowledge gap.

Academic research confirms that the public goods associated with improved cookstoves are significant. As such, there is an empirically supported justification for public sector involvement in promoting improved cookstoves to poor populations. However, knowledge gaps regarding the efficacy of improved cookstoves versus encouraging behavioral changes (such as increased ventilation; fuel switch; soaking legumes; and using pressure cookers) are understudied and further work in this area could lead to better use of public funds.

Carbon finance, while understudied in terms of its impact on the very poor in the cookstove sector, appears to be a powerful financing mechanism that effectively utilizes the strengths of the private sector: namely, in its ability to attract capital at scale; utilize effective management techniques; create self-sustaining markets; and support innovation. However, given the private sector's historic weakness in reaching indigent populations that command limited demand for goods, policy makers and academics should seek further insight into how combined public-private dissemination techniques can perform in Least Developed Countries.

Multiple benefits associated with cookstove interventions are both an opportunity and, notably, a pitfall for policy designers. Those who attempt to achieve everything within a single program (health benefits; gender empowerment; self-financing mechanisms; environmental impacts) appear to be less successful than those who concentrate their efforts on a few, targeted goals within a program, such as the NISP does in China. However, the many benefits of cookstoves mask confusion within the literature on the definition of an "improved" stove. How much donor and commercial effort is justified for advanced biomass combustion stoves versus fuel-switch programs that leapfrog developing country households to more advanced cooking models? Are cookstoves on the international agenda as an aid mechanism, whereby installing a stove in every home will suffice, or a development mechanism, whereby developing country households are empowered to source, select, and profit from a more advanced stove industry? Further examination is required from both academics and practitioners as to the purpose and reach of an improved cookstove program.

A debate regarding the advantages of utilizing imported stove technologies versus relying on local stove assembly remains unresolved, and further highlights tensions within the stove community as to the ultimate purpose of the stove intervention. Further exploration of these themes is a priority for the stove community. In addition, initial insights into the social factors leading to stove adoption point to the importance of source recommendations (that is, locals promoting stoves to locals), gender dynamics, and a nuanced interpretation of "timesaving" as a marketing incentive.

While questions about stove adoption practices certainly remain, it is noteworthy that the research frontier is no longer defined by a new series of questions, but instead by a new population of respondents. Barnes et al. famously asked the development community, nearly a generation ago, *"Why don't they buy the improved stoves?"* stimulating a field of scholarship on household preferences, the power of social networks and local marketing channels, the energy ladder and energy stacking, cookstove utilization (and cookstove stacking), and the ambivalence of women in accepting "timesaving" improvements. Today, questions on low adoption rates of the early cookstove days are no longer the sole purview of the development expert but instead are also directed at the cook herself: "What is an improved cookstove for you?" There is a need for more finely grained data. The GACC and its attendant wave of research, if done humbly, may indeed forward development through the kitchen.

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