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GLOBAL ALLIANCE FOR CLEAN COOKSTOVES

TECHNICAL REPORT 007/15

THE STATE OF THE GLOBAL CLEAN AND IMPROVED COOKING SECTOR

ENERGY SECTOR MANAGEMENT ASSISTANCE PROGRAM

The Energy Sector Management Assistance Program (ESMAP) is a global knowledge and technical assistance program administered by the World Bank. It provides analytical and advisory services to low- and middle-income countries to increase their know-how and institutional capacity to achieve environmentally sustainable energy solutions for poverty reduction and economic growth. ESMAP is funded by Australia, Austria, Denmark, Finland, France, Germany, Iceland, Lithuania, the Netherlands, Norway, Sweden, and the United Kingdom, as well as the World Bank.

GLOBAL ALLIANCE FOR CLEAN COOKSTOVES

The Global Alliance for Clean Cookstoves (Alliance) is a public-private partnership hosted by the UN Foundation to save lives, improve livelihoods, empower women, and protect the environment by creating a thriving global market for clean and efficient household cooking solutions. The Alliance's 100 by '20 goal calls for 100 million households to adopt clean and efficient cookstoves and fuels by 2020. We are working with a strong network of public, private, and non-profit partners to help overcome the market barriers that currently impede the production, deployment, and use of clean cookstoves and fuels in developing countries.

Written by | Venkata Ramana Putti, Michael Tsan, Sumi Mehta, Srilata Kammila
Energy Sector Management Assistance Program | Global Alliance for Clean Cookstoves | The World Bank


SAPLING
STOVE

TABLE OF CONTENTS

List of Boxes, Figures, and Tables

FOREWORD

This is a moment of great opportunity for the clean cooking sector. While experts have been working for decades on improving cookstoves and scaling up access to clean cooking fuels and technologies, only recently has this issue become a major priority on the global development agenda. The world has woken up to the serious health, environmental, and economic impacts of continued dependence on biomass for cooking. At the same time, rapid progress in technology and new financial mechanisms to support this sector have made real change possible.

Access to clean cooking is also central to the Sustainable Energy for All (SE4ALL) initiative, which is backed by a large and diverse global coalition of international organizations, the private sector, and civil society, and co-chaired by UN Secretary General Ban Ki-moon and World Bank Group President Jim Yong Kim. The three overarching SE4ALL goals to be achieved by 2030—universal access to modern energy services, doubling the share of renewable energy in the global energy mix, and doubling the rate of improvement of energy efficiency—have now been broadly accepted, including by 82 developing countries that have opted into SE4ALL. The result has been a large number of initiatives to help achieve universal access to clean cookstoves and cooking fuels by 2030 as part of the universal energy access goal.

At this defining moment, the Energy Sector Management Assistance Program (ESMAP) of the World Bank is pleased to present this report on The State of the Global Clean and Improved Cooking Sector, jointly developed with the Global Alliance for Clean Cookstoves. This report follows on a major re-engagement by the World Bank in this sector, through interventions such as Africa Clean Cooking Energy Solutions (ACCES), the East Asia and Pacific Clean Stove initiative (EAP CSI), and the SE4ALL Technical Assistance Program, which is focused on helping countries meet the universal energy access goal. Our strategic partnership with Global Alliance has informed our work in these endeavors, which has now been further strengthened with the new joint initiative to spur the adoption of clean and efficient cooking and heating solutions in developing countries.

We believe this report will be a key reference for sector practitioners. Beyond the comprehensive assessment of the current state of the cookstoves sector, the report provides the first global baseline for clean and improved cooking, including analyses of fuel and stove penetration, end-user segmentation, and industry structure. It also proposes a common terminology to define various types and categories of cooking devices. It offers lessons and recommendations that we hope will guide key stakeholders—governments, private sector, and the donor community—in developing increasingly effective interventions to help billions of people who still rely on biomass for their cooking needs.

Rohit Khanna
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FOREWORD

2015 is a critically important year for international development. Events such as the Post-2015 Summit, the Beijing+20 conference, and the 21st session of the Conference of Parties (COP) give world leaders an unprecedented opportunity to make momentous progress on health, women's empowerment, the environment, and climate protection.

This year, the focus must be on implementation of proven solutions that can deliver benefits across multiple sectors and are ready to scale up.

Consider, for a moment, the simple act of cooking. Imagine if we could change the way nearly five hundred million families cook their food each day. It could slow climate change, drive gender equality, and reduce poverty. The health benefits would be enormous.

Four years ago, when the Global Alliance for Clean Cookstoves (Alliance) was first launched, the issue of household air pollution and the enormous health toll that the smoke from traditional cookstoves and fuels took on the lives of women and their families in the developing world, received far less attention and funding than it deserved. Hundreds of millions of women were literally risking their lives each day to cook food for their families over inefficient cookstoves and polluting open fires, and spending hours gathering fuel often at great personal risk. The environmental toll in terms of land degradation, deforestation, and air pollution was poorly documented and largely ignored by the donor community.

Just a few years later, and with support from over 1,000 diverse global partners, including the World Bank, the Alliance has made tremendous progress to develop new markets for clean cookstoves and fuels. With growing global attention and a shift from an aid-driven approach to a market-based one that is built on the premise of sustainability, there are now at least 20 million additional households using cleaner and/or more efficient cookstoves and fuels around the world.

The Alliance is supporting market development in a number of ways: by strengthening capacity and innovation within existing enterprises to ensure that high-quality cookstoves and fuels could be brought to scale; by bringing in new manufacturers and distributors to further enhance the sector's reach; by creating awareness of and mobilizing capital for investment ready enterprises; by integrating women throughout the cookstove and fuel value chains through our Women's Empowerment Fund; and by advocating for the advancement of policies that will enable and accelerate the clean cookstoves and fuels market. The Alliance has also led the development of the standards process through engagement with the International Organization for Standardization. We are now closer to achieving a set of global standards that will help us deliver high-quality, effective, and independently tested products.

While the World Bank and Alliance have worked closely over the past few years, the Cookstove Future Summit marked the announcement of an even closer collaboration between our organizations to scale up adoption of cleaner and more efficient cookstoves and fuels. This new partnership offers a chance not only to deepen the close overall working relationship we have formed to tackle the

issue of household air pollution, but also the opportunity to mobilize the financial, technical, and policy resources needed to transform the clean cooking sector in more than a dozen focus countries. Working together to advance many of the learnings from the past four years will allow us to leverage our respective strengths in market development, standards and testing, investment, policy design, and capacity building, and support the sector in an unprecedented way that will ultimately lead to wider impact in health, gender, climate, and livelihoods.

We are pleased to work with the Bank to release this comprehensive mapping report on the clean cooking sector and build upon the Alliance's annual Results Report. The sector is a dynamic one and this report should be seen less as a representation of the sector at a given point in time, but rather one that identifies and discusses the larger trends that we are seeing and that we need to be investing in to achieve the Alliance's 100 by 2020 goal and the larger Sustainable Energy for All goal of universal adoption of clean cookstoves and fuels by the year 2030.

Radha Muthiah

Chief Executive Officer

Global Alliance for Clean Cookstoves

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This report was commissioned and coordinated by the Energy Sector Management Assistance Program (ESMAP) of the World Bank. The project team was led by Venkata Ramana Putti (ESMAP) and comprised Srilata Kammila (ESMAP) and Sumi Mehta (Global Alliance for Clean Cookstoves).

The report relied on input from a wide cross-section of World Bank staff, numerous industry experts, manufacturers, distributors, policymakers, and non-governmental organizations, including interviews with over 100 global players in the clean and improved cooking energy sector. Critical advisory and technical input came from World Bank colleagues Koffi Ekouevi, Klas Sander, Masami Kojima, Laurent Durix, Yabei Zhang, Sudeshna Ghosh Banerjee, Xiaoping Wang, Christophe de Gouvello, Sameer Akbar, Katie Kennedy Freeman, Wendy Hughes, Alain Ouedraogo, and Dana Rysankova; Lasse Ringius and Luiz Maurer from the International Finance Corporation; and Leslie Cordes, Ranyee Chiang, Jennifer Tweddell, Donee Alexander, and Julie Ipe from the Global Alliance for Clean Cookstoves.

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Dalberg Global Development Advisors (www.dalberg.com) acted as the consultants for the report and co-invested into the report's development as part of their commitment to the Global Alliance for Clean Cookstoves. The Dalberg team was led by Michael Tsan, partner and lead author, and comprised Gaurav Gupta, Jason Wendle, Paul Collett, Fauzia Jamal, Pallavi Jayannavar, Nicholas Whalley, Kira Intrator, Ibrahima Wade, and Kathleen Wade. The Dalberg team was also supported by a team of external consultants, including Yaquta Kanchwala, Ethan Kay, Neha Juneja, and Ankit Mathur.

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ABBREVIATIONS

ACCES Africa Clean Cooking Energy Solutions
ACS advanced cookstoves
ALRI acute lower respiratory infection
BC black carbon
BoP base of the pyramid
CACCI Central America Clean Cooking Initiative
CAGR compounded annual growth rate
CDM clean development mechanism
CH_4 methane
CO carbon monoxide
CO_2-eq carbon dioxide equivalent
COPD chronic obstructive pulmonary disease
DALY disability-adjusted life
DFID Department for International Development (UK)
DME dimethyl ether
EAP CSI East Asia & Pacific Clean Stove Initiative
ESMAP Energy Sector Management Assistance Program
FAO Food and Agriculture Organisation
FD fan or "force" draft stoves
GDP gross domestic product
GEA Global Energy Assessment
GERES Group for the Environment, Renewable Energy and Solidarity
GHG greenhouse gas
Gg gigagram (1 billion grams)
GIZ Gesellschaft für Internationale Zusammenarbeit
HAP household air pollution
IEA International Energy Agency
ICS improved [biomass] cookstove
IFC International Finance Corporation
ISO International Organization for Standardization
IPCC Intergovernmental Panel on Climate Change
IWA International Workshop Agreement
LED light-emitting diode
LPG liquefied petroleum gas
M&E monitoring and evaluation
MDG Millennium Development Goals
MFI micro finance institution
MJ megajoule
MSME micro, small, and medium enterprise
MT million tons
NGO non-governmental organization
OC organic carbon
PCIA Partnership for Clean Indoor Air
PAH polycyclic aromatic hydrocarbons
PM2.5 particulate matter with diameter of $<2.5\mu m$
ProBEC Program for Basic Energy and Conservation
PoA Programme of Activity (under the Clean Development Mechanism)
RBF results-based financing
RCT randomized controlled trial
R&D research and development
SACCO savings and credit cooperative
SE4ALL Sustainable Energy for All
SME small and medium enterprise
TChar combination TLUD / charcoal cookstove
TEG Thermoelectric generator
TLUD top-loading updraft cookstove
USAID United States Agency for International Development
UNEP United Nations Environment Programme
$\mu g/m^3$ microgram per cubic meter
WB World Bank
WHO World Health Organization

All dollar amounts are United States dollars (USD or US$) unless otherwise indicated.

Regions: EA/EAP – East Asia and Pacific; LCR – Latin America and Caribbean; SA – South Asia; SEA – Southeast Asia; SSA - Sub-Saharan Africa.

TERMINOLOGY

The concept of **clean cooking solutions** used in this report is relatively new terminology, and the term **improved cookstoves** is used by different organizations in different ways. This section defines how these terms are used in this report, as well as progress in establishing internationally accepted terminology.

The 2012 adoption of standards and performance tiers for stove emissions (total and indoor), fuel efficiency, and safety via the International Workshop Agreement (IWA 11:2012) through partnership with the International Organization for Standardization (ISO) has established a common quantitative vocabulary. The World Bank's energy team, in coordination with its partners the Global Alliance for Clean Cookstoves and Sustainable Energy for All, is also refining its methodology for measuring access to clean cooking; this will build on the IWA framework and include additional dimensions of cooking solution quality.

In June 2013, ISO established of ISO Technical Committee 285, to continue the work begun with the IWA to develop and approve clean cooking standards in the coming years. Kenya's Bureau of Standards (KEBS) and the United States' American National Standards Institute (ANSI) serve as co-secretariats of the Committee, which is comprised of other participating national committees, including over 20 participant countries, 14 observer nations, and approved external liaisons. The ISO Technical Committee held its first meeting in February 2014 in Nairobi, Kenya, in order to review gaps in the current standards and to align on a roadmap for future action. The Committee's subsequent meeting, in October 2014, focused on harmonizing and updating existing test protocols for field and lab testing, creating guidelines for social impact studies, and establishing a conceptual framework for cookstove assessment methods.

The following terms are defined for the purposes of this report with reference, where appropriate, to the ISO IWA tiers and standards. For more information about the ISO IWA tier classification system, please refer to the Typology section in Chapter 4.

- **Improved cooking solutions.** *Cooking solutions that improve, however minimally, the adverse health, environmental, or economic outcomes from cooking with traditional solid fuel technologies*. This definition encompasses modern fuel cookstoves, renewable fuel cooking solutions, and the entire range of improved and advanced biomass cookstoves. Clean and improved cooking solutions reduce emissions, improving health and the environment.
- **Clean cooking solutions.** *Cooking solutions with low particulate and carbon monoxide emissions levels* (IWA ISO Tier 3–4 for the indoor emissions indicator, within the Global Alliance's Monitoring and Evaluation framework). The IWA tiers for indoor emissions are consistent with the World Health Organization indoor air quality guidelines. Cooking solutions with low total emissions (ISO Tier 3–4 for the total emissions indicator) are considered clean for the environment within the Global Alliance's monitoring and evaluation framework. These stoves can include advanced biomass

cookstoves, renewable fuel solutions, and modern fuel stoves—with the partial exception of kerosene, since emerging evidence suggests that many kerosene stoves may actually create significant negative health impacts. The monitoring and evaluation framework will be updated when necessary to reflect emerging health and environmental research.

- **Modern fuel solutions.** *Petro-chemical fuel (LPG, natural gas, kerosene), electric stoves, and electromagnetic induction cookstoves*.
- **Renewable fuel cooking solutions.** *Biofuel cookstoves powered by ethanol and other plantbased liquids, oils or gels; biogas cookstoves; solar cookers; and retained-heat cooking devices*. Many of these solutions equal or even exceed the performance of modern fuel cookstoves in terms of environmental impact because of their very low emissions and reliance on renewable fuel sources. For climate and environmental impacts, the lifecycle effects of the production and distribution of renewable fuels should also be considered. Some of the renewable cooking solutions are supplementary in nature—they can augment existing household cooking solutions as part of an integrated cooking system but are unlikely to serve as primary stoves or fuels.
- **Improved [biomass] cookstoves (ICS).** *Solid-fuel stoves that improve on traditional baseline biomass technologies in terms of fuel savings via improved fuel efficiency.* Some improved cookstoves also lower particulate emissions through improved efficiency of combustion, but the critical distinction from "clean" cooking solutions is that "improved" stoves may not reach sufficiently low emissions levels to generate meaningful health benefits. Cookstoves covered by this definition include basic chimney ICS, basic portable ICS (e.g., African ceramic jiko style stoves), and intermediate ICS (e.g., rocket cookstoves, high-end charcoal cookstoves). Traditional solid fuel cooking solutions—such as three-stone fires, unvented mud/clay "U" shaped stoves, basic charcoal cookstoves, and poorly vented coal cookstoves—are excluded from this definition.
- **Basic chimney ICS.** *Solid-fuel cookstoves whose chimneys feature minimal to moderate improvements in thermal efficiency*, which this report associates with ISO Tier 1 performance for efficiency. This category includes improved chimney chulhas in South Asia, vented biomass and coal cookstoves in China, lower efficiency planchas in Central America, and a range of chimney mud cookstoves in Africa. Many of these cookstoves historically have been distributed as part of national or non-governmental organization-led programs and are sometimes labeled as "legacy" cookstoves—likely a misnomer since variants of such cookstoves are still actively promoted in many parts of the world.

  Some basic chimney ICS may be Tier 0 for thermal efficiency (<15%) and Tier 0 for total emissions. We have included such cookstoves in our analysis because chimneys do improve indoor emissions (Tier 1 or higher) and chimney cookstoves constitute the vast majority of "improved" solutions in the field. Also, it is often the only cookstove segment for which end-user uptake data are available from cross-national household surveys. Where possible, we try to differentiate between inefficient chimney cookstoves (i.e., <15% thermal efficiency) and chimney cookstoves with low to moderate efficiency (>15–25%). The current IWA v guidelines do not

yet include field performance, so cookstoves that have been demonstrated to have improved performance in the lab may have different results in the field, especially over time.

- **Basic portable ICS.** *Portable biomass cookstoves that are unvented and feature moderate improvements in thermal efficiency.* This category includes minimally improved ceramic and clay cookstoves: such as the Anagi cookstove in Sri Lanka; simple efficient wood cookstoves distributed by the United Nations programs in refugee camps throughout Africa; and metal insulator-lined "Thai bucket" cookstove technologies such as the ceramic Jiko and Jambar stoves in East and West Africa, the New Lao Stove in the Mekong region, and the Anglo Supra in Indonesia.
- **Intermediate ICS**. *A wide range of solid fuel cookstoves that this report broadly aligns to the ISO ICS Tier 2 for efficiency, with significant improvements in fuel efficiency (>25% thermal efficiency rating), but typically more limited health and environment outcomes in comparison to clean cooking solutions such as gasifier and modern fuel cookstoves.* Intermediate cookstoves utilize rocket stove principles (i.e., an L-shaped combustion chamber design) for wood/crop or waste/dung fuel cooking, or have other design features that promote thermal efficiency as in the case of intermediate coal and charcoal ICS. Stoves in this category can be portable (e.g., the Envirofit and EcoZoom charcoal and wood cookstoves), semi-portable (e.g., Ethiopia *MIRT* cookstoves, China efficient coal chimney cookstoves), or built in (e.g., Uganda Rocket Lorena, Mexico *Patsari*, Guatemala *Onil* cookstove) and may be either unvented or combined with chimneys, depending on the design.
- **Advanced [biomass] cookstoves (ACS).** *Fan draft or natural draft biomass gasification cookstoves that achieve significant particulate emission reductions and approach, but not yet to match, the performance of modern fuel cookstoves* (IWA ISO Tier 3 for indoor emisions, Tier 3-4 for efficiency). Stoves in this category include natural draft models (e.g., Awamu in Uganda, Belonio rice husk stoves in Philippines and Indonesia), fan draft rocket style stoves like the Biolite, and top loading fan gasifiers like the Oorja in India and the Phillips / ACE-1 fan gasifiers manufactured in Lesotho. At peak performance and under lab conditions several model of gasifier stoves can now exceed ISO Tier 3 emissions performance, particularly when combined with chimneys, showing the future potential of an ISO Tier 4 low emissions biomass stove.

EXECUTIVE SUMMARY

With few exceptions, access to clean and improved cooking solutions is limited in much of the developing world, leading to immense human costs. The share of households that cook primarily with wood, charcoal, coal, crop waste, and dung accounts for over half of the developing world's population and, today, is increasing or stagnant in most regions. Dependence on solid fuels, potentially harmful modern fuels such as kerosene, and inefficient and polluting cookstoves is one of the world's major public health challenges, causing more premature deaths than HIV/AIDS, malaria, and tuberculosis combined. The use of inefficient fuels and stoves also imposes significant economic costs on societies that can least afford them and contributes to adverse environmental and climate change effects.

While the challenges are daunting, there are now good reasons to believe that the next decade will be a transformative period for the global clean and improved cooking sector. Broader access to clean and improved cooking solutions is within closer reach thanks to promising new demand-side trends, including the emergence of aspirational middle classes with disposable incomes, rapid urbanization, and rising fuel prices that are pushing consumers worldwide to seek more efficient fuels and stoves. On the supply side, key trends include technological innovation—most notably, the development of clean gasifier biomass stoves—increasing investments into modern fuels such as liquefied petroleum gas (LPG), and the growth of renewable alternatives such as biogas, ethanol, and biomass pellet fuels. Market-orientated solutions account for much of the recent dynamism in the cooking landscape, as manifested by increased industrial-scale production of improved stoves, the emergence of innovative distribution and financing models, and the entry of many new entrepreneurs and investors into the sector. Increasing policy support from national programs in regions like Southeast and East Asia (e.g., Indonesia and China), South Asia (e.g., Nepal, Bangladesh, and India), multiple countries in Africa (e.g., Ghana, Rwanda, Uganda, Ethiopia, Nigeria), and Latin America (e.g., Peru, Mexico, Guatemala, Honduras). These country-level activities, combined with the momentum generated by the UN's Sustainable Energy for All, the work of the Global Alliance for Clean Cookstoves, industry-led initiatives like the Global LPG Partnership, and the range of regional efforts coordinated by the World Bank and the Energy Sector Management Assistance Program (ESMAP) like the Africa Clean Cooking Energy Solutions (ACCES), the East Asia and Pacific Clean Stove Initiative (EAP CSI), and the Central America Clean Cooking Initiative (CACCI) are beginning to transform the enabling environment for clean cooking solutions.

These trends are a window of opportunity rather than the guarantee of a tipping point. Many obstacles to the ultimate goal of universal access to clean cooking energy remain, including the lack of affordable clean cooking solutions, low consumer awareness of and willingness to pay for the health benefits of clean cooking, low stove quality and poorly defined performance standards, limited technical and financial producer and distributor capacity, and a variety of policy obstacles. This report suggests that, although a much faster transition is possible, it will require significantly higher investment, carefully coordinated interventions, and better data to measure sector progress.

This report seeks to contribute to the coming transformation. Its primary objectives are to update the impact case for clean cooking solutions, identify key cooking sector demand and supply trends, and provide the first-ever global baseline for clean and improved cooking solutions—including analyses of fuel and stove penetration, end-user segmentation, industry structure, and the enabling environment. We hope in particular that the findings and lessons captured in this report will encourage private sector actors and public sector policymakers to increase their commitment to clean cooking initiatives across the globe.

A. KEY FINDINGS

The following section summarizes the key findings discussed fully in Chapters 1 through 7.

The Case for Clean and Improved Cooking

The global solid fuel population is large and access to clean and improved cooking solutions is limited. Approximately 40% of developing world households use clean fuels and cookstoves as their primary cooking solution, including modern fuels such as LPG and electricity; renewable solutions such as biogas, ethanol, and solar; and advanced biomass gasifiers stove technologies.[1] Of the more than 2.85 billion people who rely primarily on solid fuels, less than one-third use improved cookstoves (ICSs) and even these households predominantly rely on basic ICS that have limited health and environmental benefits.[2]

Reliance on solid fuels and inefficient and polluting cookstoves costs the world dearly. The mid-range economic value of the health, environmental, and economic effects of solid fuel dependence is a staggering $ 123 billion annually ($ 22–224 billion), with multiple underlying effects:[3]

- **Economic:** significant spending of $ 38–40 billion annually on solid fuels for cooking and heating, of which a significant share is avoidable; 140 million potentially productive person-years annually wasted on biomass fuel collection and avoidable cooking time
- **Health:** at least 4.3 million premature deaths annually and 110 million disability-adjusted life years (DALYs)[4] resulting from household air pollution (HAP), including lower respiratory infections, chronic obstructive pulmonary disease, lung cancers, heart disease, and cataracts; many additional health harms not quantified include asthma, tuberculosis, adverse pregnancy outcomes, depression, bacterial meningitis, a variety of moderate-to-severe physical injuries associated with firewood collection, burns, widespread minor ailments from smoke inhalation such as eye irritation and headaches, and the emerging concerns about the harms of kerosene cooking
- **Environment:** substantial emissions from solid fuel use and charcoal production of 0.5–1.2 billion MT in carbon dioxide (CO_2) equivalent of Kyoto Protocol greenhouse gases (up to 3% of annual global CO_2 emissions) and 25% of global black carbon emissions; consumption of ~1.36 billion tons of woodfuel across the developing world, with contribution to forest degradation and deforestation most likely from charcoal production in Africa and Asia

- **Gender equity and other social impacts:** disproportionate risks of negative HAP-linked health outcomes and physical injury for women and girls, given their proximity to cooking fires and primary responsibility for firewood collection in many cultures; decreased educational opportunities for children involved in fuel collection; impaired nutrition because of the diversion of resources to fuel purchases; and home environments damaged by smoke and soot

A range of technologies can mitigate these harmful effects, but only the cleanest cooking solutions hold the potential for truly transformational impacts on health and environmental outcomes. The potential benefits of improved and clean cooking solutions vary greatly by impact objective, cooking technology, quality of the specific cookstove, and consumer willingness to adopt the solution vis-à-vis baseline cooking technologies. There is no universally applicable technological answer to addressing the harms of solid fuel cooking. A range of ICS technologies, including low-cost basic ICS, can generate attractive fuel savings and other important economic co-benefits such as time savings for households and job creation opportunities for basic ICS manufacturing. Health benefits are the most difficult impact to achieve since they require the thorough replacement of traditional stoves with clean modern fuels, such as LPG and electricity, or renewable solutions, such as biogas. For biomass cooking, pending further evidence from the field, significant health benefits are possible only with the highest quality fan gasifier stoves; more moderate health impacts may be realized with natural draft gasifiers and vented intermediate ICS (e.g., *Onil* and *Patsari* stoves in Central America; Rocket Lorena and brick rocket stoves in Africa).

The Demand for Clean and Improved Cooking Energy

Dependence on solid fuels will persist for years, serving as a long-term demand driver for improved solid fuel stoves and cleaner fuels. Global patterns in population growth, urbanization, and historical fuel use suggest that the number of people relying on solid fuels for cooking and heating will persist at a level of over 3 billion by 2020.[5] Growing firewood consumption and rising charcoal use in Sub-Saharan Africa will counterbalance the declines in solid fuel use in Asia and Latin America. Alongside primary users of solid fuels, hundreds of millions across the developing world will continue to use wood, charcoal, and coal as a secondary cooking energy source.

Rising fossil fuel and biomass prices are also spurring long-term demand for fuel-efficient cooking solutions. Nominal global LPG prices rose at a compounded annual growth rate (CAGR) of 11% over the past decade,[6] far above the rate of inflation, impeding LPG adoption. Retail price growth ranged from 5% in markets such as India, where LPG remains heavily subsidized to 12–14% in Southeast Asia and certain African markets. The elimination of lighting and cooking kerosene subsidies in markets like Indonesia has pushed up retail kerosene prices, driving large-scale fuel-switching down to biomass or up to modern fuel alternatives for households who can afford them. Coal prices have been on a steady upward trajectory because of industrial coal demand in China. Charcoal costs tripled over the past decade in Africa and Haiti (11% CAGR) and are seeing fast growth in charcoal-dependent Asian markets like Cambodia and Myanmar. While poorly documented, cooking firewood

scarcity appears to be increasing in parts of Africa and Asia, though wood prices, thus far, have seen only limited increases in most markets relative to the rate of overall inflation. These trends all point to the increasing appeal of fuel-saving stoves globally—and, in some regions, the increased potential for consumer adoption of cleaner modern and renewable fuels, given the relatively faster rise in costs of alternatives like charcoal, coal, and kerosene.

The size of existing cooking fuel markets suggests that the potential demand for clean and improved cooking solutions is large. In 2010 alone, consumers in the developing world spent $ 100 billion across all cooking fuels, with charcoal, coal, and wood, accounting for approximately one-third of this total.[7] This figure dwarfs annual developing world consumer spending on cooking appliances across all clean or improved technologies, which this report estimates at less than $ 8 billion,[8] inclusive of government appliance subsidies. This discrepancy suggests that the fuel supply market and integrated fuel-stove distribution business models are a major opportunity for the private sector.

End-user demand and product preferences vary significantly across customer segments. As is expected of a global market of this scale, the potential consumer for improved and clean cooking solutions is diverse, with variable ability and willingness to pay and a range of preferences across fuel types, cookstove sizes, and features based on household characteristics such as income, family size, urban or rural status, cultural practices, stove end-use (e.g., space heating or water heating), and fuel procurement approaches.[9] Approximately one-half of the households in the developing world primarily rely on modern fuels or high-cost charcoal and coal to fulfill their cooking and heating needs. These largely urban and middle-income consumers have the highest propensity and ability to pay for improved biomass and clean cookstoves. Another 13% of households rely partly or exclusively on purchased firewood and should theoretically find the fuel-saving value proposition of ICS attractive. The remaining (~30%) of the global cooking market consists of poor to middle-income households who collect their fuel, and often do not place a high value on the time lost for fuel collection, and, therefore, are less motivated by the fuel-saving potential of improved stoves.

Although most consumer segments can be reached by market-based cooking solutions, affordability is a major barrier. Household surveys and the historical experience of improved cookstove programs suggest that the share of global cookstove customers considered "marketable"—that is, consumers with sufficient income to afford paying $ 5 toward the cost of an improved cookstove—likely includes more than 85% of the global population.[10] Even in rural areas, the marketable segment for basic improved cooking solutions remains significant, with evidence from cookstove pilot and program surveys around the world indicating that only around 10–30% of the population report being unwilling or unable to pay for even a basic ICS. Evidence from the field in Africa and Asia, for instance, suggests that even among rural wood collectors, over two-thirds of whom have some disposable income, there is a willingness to purchase improved cooking appliances once they become aware of improved cookstove benefits. While consumer ability to afford low-cost basic ICS purchases ($ 3–10) is generally high, intermediate ICS technologies costing $ 15–30 will likely be affordable to around 60% of developing country cooking consumers in Asia and Africa. Latin America and, in particular, Central America, is a special case with intermediate rocket plancha-style ICS prices

in the $ 60–250 range and corresponding affordability challenges despite higher rural incomes. Stoves at the higher price range, such as the emerging biomass fan gasifier technology ($ 50–120), modern fuel stoves such as LPG ($ 30–70), and renewable solutions like biogas ($ 500–1,500 for household biogas plant and stove) will be affordable to far fewer consumers, likely under 20–30% of households in most countries in South Asia, Southeast Asia, and Africa, with fuel costs rather than stove costs being the biggest constraint in the case of modern fuels like LPG and electricity.

Significantly extending access to clean cooking solutions is only feasible with price reductions, increased end-user financing and, in the case of the very poorest, non-market distribution approaches. Across all consumer segments, expanding access to clean cooking requires continued innovation in design and manufacturing to lower stove costs, consumer financing, and new payment models (e.g., layaway plans, "pay-as-you-go" pricing, fuel/stove rental models, electronic payment metering) that can minimize or even eliminate upfront product costs. Accelerated uptake of higher cost clean cooking solutions also requires the use of carbon credits to lower prices for consumers and, where feasible, targeted incentives (e.g., results-based grant financing credits) for those cooking solutions that have proven benefits in livelihood and health terms that go beyond their positive environmental impacts. While direct consumer subsidies can be unsustainable and, in some cases, have led to counter-productive market distortion, targeted subsidies are needed for extending clean cooking solution access in humanitarian aid contexts or to the poorest segments of the population, where downstream financing and business model innovation alone are unlikely to meaningfully expand market-based access to higher cost clean cooking technologies for decades to come.

The Supply Landscape

Few countries have managed to introduce clean and improved cooking solutions on a broad scale to address the widespread pernicious impacts of solid fuel use. Clean cooking penetration in 2010, covering access to all modern fuels (aside from kerosene), renewable fuels, and advanced biomass solutions, is particularly low in Sub-Saharan Africa (10% of households) and South Asia (27%), with better access in Southeast Asia (41%), East Asia (51%), and Latin America (80%).[11] Improved biomass cookstove penetration is also limited. Including households that utilize minimally improved "legacy" chimney stoves, up to 245 million developing world households in 2012 (37% of solid fuel users) used an improved cookstove of some sort, with significant ICS penetration of solid fuel users in East Asia (85%), moderate levels in Latin America (39%) and Southeast Asia (21%), and low penetration in Sub-Saharan Africa (14%) and South Asia (11%).[12] Improved cookstove distribution has seen the greatest success in China, where an estimated 85% of biomass users and over 65% of coal-burning households have access to cooking and heating stoves with at least some improved efficiency and emission features. Even excluding legacy stoves, the vast majority of these ICS are basic solutions which, despite their "improved" label, offer only minimal improvement on most performance dimensions. The market penetration of intermediate ICS technologies, such as portable biomass rocket cookstoves, rocket chimney stoves, and highly efficient charcoal and coal stoves, is a small share of the total—20–25 million households globally in 2012—but is growing quickly, with another

2–5 million households added by late 2014 based on the latest Global Alliance survey and self-reported manufacturer data. The penetration of clean advanced gasifier solutions that can approach the performance of modern and renewable fuels is still negligible, with fewer than 1.5 million gasifier stoves in use across the globe, the vast majority of them in China and India.

Although the market penetration of higher performing, industrially produced stoves is growing, the ICS sector is currently dominated by artisanal and semi-industrial cooking solutions. Analysis of the global ICS market suggests that roughly one-fifth of the ICS in use around the globe today have been produced by artisanal methods in local workshops or on location by trained builders. Semi-industrial stoves, featuring greater scale, some mechanization of production, pre-fabricated standardized parts, and improved quality controls represent up to 70% of households. Industrial stoves produced with fully mechanized methods, using precision-tooling and higher performing materials, are being utilized by <10% of ICS-owning households (<20 million). The situation is particularly stark in Africa where underdeveloped semi-industrial and industrial ICS markets mean that artisanal solutions account for over 90% of improved stoves in use. In markets like China, in contrast, the vast majority of improved stoves are industrially or semi-industrially produced.

Sales growth has been rapid across all ICS technologies and methods of production. Annual growth in cookstove sales based on the self-reported data from Global Alliance for Clean Cookstoves partners, and building on the legacy data of the Partnership for Clean Indoor Air (PCIA), has exceeded 50% over the past decade (2003–13), quadrupling from 3.6 million units distributed and sold in 2011 to 14.3 million units in 2013, based on the latest partner survey. Self-reported global manufacturer and cookstove program data available to the report team suggests that sales of industrial and semi-industrial stoves have risen much more rapidly (50–300% annually) than the artisanal sector (10–50%) over the past five years, albeit from a much lower base. World Bank survey data shows that improved biomass stove sales from industrial and semi-industrial manufacturers serving the Chinese market, for instance, grew tenfold over a six-year period ending in 2011, now likely exceeding 2 million units annually in 2014. The fast global growth of industrial ICS is reflected in the rising number of industrial and semi-industrial manufacturers. For instance, of the 35–40 semi-industrial and industrial players active in Sub-Saharan Africa today, one-third started their operations in the past two years, and 80% did not exist five years ago. Globally, in 2014, there were over 10 industrial ICS manufacturers with annual sales of over 100,000 units and over 40 with annual sales above 20,000 units—a major leap in scale and sophistication for the sector in just a few years.

It is difficult to foresee quick adoption for clean cooking solutions without some mechanism for reducing price. The biggest successes in scaling up access to improved biomass cooking solutions have involved public sector or donor-driven cookstove programs with strong market-based logic. For more expensive industrial intermediate or clean ICSs ($ 25–250), price subsidies via carbon market credits have played an important role, typically involving a 20–50% reduction in the consumer price via the pass-through of carbon market financing proceeds to the end user. The importance of carbon finance markets is growing despite depressed carbon prices—of the 8.2 million stoves distributed and sold in 2012 that were tracked by the Global Alliance, half received some support from carbon

finance projects, this is up from 15% in 2010–11, with carbon finance market growth continuing into 2013–15 from 2008–11 levels despite some contraction in 2013.[13] Uptake of higher priced ICSs would likely be substantially slower without such carbon subsidies, but the business models of most semi-industrial players (typically $ 8–25 products) and all artisanal ICS producers are sustainable even in the absence of carbon finance. Nonetheless, it is clear that faster adoption requires the continuation of carbon revenue streams and, likely, the introduction of additional incentives to accelerate the adoption of those stoves that create incremental health benefits for which households are unable or unwilling to pay. Potential mechanisms for such targeted incentives include results-based financing (e.g., linked to measured or likely health outcomes) and other innovative mechanisms like social bonds for cookstoves—ideas that are only beginning to be explored.

Evolution in stove technologies is a critical supply-side trend to watch. New biomass cookstove technologies include better performing and more durable basic ICS, a growing number of intermediate ICS rocket cookstove models with advanced materials and market-specific design adaptations, and, critically, the emergence of semi-industrially and industrially produced advanced biomass stoves (ACSs) that can, in some cases, approach the performance of modern fuel cooking and hold the promise of truly transformative health and environment benefits. Though at an early stage of commercialization, the ACS segment is experiencing the most rapid evolution in design with recent innovations, including fan gasifier and fan jet stoves—some with integrated thermoelectric generators that power stove fans without the need for an external power source; a growing number of more user-friendly form factors (e.g., side-loading “rockifier” designs); and widening tolerance for a range of minimally processed or unprocessed solid fuels. Consumer uptake of these solutions is not a foregone conclusion: several efforts have seen less traction than hoped for because of difficulties in ensuring steady low-cost processed fuel supply and other barriers related to consumer cooking preferences, including the need for frequent fuel loading and potentially tedious fuel processing requirements. Many of these disadvantages have been addressed in new products, however, and the evidence (at this stage largely anecdotal) from new ACS pilots in Africa, India, Central America, and China suggest that the challenges could be overcome by continuous innovation. Beyond biomass cooking, there is ongoing innovation in clean fuel technologies with increased interest in recent years in low cost LPG stoves across a range of Asian, African, and Latin American markets and the emergence of electric induction stoves as a popular technology for many middle-class end users across the developing world.

Innovation in distribution and financing models is as important as the rapid evolution in cooking technologies. The most important business model innovations in the ICS sector include the emergence of integrated fuel/stove project designs that can dramatically improve both manufacturer and—critically—low-income end-user economics by amortizing stove costs into fuel pricing. Other important innovations include the creation of sustainable clean fuel supply chains (e.g., briquettes, pellets, and ethanol), the emergence of new pay-as-you-go models with potential linkages to mobile payments (i.e., replicated from off-grid lighting to clean cooking solutions), and growing diversification of distribution models, including micro-franchising and large-scale institutional partnerships. Much of the innovation does not entail the creation of entirely new ways of doing business, but represents

the diffusion of base of the pyramid (BoP) marketing best practices to the cookstove sector. Stove entrepreneurs, for instance, are increasingly deploying models that prioritize proximity to the consumer via village-level entrepreneurs or close monitoring and training of partner sales forces, free trials, installment payment plans, and warranties that have been proven to address end users' liquidity constraints and enhance consumers' willingness to pay.

Changes in the enabling ecosystem for clean and improved cooking solutions are also transforming the potential for widespread access. Important developments include industry convergence on ICS quality requirements with the establishment of the International Standards Organization International Workshop Agreement (ISO IWA) 11:2012 and ISO Technical Committee 285, growth of local cooking solution testing infrastructure with over 20 testing centers established or in development across the globe; the evolution of new cookstove monitoring and performance measurement solutions; increased government focus on regulation of biomass fuel production; better market intelligence resulting from new investments in consumer and market research; and more rigorous program evaluation approaches. Most recently, platform initiatives—such as the Global Alliance for Clean Cookstoves, subregional and country-level industry alliances, and specific technology and fuel champions such as the Global LPG Partnership—have begun to improve coordination across donors, governments, and the private sector, and are mobilizing significant new funding and attention for the sector.

Looking Forward

Major challenges remain on the path to maximizing the reach of clean and improved cooking solutions. The most important barriers are affordability of clean cooking fuels and high-quality cookstoves, low consumer willingness to pay for the incremental benefits of clean cooking solutions, and limited accessibility of quality, high-performing products to end users. Other important challenges include behavior-change barriers that contribute to the persistence of baseline cooking technologies, the limited business-management capacity and financial constraints of small- and medium-enterprises (SMEs) active across clean and improved cooking value chains, the still limited product testing capacity to enforce emerging quality standards and minimize market spoilage, insufficient investment into research and development (R&D), low sustainability in biomass fuel supply markets, and a range of regulatory constraints (i.e., taxes and poorly targeted subsidies) to foster sector development.

Finance, in particular, is a cross-cutting challenge, encompassing the need for financing for improved biomass and clean-fuel supply chains, working capital for improved cookstove producers and distributors, support for market transformation programs and enabling infrastructure, and—where sensible—targeted subsidies and incentives tied to clearly defined access, health, and environment goals. Estimates of the total funding gap vary, but they suggest that the sector is significantly under-funded despite significant progress made by sector stakeholders in resource mobilization in recent years, including the $ 413 million of new commitments announced at the November 2014 Global Alliance for Clean Cookstoves Future Summit. The International Energy Agency (IEA) projects that annual investments of $ 4.7 billion are needed globally to ensure universal access to clean cooking

energy through 2030. Other sources—such as the Global Energy Assessment, which is based on assumptions of significant fuel subsidies—suggest that the need may be even higher.[14] This stands in contrast to $ 70 million of investments globally in ICS interventions by donors, as estimated by IEA in 2011, or the $ 0.5–1 billion of investments annually into both clean and improved stoves from all public sector programs, the private sector, and carbon finance markets, as estimated in this report. From a public health perspective, the funding gap is stark even at the high end of the range of estimates. Total current clean and improved cookstove funding is under $ 30–250 per premature household air pollution death vis-à-vis global funding in the range of $ 2,000–4,000 per death for diseases like Malaria and HIV/AIDS.[15]

The "business-as-usual" scenario for the sector is encouraging but will fall far short of potential. Without major new interventions, existing market dynamics will ensure that over 180 million households globally will gain access to, at least, minimally improved cooking solutions by the end of the decade. This is encouraging, but not sufficient. The business-as-usual scenario would still leave over one-half (57%) of the developing world's population without access to clean cooking in 2020, and 38% without even minimally improved cooking solutions. The global share of consumers using modern fuels will not shift significantly, the market penetration of advanced biomass stoves will remain at a relatively low level, and millions will continue to die annually from exposure to HAP from solid fuels and cookstoves. Furthermore, in the absence of interventions, historical trends suggest that any gains in clean cooking access would be highly unequal across geographies and income tiers.

Governments, the development community, and the private sector can and must do better. While this is a moment of great promise, it is also one of great responsibility for sector stakeholders. The clean and improved cooking sector is the wizened veteran of development causes and has seen false dawns in the past. To ensure that the current revival of interest in clean cooking solutions does not become a passing fad, there is need for major new investments and interventions to accelerate the uptake of cleaner, higher quality cooking appliances and fuels in geographies where clean cooking solutions have already shown promise—and, alternatively, to lay the foundations for clean fuel and improved cookstove ecosystems in those countries where current penetration of improved cooking solutions is minimal and enabling environment antecedents are weak. Purely market-based approaches hold significant promise for businesses focused on middle- and upper-income cooking consumers (LPG, biomass ACS, industrial rocket ICS) and there are growing opportunities for entrepreneurs to establish social businesses that focus on clean cooking for the BoP. At the same time, universal access to clean cooking energy will not be feasible without public sector leadership. As in the case of other public health crises, governments and donors must exercise leadership to ensure sufficient public awareness and funding for clean cooking solutions that will not reach most developing world households via private sector efforts alone.

B. RECOMMENDATIONS

Aside from a cross-cutting need for new investments, report findings suggest a number of immediate recommendations for sector stakeholders. Summarized here, they are presented in full in Chapter 7.

Governments, Donors, and Non-Governmental Organizations

- Significantly increase focus on clean cooking solutions, potentially via smart and targeted subsidies, but continue to invest in intermediate and basic ICS given the segmented nature of the consumer and the slow pace of market transition.
- Prioritize market-based approaches wherever feasible to maximize cooking market sustainability, but also deploy more direct incentives that can be tightly linked to resource, health, and environmental impacts.
- Support the sustainable production of clean biomass fuels and renewable fuel alternatives alongside the current focus on stove efficiency and emissions; demand-side solutions alone are not enough.
- Provide critical public goods to accelerate sector development, with a particular emphasis on access to finance, consumer education, quality standards, policy reform, and market intelligence.

Private Sector Stakeholders

- Capture the opportunity—despite many challenges, the potential for the clean cooking market is immense, with growing opportunities and a quickly rising number of new entrants.
- Reduce prices to address affordability challenges via low-cost design, local production or assembly, and innovative distribution and financing models that lower upfront cooking appliance costs.
- Focus on performance and quality. Consumers, even the poor, are willing to pay for better design and fuel savings; and the public sector is increasingly willing to support solutions that offer health benefits.
- Focus on opportunities in cooking fuel, not just cookstoves, because the market for cooking fuel is orders of magnitude larger than that for cooking appliances.
- Get close to the consumer. Although expensive, extensive marketing and the deployment of direct and indirect sales forces that build product awareness are essential for achieving scale.

ENDNOTES

1 Excludes 28 million users of kerosene stoves (2.4% of total) given evidence of the negative health effects of kerosene cooking. Estimates of fuel mix are based on the WHO Global Fuels Database, national surveys, and other publicly available data.

2 Estimates are based on a 77-country inventory of improved and clean cookstove penetration; this, in turn, is derived from hundreds of sources globally, including self-reported program and private sector data, household surveys, Global Alliance markets assessments, and over 100 interviews with key country stakeholders. The 2.85 billion figure reflects 98–99% of all households cooking with solid fuels globally; the total number of households using solid fuels for either heating or cooking is larger, likely up to 3.2 billion globally.

3 Estimate based on avoidable health, environmental, and economic costs for households and economies based on a scenario of universal migration to advanced biomass gasifier stoves for those who do not have access to modern fuels (see Section 2A, Table 2.2, and related text). The estimate is conservative and highly sensitive to assumptions on the share of negative effects that can be avoided by new cooking technologies. The McKinsey Global Institute

(2014), for instance, has estimated the global direct economic health impact of household air pollution alone at $ 400 billion, or 0.5% of annual global GDP.

4 The 2010 *Global Burden of Disease* (GBD 2010) analysis indicated 3.5 million deaths and 110 millions DALYs directly due to HAP and 0.5 million deaths due to ambient air pollution that can indirectly be traced to indoor-cooking particulate emissions. More recent estimates from the WHO for 2012 (WHO 2014), relying on an updated methodology, estimate the global mortality burden of HAP at 4.3 million people annually.

5 Solid fuel population projection based on historical (2000–10) trends for each fuel, adjusted for forecasted urbanization. By 2020, the population reliant on solid fuel for cooking and heating is estimated in this report at 3.1 billion for the 77 tracked countries or up to 3.2 billion overall.

6 Saudi Aramco LPG benchmark (2000–12) for wholesale index; regional retail prices are based on time series of urban market prices collected via press searches for 27 countries for LPG, 62 countries for kerosene, 30 for charcoal, and 5 for coal.

7 Estimate based on national survey fuel mix data, standardized per-household fuel consumption figures, survey-based estimates of share of households purchasing (rather than foraging for fuels), and retail fuel prices for all key cooking fuels for key countries globally in 2010–12. Where possible, the data was triangulated with aggregate fuel consumption figures for modern fuel (e.g., World LPG Association) and biomass (e.g., Food and Agricultural Organization or FAO) markets.

8 Market estimate based on projected new-stove households, replacements based on average stove life, and average cooking-solution prices for all major stove types globally, including the full cost of installing household biogas digesters/plants.

9 The consumer segmentation in the report is based on a custom segmentation database that draws on a global cooking and heating fuel mix database (2010–13), fuel mix data by income segment for representative countries, and data for over 20 geographies on wood purchasing vs. collection rates. For more details on the global cooking consumer segmentation, see Section 3.B.

10 For a discussion of consumer willingness to pay and estimates of marketable stove and fuel buyer segments summarized in this paragraph, see the discussion in Section 3.B.

11 Based on aggregated national data on modern fuel penetration and country level estimates for renewable fuel and clean biomass (advanced gasifier) solutions. See Section 4.C.

12 Total ICS household numbers are based on aggregated country level estimates for 77 countries globally using 2012 numbers, including information from country-level household surveys and producer stove production reports.

13 http://www.ecosystemmarketplace.com/pages/dynamic/article.page.php?page_id=10629&section=carbon_market&eod=1.

14 The most recent Global Energy Assessment (GEA 2012) estimates that $ 36–41 billion will be needed annually to achieve universal access to electricity and modern cooking solutions by 2030, with at least 20% of the total being attributed to the costs of clean cooking.

15 Relative to the 4.3 million deaths due to HAP annually, funding for clean and improved cooking is estimated in this report at $ 125 million to $ 1 billion annually, with the higher range reflecting public sector investments into household biogas plants. Data on Malaria and HIV/AIDS is based on WHO reported funding and mortality estimates for 2012–13.

INTRODUCTION

The global clean and improved cooking solutions sector has evolved significantly in recent years. Emerging demand and supply trends suggest that the sector has the potential for rapid growth, with life-changing benefits for the more than 3 billion people who today rely on inefficient, dangerous, and environmentally harmful stoves and fuels. Clean and improved cooking solutions are also beginning to generate attractive market opportunities for local and international private enterprises in the provision of cooking appliances, fuels, and financing.

Despite this great promise, the market penetration of modern fuels, renewable cooking alternatives, advanced biomass cookstoves (ACSs) and improved biomass cookstoves (ICSs) is still at a very low level. Major persisting challenges include cookstove and fuel affordability for end users; low levels of consumer awareness; behavior change obstacles to the reduced use of traditional stoves after the adoption of new solutions; and limited consumer access to appropriately designed and durable products. Supply-side constraints include the difficulty of cost-effective distribution to rural areas; limited technical and management capacity for producers and distributors; a lack of access to finance; and a variety of policy and infrastructure gaps impeding market development.

Ensuring that the growth of clean cooking in the coming years is faster, more equitable, and more sustainable will require substantially increased investment from the private sector; the success of market support and transformation initiatives from development institutions, non-governmental organizations (NGOs), and foundations; greater scale and ambition in national clean cooking programs; improved program coordination; and support from funders.

A. TYPOLOGY OF IMPROVED AND CLEAN SOLUTIONS

This report covers all **clean and improved cooking solutions that can improve on the fuel efficiency and emissions performance of traditional cooking technologies** such as the three-stone fire, open U-shaped clay or mud stoves, "metal bucket" charcoal stoves, and unvented coal stoves.[16] There is now a range of cookstoves on the market that vary widely in terms of fuel feedstock, form factor, construction materials, methods of production, and potential for mitigating harmful effects (Figure 1.1).

Under the definition of **improved cooking solutions** the report includes all cookstoves that improve fuel efficiency without reducing particulate matter emissions to the low levels necessary for optimal health and environmental outcomes as defined by World Health Organization (WHO) household air pollution guidelines and the International Standards Organization International Workshop Agreement (ISO IWA) guidelines for improved cookstoves. The basic "improved cookstove" category includes "legacy" chimney biomass and coal stoves (e.g., South Asia *chulhas*, Chinese national program chimney wood stoves from the 1990s, and Malawi mud chimney stoves) and moderately fuel-efficient "basic" wood and charcoal portable ICS (e.g., the Kenya Ceramic *Jiko*). Intermediate ICS include a range of rocket-

FIGURE 1.1:
Overview of Improved and Clean Cooking Technologies

	Improved Solutions		Clean Cooking Solutions		
	Legacy and Basic ICS	**Intermediate ICS**	**Advanced ICS**	**Modern Fuel Stoves**	**Renewable Fuel Stoves**
Key Features	Small functional improvements in fuel efficiency over baseline technologies; typically artisan produced	Rocket style designs with highly improved fuel efficiency and moderate gains in combustion efficiency; some with high-end materials	Fan jet or natural draft biomass gasifiers with very high fuel and combustion efficiencies; may require pellet/briquette fuel	Rely on fossil fuels or electricity, have high fuel efficiency, and very low particulate emissions	Derive energy from renewable non-woodfuel energy sources; some are supplementary rather than primary cookstoves
What's Included?	• Legacy biomass and coal chimney [a] • Basic efficient charcoal • Basic efficient wood	• Portable rocket stoves • Fixed rocket chimney • Highly improved (low CO_2) charcoal stoves	• Natural draft gasifier (TLUD or side-loading) • Fan gasifier/ fan jet • TChar stoves	• LPG and DME • Electric and Induction • Natural gas • Kerosene[b]	• Biogas • Methanol • Ethanol • Solar ovens • Retained heat cookers
Potential Impact[c]	**Moderate**				**High**

Sources: World Bank; Global Alliance for Clean Cookstoves; Task Team analysis.

a Although legacy stoves are categorized as "improved" within the typology, the actual performance of many legacy stoves likely falls below provisional ISO/IWA standards.

b Controlled tests of good quality kerosene pressure stoves show low emissions, but field data suggest that many kerosene stoves are actually highly polluting.

c "Potential impact" defined as potential positive impact on health and environment outcomes vis-a-vis traditional cooking solutions.

style cooking solutions such as the Onil cookstove in Central America; fixed mud, cement, and brick rocket stoves in East Africa; and a variety of portable rocket-style biomass stoves across the developing world. **Clean cooking solutions** include low-emission technologies such as ACSs, which use fans or natural draft gasification principles; stoves using modern fuels such as LPG, dimethyl ether (DME), natural gas, and electricity; a subset of kerosene stoves;[17] and a variety of renewable cooking solutions such as biogas stoves, ethanol stoves, solar cookers, and retained-heat cooking devices.

B. REPORT OBJECTIVES

The emerging clean and improved cooking opportunity is not *terra incognita* for researchers. Over the years, the sector has been covered by hundreds of publications that have focused on the harmful effects of traditional fuels, the benefits of improved cooking solutions, success factors for improved-cookstove and clean-fuel interventions, market barriers—and, increasingly, on insights into consumer preferences and distribution, marketing, and financing business models.

Sector overview reports, most notably *Igniting Change: A Sector Strategy for Universal Adoption of Clean Cookstoves and Fuels* (Global Alliance for Clean Cookstoves 2011), *Household Energy Access for Cooking and Heating: Lessons Learned and the Way Forward* (World Bank 2012), *Household Cookstoves, Environment, Health, and Climate Change: A New Look at an Old Problem* (World Bank 2012), and *Scaling Up Clean Cooking Solutions* (IFC 2013) have summarized the overall case for clean cooking solutions and have presented recommendations for addressing the sector's challenges. In the past few years, these overview reports have been supplemented by 18 country market assessment reports prepared by the Global Alliance, detailed 2012 and 2013 surveys of the Global Alliance's partner base, which elucidate many key trends, and more recent in-depth reports published by the World Bank and ESMAP on Africa and Central America regions and large national markets in Asia like India, Indonesia, and China.[18]

While it builds on the existing literature, this report differs from past efforts by constructing a comprehensive global quantitative fact base. It also situates the discussion of improved and clean biomass stoves within the context of the broader cooking fuels landscape, including modern fuel markets, renewable fuel alternatives, and sustainability strategies for biomass supply.

The objectives of this report are threefold:

1. Establish a common fact base for sector analysis. The report is an opportunity to build sector consensus and start to remedy the absence of agreed-upon regional and global baselines for basic questions on cooking solution typologies, fuel market trends, consumer segments, cookstove penetration levels, key players, and enabling environment.

2. Build a case for increased sector focus and investment. The World Bank, the Global Alliance for Clean Cookstoves, Sustainable Energy for All, and other global clean cooking sector players, such as GIZ, DFID, and USAID, are working toward the increased mobilization of funding for clean cooking solutions. The current report supports these efforts by introducing new evidence for why clean cooking matters and a roadmap for how donors, governments, NGOs, and private enterprises can help. The

private sector is an important audience for this report. Much of the material herein is aimed to arm entrepreneurs and financiers with the evidence they will need to boost their investment levels and appropriately prioritize cookstove market entry and expansion efforts.

3. Inform intervention strategies. Although the clean cooking sector is replete with interesting new products, distribution models, financing approaches, and program designs, many of the innovative efforts are still at an early stage and there is little consensus on successful models or priority intervention levers. This report is an attempt to advance the debate by highlighting existing successes, summarizing lessons learned to date, and offering recommendations on intervention options for donors, policymakers, and the private sector.

C. REPORT METHODOLOGY

This report is based on a multi-pronged research approach. The methodology incorporates the systemic review of over 300 secondary sources, analysis of primary data in dozens of existing market and household surveys, including the recent Global Alliance market assessment reports and 2012–13 member surveys, publicly available product testing result databases, impact evaluation data from large regional and country programs, focus group discussions with sector stakeholders in Africa and South Asia regional consultations, and interviews with more than 100 key global sector participants, including product designers, manufacturers, distributors, financiers, program managers, and policymakers.

Data collection efforts have included the development of several country-level databases on historical fuel mix, energy expenditures, fuel prices over time, impact data (e.g., HAP-linked premature deaths and DALYs, fuel collection times, deforestation rates), and cookstove market penetration. Market models and analyses built for the report include a global cost-benefit analysis tool for evaluating sector opportunity costs and impacts, a fuel use and expenditure forecast model, a regional cooking consumer segmentation, a sales database of improved and advanced biomass cookstove manufacturers, ICS market growth forecast models, and a multi-dimensional country prioritization tool.

We use 2012 as the baseline year for the stove and fuel penetration data in this report for the purposes of cross-regional comparability, but where applicable more recent information from 2013 and 2014 is incorporated by way of illustration and example. The resulting set of data and analyses provides the most comprehensive picture of the clean and improved cooking solutions sector available to date, but also has several weaknesses due to underlying data challenges. Sector technology definitions, impact indicators, and sales tracking methodologies are inconsistently defined and variably applied. End-user data, including information on consumer usage patterns and preferences, are of variable quality and available for only a small proportion of markets. Finally, because private sector ICS and fuel sales information and public sector cookstove program indicators are self-reported, they are not always credible.

The information provided in this report constitutes a best-effort attempt to harmonize definitions and data sources to give a comprehensive picture of the overall sector landscape, with the caveat that

this is likely to be somewhat imprecise in various instances because of these definitional and data quality challenges. We have interpreted data conservatively and highlighted potentially contentious and ambiguous areas where appropriate. Ultimately, this report should be seen as a starting point for sector analysis and the data should be updated in future editions as the cooking sector evolves.

D. REPORT SCOPE

There are no "magic bullets" or one-size-fits-all solutions to addressing the challenges of the household air pollution (HAP) issue. Clean cooking solutions currently span a vast and constantly growing range of products with different objectives, usage features, and impact potentials. The consumer base for clean fuels and improved stoves is highly diverse—straddling poor rural firewood collectors living in remote areas and using age-old cooking techniques; middle-income farmers who can afford to transition to modern fuels or renewable solutions but fail to do so due to the weight of custom and tradition; urban slum dwellers desperate for alternatives to the high fuel costs that predominate in urban environments; and a growing aspirational urban middle class that, though it has the means for adopting cutting-edge clean fuel and advanced biomass cookstove technologies, in many instances, continues to use traditional fuels and stoves.

This diversity of market needs and solutions has dictated an approach for this report that is agnostic with respect to technologies and inclusive in terms of target customer segments, intervention approaches, distribution models, and financing mechanisms. In accordance with these principles, the scope of this report is defined within the following bounds:

- **All major developing countries.** This report covers 82 countries in Sub-Saharan Africa, Latin America, the Caribbean, and developing Asia, accounting for 98% of all global users of solid fuel.
- **Residential cooking.** This report focuses on the cooking needs of households rather than those of institutions or small businesses, though many of the report's insights may hold true for the institutional sector as well.
- **Clean cooking ecosystem.** While this report focuses on improved solid fuel cookstoves, it covers the full landscape of clean cooking solutions, including modern and renewable solutions, processed solid fuel technologies, and intervention opportunities for improving the efficiency and sustainability of traditional biomass fuel value chains.
- **Cooking uses.** Although this report touches on the fact that cookstoves serve many different purposes—including most notably space and water heating—the analysis, where possible, focuses on cooking solutions and cooking-related aspects of more multidimensional stoves.
- **Improved biomass cookstoves.** This report covers the full spectrum of ICSs (see the "Terminology" section for further detail), which includes all stoves that improve on the traditional open fire and other baseline cooking technologies.
- **Modes of production.** This report covers all methods of cookstove production. These include artisanal manufactured stoves (built-in and portable); semi-industrial cookstove production models, involving networks of artisans or large workshops; and industrial production models, involving precision tooling, automation, and scaled manufacturing.

E. REPORT STRUCTURE

Following this introduction, this report is divided into the following chapters:

Chapter 2: The Case for Clean and Improved Cooking. An overview of the case for clean cooking solutions, including an analysis of the negative externalities of solid fuel dependence; a review of the latest state of knowledge on key health, environment, economic, and gender impact drivers; and a summary of the emerging evidence for the mitigation potentials of a range of clean fuel and improved cookstove solutions.

Chapter 3: The Demand for Clean and Improved Cooking Energy. A review of the clean cooking demand landscape, including fuel market evolution, fuel demand drivers, and a high-level market segmentation of global cookstove users.

Chapter 4: The Supply Landscape. An overview of the clean and improved cooking solution space, including the current status and market penetration of various fuel and cookstove technologies.

Chapter 5: The Cooking Appliance Supply Chain. A review of key elements of the supply chain for clean and improved cookstoves, including methods of production, product economics, distribution, and financing models.

Chapter 6: The Sector Ecosystem. An overview of public and donor sector models for reaching scale, sector funding, and the regulatory environment.

Chapter 7: Looking Forward and Recommendations. A market forecast for the sector, an overview of barriers to more rapid growth, and recommendations for public and private sector stakeholders.

ENDNOTES

16 See the "Terminology" section for a clarification of terms used; also see more detailed discussion of relative performance, features, and examples of improved and clean stove types in Chapter 4.

17 A large but unknown share of kerosene stoves likely produce significant harmful particulate emissions globally and, consequently, should be excluded from the clean cooking definition. See Lam et al., 2012.

18 For 2011–14 country market assessment reports from the Global Alliance, see www.cleancookstoves.org; additional market assessment reports for key markets like China are forthcoming in 2015. The Global Alliance's *Results Report 2013: Sharing Progress on the Path to Adoption of Cleaner and More Efficient Cooking Solutions* (2014) is another important resource with survey data from over 456 Global Alliance members that is referenced throughout this report. Key regional World Bank and ESMAP reports include *Clean and Improved Cooking in Sub-Saharan Africa: A Landscape Report* (World Bank/ESMAP/ACCES, 2014), *China: Accelerating Household Access to Clean Cooking and Heating* (World Bank, 2013), *Cleaner Hearths, Better Homes: New Stoves for India and the Developing World* (Barnes et. al, 2012), and *What We Have Learned about Household Biomass Cooking in Central America* (Wang et. al, 2013).

THE CASE FOR CLEAN AND IMPROVED COOKING

Worldwide, solid fuels—including wood, charcoal, coal, animal dung, and crop waste—are the primary cooking and heating energy supply for more than **3 billion people**, particularly rural poor households in developing countries.[19] Excluding "legacy" traditional stoves with chimneys, under one-third (31%) of these solid fuel households **(~200 million)** have access to improved or clean cookstoves.[20] Fewer than **1.5 million solid fuel households** use clean, advanced gasifier stoves, and the market penetration of fuel-efficient "intermediate" ICS technologies such as rocket stoves is similarly low (**20–25 million households**).

Households that use modern fuel cooking solutions as their primary stove cover 1.8 billion people or 37% of the total in the developing world. Due to the phenomenon of fuel and stove "stacking," many of these households, in some markets the majority, continue to use solid fuel stoves in parallel as secondary cooking solutions. A significant minority of modern fuel households (28 million) cook with polluting kerosene stoves. The market penetration of clean renewable cooking alternatives such as ethanol, biogas, solar, or retained-heat cookers is low and highly concentrated in several countries like China and India.

This high level of dependence on traditional solid fuels and unimproved or minimally improved cookstoves imposes immense health, environmental, economic, and social costs on developing country households and economies. This chapter quantifies the cumulative impact of global solid fuel use, reviews the key impact levers, and assesses the growing, though not yet unequivocal, evidence for the potential of different clean-fuel and improved biomass solutions to mitigate the harmful effects of solid fuel cooking.

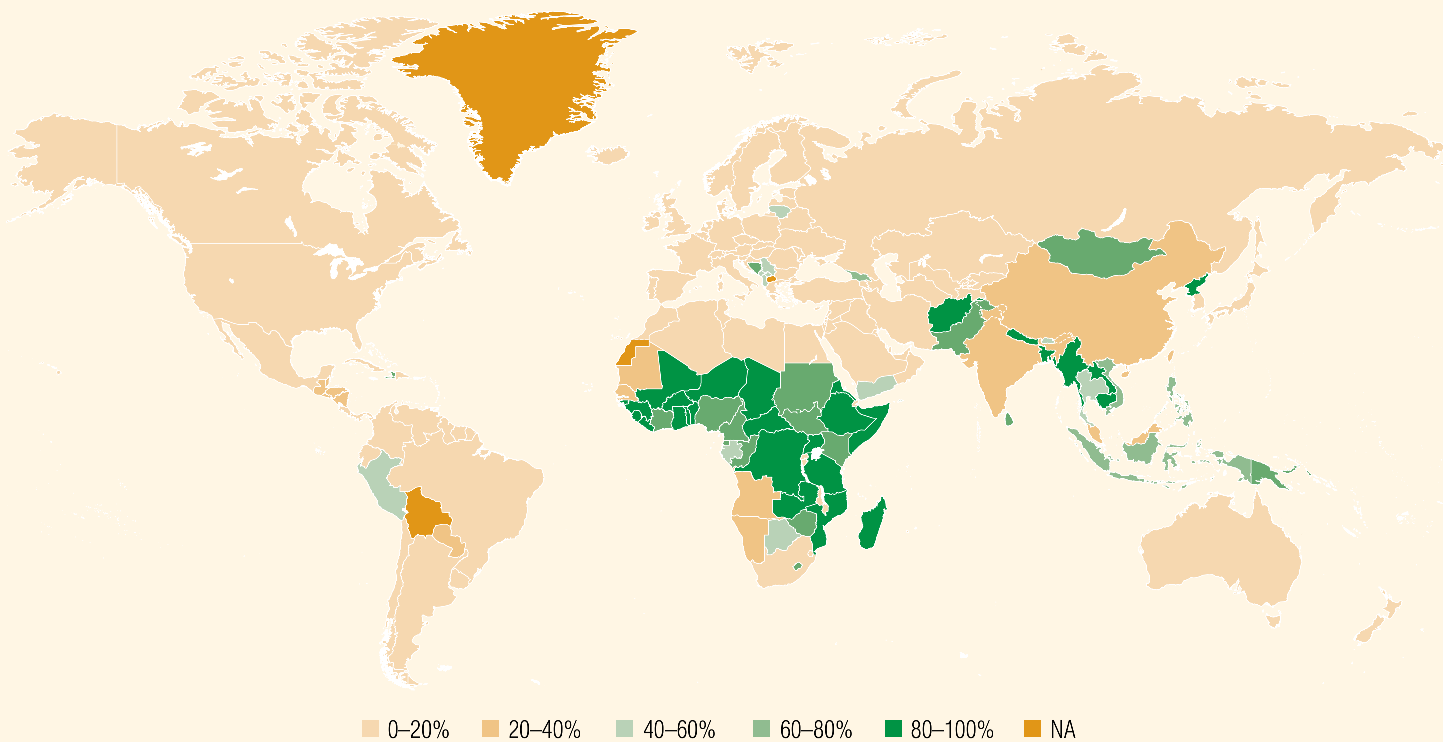
A. THE IMPACT OF COOKING WITH SOLID FUELS

The cumulative negative impact of cooking with solid fuels on developing world households, economies, and the global environment is large. The past few decades have seen the appearance of an extensive literature on the harmful effects of cooking with solid fuels. Although many questions remain on the magnitude of specific impacts, there is growing academic and policymaker consensus that negative externalities are extensive and touch on issues of health, the environment, and poverty—as well as a host of other critical factors that are more difficult to quantify, such as gender equity, nutritional status, and education.[21]

We estimate the mid-range economic value of these negative externalities globally at over $ 120 billion annually against a scenario of shifting all solid fuel users to high performing ICSs. Although staggering, the figure is likely conservative as it quantifies only a subset of known health, economic, and environmental effects. The largest impact driver is economic ($ 20–147 billion), stemming from the direct financial burden on households from avoidable solid fuel purchases and the opportunity cost of time spent on firewood collection. The estimated cost of health impacts ($ 3–57 billion) results from the valuation of avoidable deaths and disability-adjusted life years (DALYs) currently lost to household air pollution. There is significant uncertainty around the health externality, depending on the methodology

FIGURE 2.1:

Global Use of Solid Fuel for Cooking (2010)



Source: Global fuel-use data drawing on WHO, DHD, MICS, LSMS, and national census survey data for 2005–12.

TABLE 2.1:
Negative Externalities of Solid Fuel Cooking, by Impact Area

Health	Broad range of health conditions associated with IAP Burns suffered by household members from traditional fuels/cooking appliances Chronic and acute physical ailments due to firewood collection
Environment	GHG emissions due to the use of inefficient fuel production and consumption Catalytic warming effects of black carbon emissions tied to solid fuel cooking Forest degradation and deforestation due to fuel collection and production Foregone agricultural productivity due to habitat degradation and combustion of dung as fuel
Economic	Avoidable spending on fuel due to reliance on inefficient fuels and stoves Lost opportunities for income generation from time spent on fuel collection Lost opportunities for income generation due to time spent cooking
Gender	Disproportional effects on women and young girls including: • Health effects including IAP, burns, and firewood collection injuries • Reduced leisure time • Reduced opportunities for market employment and resulting status in household • Violence during wood collection
Other Social Effects	Reduced access to education due to impaired child health and time spent on fuel collection Negative aesthetic effects (e.g., poor lighting and soot-darkened home environment) Poorer nutrition due to partly prepared food or reduced food budgets Increased poverty due to diversion of scarce resources to pay for fuel

Sources: Literature review; interviews; Task Team analysis.

used—a recent McKinsey report, for instance, has estimated that the 4.3 million deaths due to HAP translate into direct economic impact of $ 400 billion, or 0.5% of annual global GDP. There is significant uncertainty around the health externality depending on the methodology used—a recent McKinsey report, for instance, has estimated that the 4.3 million deaths due to HAP translate into direct economic impact of $ 400 billion, or 0.5% of annual global GDP. The value of environmental damages, including quantifiable global warming and deforestation effects, comes third ($ 1.5–18.5 billion). Naturally, precise numbers will vary based on assumptions and the counterfactual baseline. But clearly, the opportunity cost is in the high tens to hundreds of billion of dollars.

Both in overall scale and in relative terms, this valuation is consistent with other earlier cost-benefit analyses that have found the economic burden of solid fuel cooking at both social and household levels to be the largest avoidable opportunity cost, followed by health and environmental effects.[22]

The potential human and societal costs that underpin these numbers are daunting. Release of smoke from open fires and primitive cookstoves exposes households to harmful substances and constitutes a public health crisis, affecting the lives of millions. Solid-fuel cooking imposes major financial costs on households and contributes to the waste of billions of hours of potentially productive

TABLE 2.2:
Economic Impact of Global Solid Fuel Dependence ($, billions)

	LOW	MID-RANGE	HIGH
Health	**$ 2.5**	**$ 30**	**$ 57**
Mortality for HAP	$ 1.5	$ 22	$ 44
Morbidity for HAP	$ 0.5	$ 4	$ 7
Other Health Conditions (burns, eye disease)	$ 0.5	$ 3	$ 6
Environment	**$ 1.5**	**$ 10.0**	**$ 18.5**
GHG Emissions (fuel consumption)	$ 0.9	$ 5.6	$ 10.4
GHG Emissions (charcoal production)	$ 0.2	$ 0.6	$ 1.1
Deforestation	$ 0.4	$ 3.7	$ 7.0
Economic Effects	**$ 20**	**$ 83**	**$ 17**
Spending on Solid Fuels	$ 4.2	$ 7.0	$ 9.9
Time Wastage (fuel collection)	$ 2.7	$ 37.0	$ 71.2
Time Wastage (cooking time)	$ 12.9	$ 39.2	$ 65.6
Total	**$ 24**	**$ 123**	**$ 222**

Source: Global impact model by Task Team analysis, using 2010 baseline data for comparability; methodology from the World Bank energy team upon request.

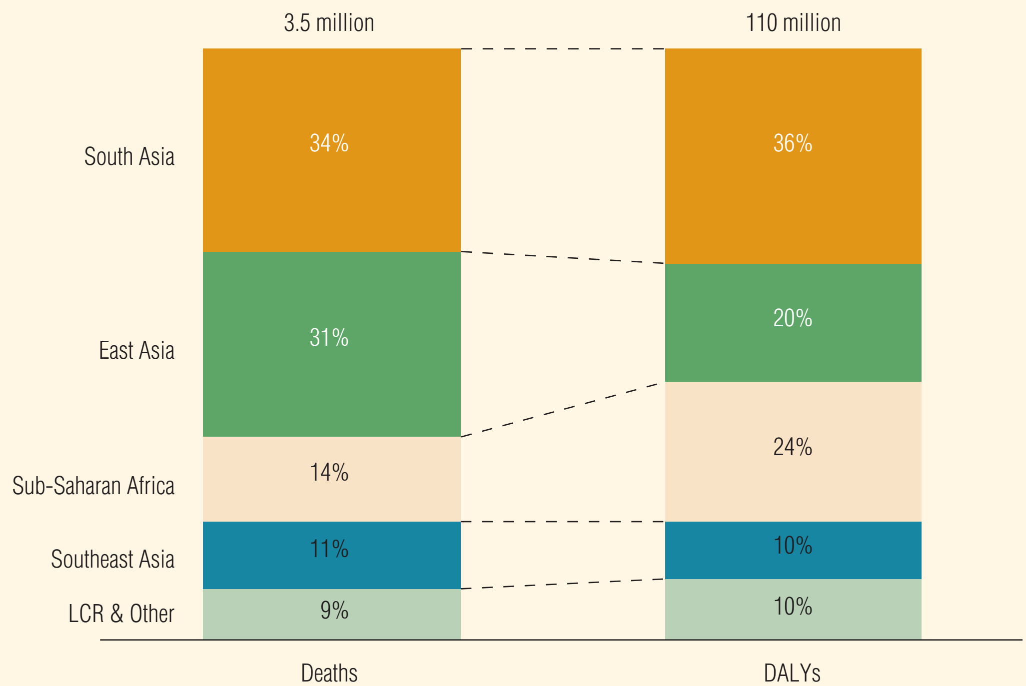
hours in the search for fuel. Inefficient stoves and unsustainable charcoal production also contribute to global warming, localized deforestation, and habitat degradation. Most of these effects tend to be gender specific, with much of the health and time burdens falling on women and female children. At the same time, the traditional biomass sector employs millions, so any fuel-saving intervention must account for the full balance of livelihood impacts.

Health Impacts

Solid-fuel cooking is a major public health crisis. The combustion of solid cooking fuels such as charcoal, wood, and coal produces significant levels of HAP that include particulate emissions, carbon monoxide, an array of less-well-studied gases and compounds, including unsaturated hydrocarbons like butadiene, mono-aromatics like benzene and styrene, polycyclic aromatics, and a variety of other oxygenated and chlorinated organics with potential carcinogenic and other adverse effects.[23]

A recent WHO analysis suggests that these emissions contributed to the premature deaths of at least 4.3 million people (2012) and over 110 million DALYs (2010).[24] Of this mortality figure, it is estimated that over 500,000 deaths stem from household air pollution via it's contribution to ambient air pollution (AAP), with HAP contributing to 12% of AAP globally.[25] Figure 2.2, relying on slightly earlier mortality and morbidity data from the 2010 Global Burden of Disease (GBD) analysis, shows the regional

FIGURE 2.2:
Household Air Pollution Mortality and Morbidity, by Region (2010)



Source: Lim et al., 2012; Task team analysis.
Note: The 3.5 million figure excludes 0.5 million premature deaths from ambient air pollution that can be ultimately attributed to HAP; more recent data from WHO has further revised the global HAP mortality figure to 4.3 million, but 2010 data is used here for deaths and DALYs to show comparable mortality and morbidity figures by global region.

distribution of premature deaths and DALYs by region. GBD data suggests that HAP is the fourth leading risk factor for premature deaths and DALYs across the globe, with a particularly significant burden in South Asia (top risk factor), Sub-Saharan Africa (second largest risk factor), Southeast Asia (third largest), and East Asia (fifth largest). Annual HAP related deaths already exceed those from public health epidemics such as HIV/AIDS (1.5 million), malaria (1.2 million), and tuberculosis (1.2 million) combined.[26]

Current HAP mortality and morbidity data almost certainly underestimate the full health impacts of households cooking with unprocessed solid fuels and low-quality kerosene stoves. The current estimate draws on a solid epidemiological literature that links indoor fine particulate matter (PM) emissions from solid fuel combustion with acute lower respiratory infections (ALRI),[27] chronic obstructive pulmonary disease (COPD),[28] lung cancer,[29] and cataracts,[30] and and low birth weights.[31] The estimates exclude a number of compelling, but currently understudied epidemiological

linkages where research is currently under way, including asthma; tuberculosis; childhood nutritional deficiencies, including anemia and stunted growth; blindness; maternal depression; cognitive impairment in the young and old; upper respiratory, digestive, and cervical cancers; the exacerbation of the effects of HIV/AIDS; and bacterial meningitis.[32]

The data also exclude more prosaic discomforts and physical injuries associated with HAP from solid fuel cooking such as headaches and eye irritation, which are almost universally reported in surveys of solid fuel users in Africa and are a particularly common complaint for households with carbon monoxide exposure from charcoal cooking.[33] Finally, the HAP disease burden estimates do not account for the health effects of cooking with polluting kerosene stoves—an emerging area of research.[34] Data from Asia, which still needs to be corroborated by field research in large African kerosene cooking markets like Nigeria and South Africa, suggests that many types of kerosene stoves elevate indoor PM concentrations above WHO guideline levels and generate potentially dangerous levels of carbon monoxide and aromatic hydrocarbons; there is also some evidence of links to impaired lung function, asthma, cataracts, and respiratory and salivary gland cancers.[35]

Firewood collection injuries and cooking burns are additional underappreciated health consequences of unimproved biomass and kerosene stoves. Though largely anecdotal, evidence from multiple countries suggests that household members involved in wood collection suffer from a range of maladies, including, cuts, broken bones, skin irritations, infections, and bites.[36] Head-loading and transport of heavy firewood bundles, in particular, can contribute to fatigue, headaches, pains in the joints and chest, chronic back pains, waist pains, and spinal injuries with incidence of some of these symptoms ranging from **15–80% of households** depending on geography and condition.[37] Robust data on these conditions are limited,[38] but even low incidence rates will translate into a large disease burden since more than 360 million households regularly engage in firewood collection across the developing world.[39] Cooking with solid fuels and unimproved kerosene (i.e., paraffin) stoves also contributes to burns, reportedly accounting for a large share of the 300,000 global burn deaths.[40]

The quality of data on "minor" physical injuries from solid fuel reliance is a major gap in the literature. Though of less interest to epidemiologists, from an end-beneficiary perspective the avoidance of basic injuries and immediate physical discomfort is often more important than the long-term prospects of developing deadly conditions. Strong and consistent anecdotal evidence shows that awareness of basic injuries is high relative to long-term chronic disease potential[41] and causality is far more apparent for populations with limited medical literacy. The value of highlighting these health effects in ICS and clean-fuel marketing and behavior-change campaigns, therefore, is likely to be high.[42]

Environment and Climate Impacts

Solid-fuel cooking has a range of negative environmental and climatic effects. In 2010, solid fuel households across the developing world used at least **720 MT of firewood** and **33 MT of charcoal**

for cooking, a total of over **1 billion MT or 1.3m³** of woodfuel annually,[43] along with **150 MT** of coal.[44] A recent Global Alliance funded study estimates the total biomass fuel demand at **1.36 billion MT** annually.[45] It is clear that such high levels of solid fuel combustion contribute to global warming, have negative local climatic effects, and—largely because of charcoal production—are contributing factors to localized deforestation and forest degradation. Significant methodological uncertainty remains, however, on estimating the scale of many of these effects.

Large-scale consumption of solid fuels produces greenhouse gas emissions that contribute to global warming. Solid-fuel cooking and related charcoal production across the developing world generate greenhouse gas emissions of 0.5–1.2 billion MT of carbon dioxide (CO_2), including the CO_2 equivalents of N_2O, and CH_4 emissions covered by the Kyoto Protocol.[46] This represents 1.5–3.0% of global CO_2 emissions. These CO_2 emissions are on par with the 2010 carbon footprint of an industrialized country like the United Kingdom at the bottom of this range and approach that of Japan at the top of the range.[47] Uncertainty around the precise greenhouse gas figure stems from the fact that CO_2 emitted from the combustion of renewably harvested wood is re-absorbed during biomass regrowth and therefore does not qualify as a climate forcing emission. The level of woodfuel renewability is an area of ongoing debate and research.[48]

Black carbon and other particles of incomplete combustion from solid fuel cooking may play a more important role than CO_2 in anthropogenic global warming. Traditional solid fuel stoves and open cooking fires account for over 1,500 Gg of black carbon, which represents 20% of global black carbon emissions and is consistent with earlier estimates of residential solid fuel use, equaling up to 25% of all black carbon emissions globally.[49] When the assessment includes these black carbon emissions and other particles of incomplete combustion not listed in the Kyoto Protocol, like carbon monoxide and non-methane hydrocarbons, the potential annual carbon footprint of global solid fuel cooking increases to 1.3–1.7 MT CO_2-equivalent.[50]

While CO_2 remains in the atmosphere for decades, black carbon particles have an atmospheric lifetime of only 8–10 days,[51] so the reduction of black carbon emissions can theoretically lead to relatively rapid global cooling benefits. This has led to speculation that the reduction of black carbon emissions from traditional solid fuel stoves and open fires could be one of the “critical near-term levers” for addressing global warming[52] in addition to the various health co-benefits of removing black carbon from household environments.

Claims about black carbon cooking impacts must at this stage be interpreted with caution. The current climate-science consensus is that solid-fuel black carbon and products of incomplete combustion emissions contribute to global warming over the long term. However, the magnitude of the effect is subject to significant uncertainty and, in the short term, the climate-forcing impact of biofuel cooking may be close to neutral due to offsetting cooling factors.[53] Although the direct climate-forcing impact of cookstove black carbon emissions is very positive, roughly 20% of the warming effect is offset by the simultaneous release of organic aerosols from solid fuel cooking.[54] Organic aerosols have additional indirect cooling effects via still-poorly-understood liquid-cloud interactions that, in the near term, may offset all or the majority of the warming impact of solid fuel cooking. The ratio of organic

carbon to black carbon, which varies widely by cookstove type, is therefore a critical consideration in any analysis of climatic impacts of alternatives to traditional solid fuel stoves.

Short-term local climatic effects of black carbon emissions, including from traditional biomass cooking, are also likely to be harmful. Black carbon emissions can influence regional precipitation and temperature patterns through albedo cooling effects and glacial melting, contributing to anthropogenic changes in monsoon circulation and the retreat of mountain glaciers in South Asia.[55] While less documented, local climactic effects of black carbon emissions are also likely to be substantial in Africa, potentially affecting snow melt on Mount Kilimanjaro and rainfall patterns in the mountain ecosystems of the Rwenzori Range, which serve as water catchments for a large part of Central Africa.[56] Via such local climate impacts, black carbon can also have significant negative effects on agriculture production, most directly for mountain cash crops such as coffee and tea. The impacts of such effects may be important, but have not yet been analyzed.

Biomass cooking is among the contributing factors to forest degradation and localized deforestation, though the precise extent of these effects is a matter of debate. The current consensus view is that the primary causes of deforestation are land clearing for agriculture, exploitation of wood for lumber and road building, commercial and residential development, and other permanent land uses rather than the collection of firewood for energy.[57] There is less agreement in the literature on forest degradation[58] and the deforestation effects of charcoal production. Some analysts suggest that charcoal may be a significant new driver of degradation and localized deforestation in Africa and Asia, but most experts characterize charcoal production as just one forest-degradation factor among many.

What is clear is that occasional claims of a renewed "woodfuel crisis" are not supported by the data and, despite very real localized instances of severe pressure on forest resources, the general renewability of wood stocks is higher than is usually assumed.[59] The availability of woody biomass outside of forests, such as in woodlots, plantations, and agroforestry systems, is often systematically neglected. Assessments of woodfuel renewability, in the case of both firewood collection and charcoal production, also do not consider forest developments at the micro scale. The exploitation of forests for woodfuel often triggers a change in forest structure towards a short-rotation management system dominated by more trees and woody plants of smaller diameters rather than fewer but larger trees. The regrowth potential of natural forests is likewise poorly understood and often underestimated, contributing to false assessments of physical biomass scarcity.

Firewood collection. The vast majority of firewood collected in rural areas comes not from live forest trees but from 'invisible trees' such as bushes and biomass lying around roads, next to houses, and in farm fields.[60] Thus when local firewood demand exceeds the growth rates of local forests, it does not mean that deforestation has taken or is taking place. There is somewhat more evidence that firewood gathering may contribute to forest degradation when other contributing factors are present,[61] though it is not possible to separate and identify the precise impact of firewood collection from these other factors. Degradation effects related to firewood collection may include path clearing in forests, the lopping of tree branches, and the collection of dead wood and branch detritus from the forest floor.[62] In

localized cases of excessive wood foraging, degradation can lead to the thinning of tree crowns and ground-level plant densities, soil nutrient depletion, changes in tree species composition, and the loss of floral and faunal biodiversity.[63]

Dung and crop-waste collection. The habitat-degradation effects of the collection of other traditional biomass such as dung and crop waste are less well studied, but may also be material in some cases. Studies in Ethiopia, for example, have suggested that dung use lowers agricultural productivity because cooking with dung reduces its availability as a fertilizer.[64] In South Asia, the evidence for the soil erosion effects of dung and crop-residue use for fuel has been more mixed and further research is needed for meaningful impact attribution.[65]

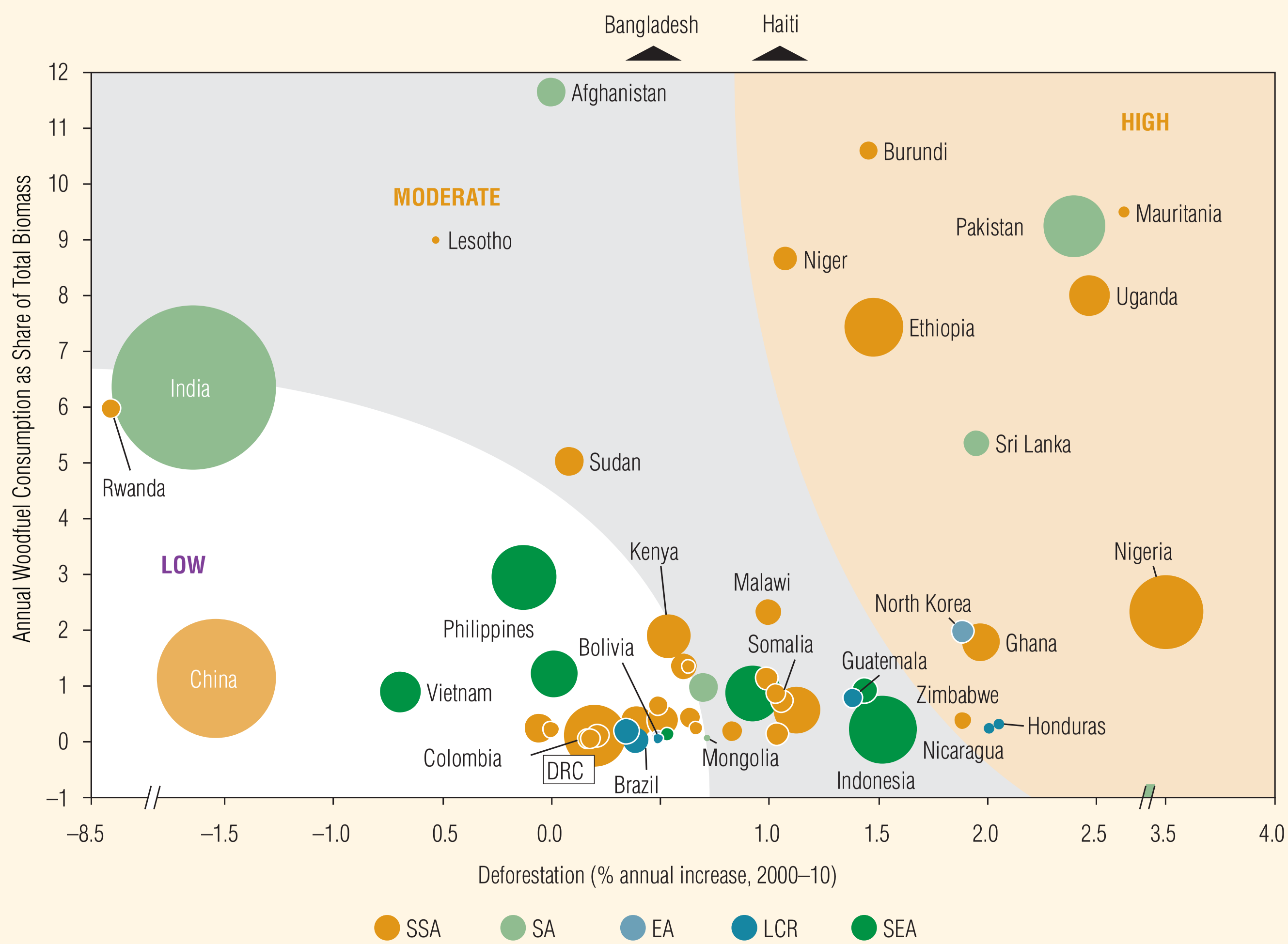
Charcoal production. Evidence for forest degradation and localized deforestation from charcoal production is more compelling, though the scale and scope of such effects is highly dependent on country context.[66] In some countries—Tanzania, for example—there is evidence that charcoal producers selectively focus on wood that produces a dense, slow-burning product, a characteristic of slow-growing tree species that are more vulnerable to overexploitation.[67] In other countries, such as Rwanda, where charcoal production relies entirely on planted trees such as eucalyptus and pine, it is much less likely to have negative environmental impacts. Unlike firewood harvesting, which focuses on dry wood and forest remnants, the production of charcoal typically involves cutting large live trees down to stump level. The logged trunks are then typically transformed into charcoal using kilns that require 4–12 times the wood (by volume) for each kilogram of charcoal produced.[68] Because a significant share of the wood used for charcoal production is sourced illegally from public forest land, charcoal prices do not reflect the scarcity of wood inputs—a strong incentive for unsustainable overharvesting.[69]

The overall role of charcoal in most markets, relative to other deforestation and forest-degradation factors such as agriculture, is still likely to be secondary, though there is little consensus on the scale of the effect.[70] Charcoal production pressures are most acute in Africa and select non-African markets like Haiti. Existing fuel-use trends and urbanization forecasts indicate that Sub-Saharan Africa charcoal consumption for household cooking will increase 50% over the current decade, from 22 MT in 2010 to 33 MT—with some estimates showing total annual consumption, including non-household cooking uses of charcoal, increasing to as much as 38 MT by 2020.[71] The ultimate effects of charcoal-based forest degradation are likely more severe than those of firewood foraging. Among potential impacts, are vegetative cover and subsoil nutrient loss, reduced tree species biodiversity,[72] reduced faunal diversity and abundance,[73] and—in extreme cases—the acceleration of processes that leads to the conversion of degraded forests into agricultural land.

The scale and severity of environmental impacts of traditional biomass cooking vary greatly across geographies. The influence of solid fuel use on biomass sustainability varies greatly by country. Likewise, climate forcing emissions from traditional solid fuel cooking are not spread evenly. One way of visualizing the relative environmental threat potential appears in Figure 2.3. The intensity of woodfuel harvesting is shown on the vertical axis[74] and existing deforestation pressures appear on the horizontal axis.[75] The bubble size reflects a country's total woodfuel (charcoal and firewood) consumption from biomass cooking. The total solid fuel population size is highly correlated with the

FIGURE 2.3:

Global Solid-Fuel Cooking Biomass Pressure Map



Sources: FAO deforestation data; global cooking fuel-use data drawing on WHO, DHS, MICS, LSMS and national survey data; Task Team analysis.
Notes: Bubble size reflects total metric tons of woodfuel. Biomass is defined as above-ground biomass. Woodfuel includes charcoal and firewood.

greenhouse gas and black carbon emission potential of each country and also shows the relative scale of the deforestation/degradation challenge across geographies.

The figure shows clearly that a number of countries—Ethiopia, Nigeria, Pakistan, Sri Lanka, and Uganda, as well as several smaller nations—fall into the highest woodfuel biomass pressure zone. In this zone, high rates of deforestation are accompanied by significant use of national firewood stock for cooking activities. With high rates of deforestation, the significant population of firewood users is likely to come under pressure if resources become too scarce. There is also a wide intermediate zone of countries where the likelihood of forest degradation effects is significant, especially for those countries using significant portion of their national stocks for cooking. For a number of countries in the low pressure zone, biomass scarcity and forest degradation may still be significant issues at the subnational level, even if the effect is not visible in aggregate because of large overall biomass stocks. Furthermore, recent research suggests that, in countries like Rwanda, the official Food and Agriculture Organization (FAO) forest cover data used in the deforestation pressure analysis may significantly understate actual deforestation rates.[76]

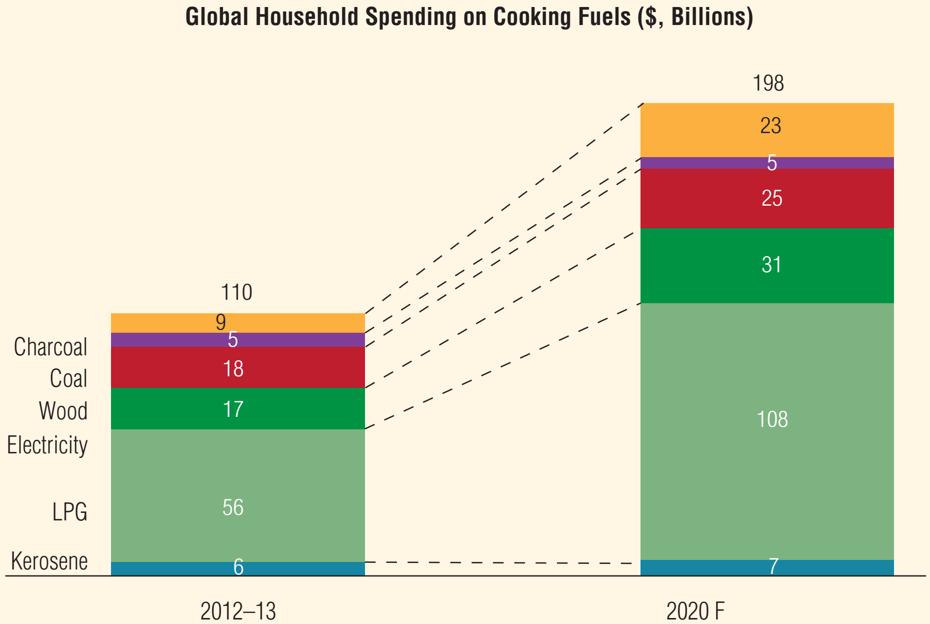
Woodfuel consumption is not the only environmental challenge of solid fuel cooking: the inefficiency and poor sustainability of woodfuel supply must also be addressed. Achieving lower woodfuel consumption requires that demand-side efficient stove interventions be augmented by steps to improve the sustainability of woodfuel harvesting and, specifically, by measures to improve charcoal production efficiency and, potentially, the production of 'green charcoal' alternatives from sustainable biomass sources like agricultural waste.

Even if the world moves to universal adoption of more efficient stoves, in many countries the quantity of wood-based biomass, particularly charcoal, used to satisfy energy demand will likely grow in absolute terms given the rapid demographically fueled increase in woodfuel consumption. For example, FAO's estimates suggest that charcoal use will more than double between 2010 and 2030 in most subregions of Sub-Saharan Africa, suggesting that even the universal adoption of more efficient cookstoves (e.g., basic improved charcoal stoves saving 20–30% of fuel) over the next two decades would not prevent increased consumption.[77] A similar phenomenon is clear outside Africa in those areas where charcoal is a major fuel or where firewood scarcity already presents a critical challenge, including countries like Haiti, Myanmar, the Philippines, Cambodia, Bangladesh, Pakistan, Indonesia, and parts of Central America. More broadly, the long-term reality of a cooking sector dominated by woodfuel suggests that woodfuel use must be reframed as an opportunity for improving supply-side market and policy rather than just a crisis in demand-side overconsumption.

Economics and Livelihoods

Alongside environmental and health impacts, dependence on solid fuel imposes significant economic costs on households and societies. The most immediate and direct cost is the $ 100 billion cooking bill paid for typically inefficient and increasingly costly cooking fuels (Figure 2.4)—an amount set to double by 2020, assuming the continuation of historical (2000–10) growth trends in fuel

FIGURE 2.4:
Total Household Expenditures on Residential Cooking Fuels



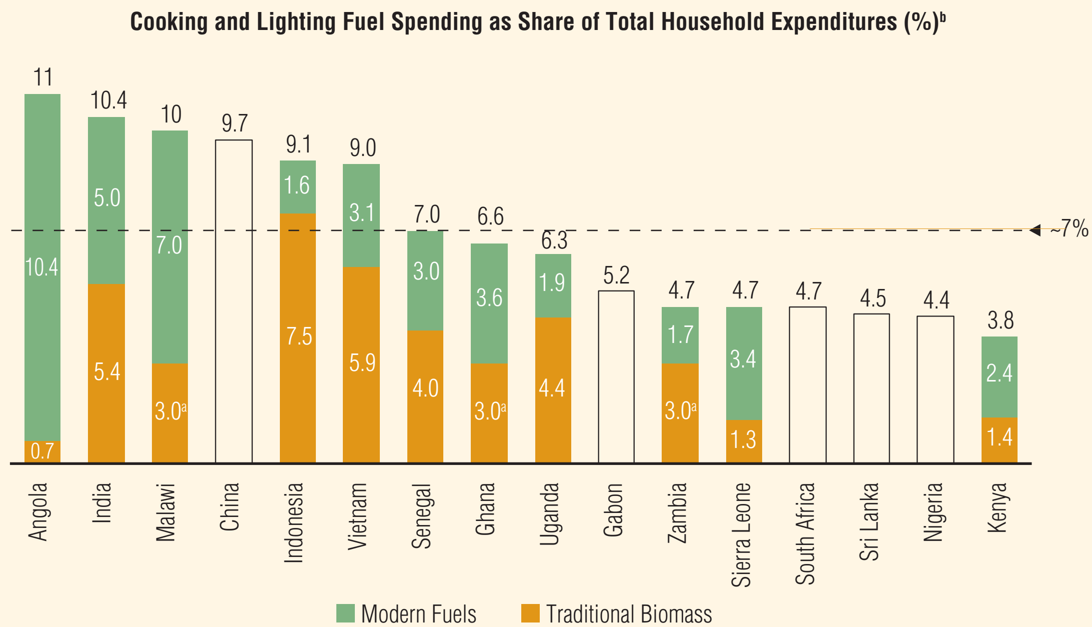
Source: Fuel market sizing and forecast model; Task Team analysis.
Note: This is an inertial scenario that assumes no major shifts in fuel-use patterns toward modern or renewable fuels. Excludes use of fuel for non-cooking purposes (e.g., space heating) and excludes non-residential fuel use (e.g., charcoal use by small industry and commercial sector).

prices and fuel consumption. Roughly one-half of this spending is dedicated to solid fuels, though not all of the expenditure is avoidable.

At the household level, cooking-fuel spending constitutes a significant share of household incomes and expenditures, particularly for the urban poor. BoP population surveys suggest an average household cooking and lighting fuel bill of roughly 7% of expenditures for developing countries (Figure 2.5).[78] The balance between spending on cooking and lighting is not possible to disaggregate from the available data. For some fuels, such as LPG, the majority will likely be spent on cooking while kerosene is more likely to be used for lighting. There will also be variability in this balance by country.[79] These findings should be interpreted with caution, as solid fuels such as purchased firewood are often not captured in survey data. Additionally, much of the survey information is dated; current expenditures are likely higher because of the rising costs of key fuels such as LPG, kerosene, and charcoal relative to household incomes over the past decade.[80] Sharp increases in the cost of charcoal in the past two to three years, in particular, have had an outsize impact on the energy expenditures of the urban poor.

FIGURE 2.5:

Energy Share of Total Household Expenditures in Several Countries (%)



Sources: WB country surveys in Bacon, et al. (2010); national consumption surveys, WB Survey-Based Harmonized Indicators Program (SHIP); Task Team analysis.

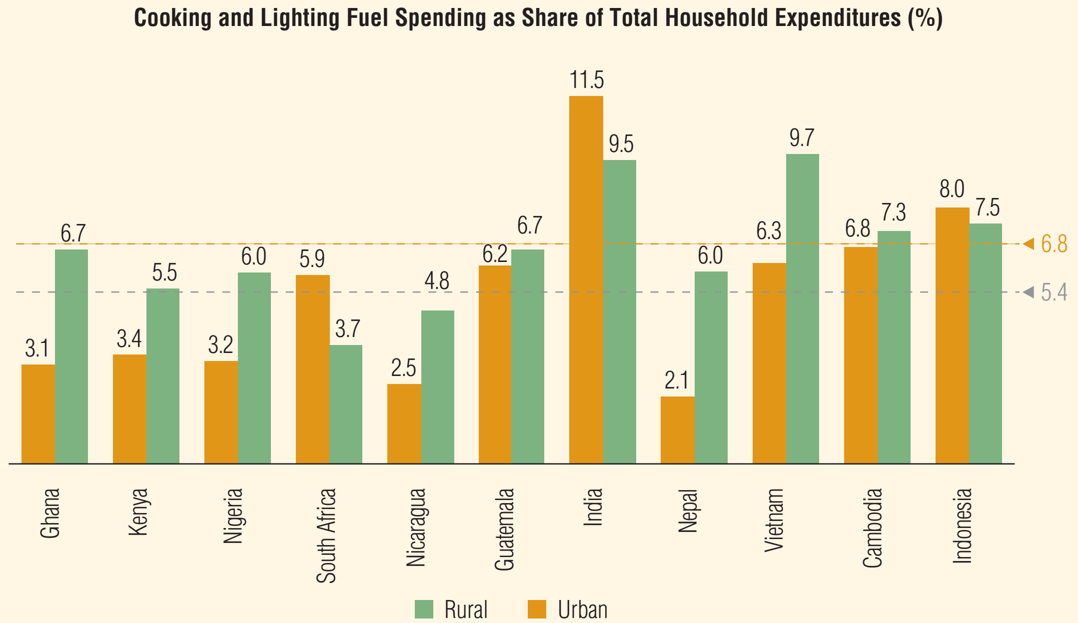
a Solid fuel share estimated at 3.2% based on country average (Daurella and Foster, 2009) wherever only modern fuel data is reported.

b Although this includes the use of kerosene and wood fuel for lighting, lighting is typically a small proportion of the total fuel costs.

The economic challenge of solid fuel dependence is not uniform across all populations. There is significant variation in expenditures as urban households and poorer households tend to pay out higher proportions of their household budgets to meet their cooking energy needs.[81] Urban consumers on average spend 1.3 times more on energy as a share of their expenditures than rural consumers, though the trend is reversed in countries such as South Africa and parts of South and Southeast Asia, where modern fuel penetration of rural markets is relatively high (Figure 2.6). Inequalities also exist in line with income level. The poorest quintile of households in many countries spends many times the relative share of expenditures of the richest population quintile (Figure 2.7). Urban slum-dwellers tend to experience the most acute energy poverty, with expenditure levels of up to 25% of monthly income in city slums.[82]

The issue is partly rooted in the widely observed phenomenon of a poverty premium faced by BoP households for access to basic goods and services.[83] Across all income segments, data from across the continent suggests that pressure on household finances is particularly acute during the rainy season, when dry firewood and charcoal can see price premiums of between 20 and 50%.[84]

FIGURE 2.6:
Energy Spending of Rural vs. Urban Consumers



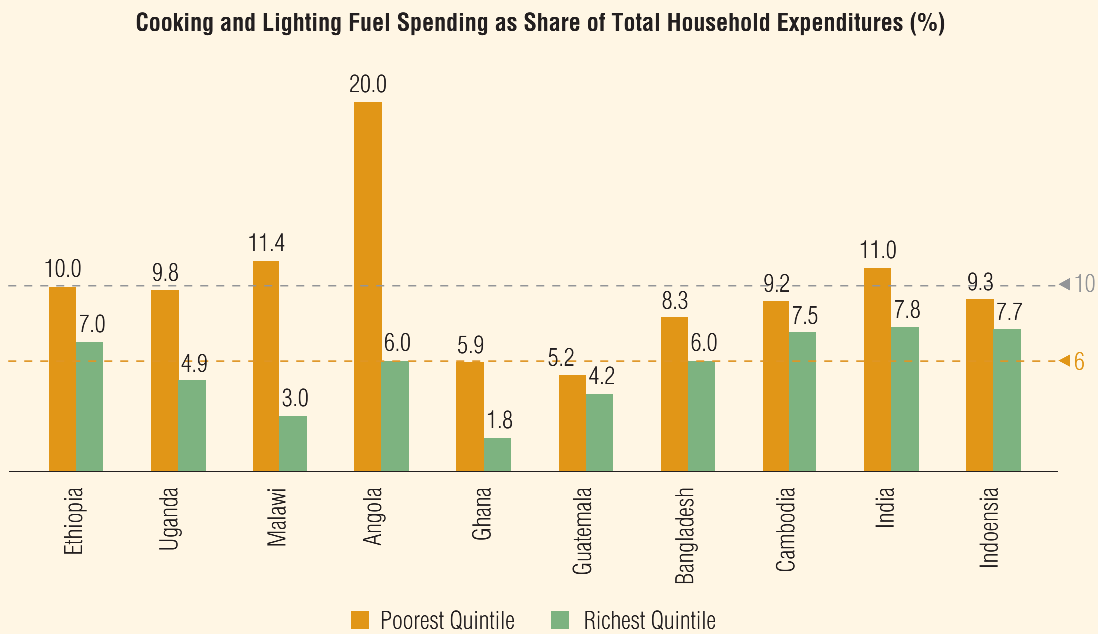
Sources: Bacon, 2010; national household surveys; Task Team analysis.

Aside from direct fuel costs, the loss of potentially productive household time for fuel foraging and solid fuel cooking is also a major challenge. Our systemic review of over 70 national time-use and household energy surveys suggests a fuel collection average of roughly 1.3 hours per day for households collecting fuel, with a range of 30 minutes to over 6 hours daily for rural households across different geographies.[85] The longest collection times are reported in Sub-Saharan Africa (2-hour average across 20+ countries and 50 data points) and South Asia (0.6–2.0 hours in India, 2.0–4.0 hours in Nepal). Collection times are lower in East Asia (0.3–0.5 hours in China), Southeast Asia (1.2 in Indonesia, 0.8 in Myanmar), and Latin America (0.5–1.0 hours in Guatemala and Nicaragua). Largely anecdotal evidence from the field suggests that fuel collection times and distances are increasing because of rising firewood scarcity,[86] but significant variation across and within geographies[87] and the absence of reliable longitudinal data makes it difficult to quantify the scale of the changes over time.[88]

Aside from their fuel collection duties, households also lose significant time on preparing solid fuel (i.e., drying, cutting down to size), cooking more slowly than necessary using low-efficiency traditional stoves that require constant attention, and cleaning kitchens and dishware covered by woodfuel soot.

FIGURE 2.7:

Energy Spending of Top vs. Bottom Income Quintiles



Sources: Bacon, 2010; national household survey data (2000–15); Task Team analysis.
Note: Includes all biomass and modern fuel expenditures on energy, excluding diesel/petroleum for transport.

Cooking time, in particular, is a significant burden, with surveys reporting cooking times of 2–6 hours daily.[89] As discussed in the section on gender and social impacts later in this chapter, this time burden of solid fuel cooking and fuel collection falls disproportionately on women and young girls.

The opportunity cost of time lost resulting from solid fuel collection and cooking is significant in monetary terms. The total opportunity cost of time lost to avoidable cooking drudgery and fuel collection tasks globally is over 60 million person years annually.[90] Researchers have suggested that up to one-half of this time could be redeployed to economically productive activities, including both farming activities and other income-generating labor,[91] but household survey data from Africa and Asia suggests that a more realistic figure is likely in the 20–35% range,[92] with the level of income-generating opportunities likely to vary significantly across geographies, the location of the household (i.e., greater opportunities for income generation in urban settings), and the level of women's access to both formal and informal economic activities outside the household. Even with moderate assumptions, these time savings could translate into incremental annual household income of $ 5–30 billion annually.[93]

Household Economics of Firewood Collection and Charcoal Production

The economic impact of solid fuel dependence is not unequivocally negative because the wood fuel value chain employs millions of poor rural and urban households. While highly negative from the standpoint of energy poverty, dependence on solid fuels has positive impacts in terms of rural livelihoods and urban employment for tens of millions of small-scale wood collectors, charcoal producers, transporters, and last-mile retailers around the globe.

Africa has some of the best data on the sector. The World Bank estimates that the Sub-Saharan Africa charcoal sector alone employs 7 million Africans, with aggregate employment expected to reach 12 million people by 2030.[94] Recent individual country studies estimate the involvement of 700,000 in the charcoal sector in Kenya,[95] around 200,000 in Uganda,[96] over 100,000 in Malawi,[97] and several hundred thousand supplying the needs of Dar es Salaam in Tanzania.[98] Country-level estimates for the firewood trade are unavailable, but are likely to be on a comparable scale, particularly in West African nations with large trade markets in urban firewood. In aggregate, employment in the informal and formal woodfuel sectors, including part-time labor and the entire charcoal-production value chain, could exceed 15 million individuals across the entire Sub-Saharan Africa region.[99] Assuming the employment of one family member per household, this equates to 9% of Sub-Saharan Africa households—a scale that, at the country level, exceeds employment levels in large economic sectors, such as tourism and industrial manufacturing, and in cash crops, such as coffee and tea.

Similarly high numbers have been reported in other regions. UN Development Programme (UNDP) and ESMAP have estimated that about 840,000 jobs exist in the biomass/woodfuel sector in the Philippines, touching 10% of Philippine's rural population, 3–4 million woodfuel sector jobs in India, and 600,000 jobs in Pakistan.[100] Formal and informal charcoal and woodfuel markets, while poorly studied, also play an important role in Asian countries like Bangladesh, Bhutan, Nepal, Myanmar, Cambodia, Lao PDR, and Vietnam. In Latin America, it is estimated that woodfuel production and collection accounts for 200,000 jobs in Brazil, tens of thousands of jobs in Peru, and over 150,000 jobs in Haiti in charcoal value chains alone, one of the biggest sectors of Haiti's rural economy.[101] The woodfuel sector is likewise a significant employer in Central American countries like Honduras, Nicaragua, and Guatemala where over half of the solid fuel using population purchase their firewood.[102]

There are few skill- or capital-based barriers to entry to the lowest rungs of the woodfuel value chain, the work of fuel collection and production is typically extremely laborious, and work in the sector generates little income.[103] Many households engage in woodfuel production and/or trade in tandem with agriculture. The sector sees great seasonality with increased participation in charcoal markets during the rainy season when urban charcoal prices are high and there is more free time available from agricultural activities.[104] A large number of households also resort to the woodfuel sector in times of financial stress, such as when making large payments for medical costs, funeral expenses, food supplies in the event of poor harvests, marriage ceremonies, and other exigencies.[105]

Earnings from the sector are low in absolute terms, but are an important source of cash income and a significant contributor to poverty alleviation. The most thorough data on woodfuel production

and retail markets comes from Africa. Surveys show that monthly earnings from charcoal producers are $ 12–45 in Uganda,[106] $ 24–33 in the Democratic Republic of Congo,[107] $ 30–50 in Madagascar,[108] $ 60 in Kenya,[109] $ 75–135 in Mozambique,[110] $ 80–100 in Burkina Faso, Chad, and Niger,[111] and up to $ 130 in Ghana,[112] accounting for between 30% and 90% of the incomes of rural households in charcoal producing regions. Charcoal producer earnings have important poverty alleviation impacts. In the Democratic Republic of Congo, revenues from firewood and charcoal production are used for basic needs such as food (92% of producers), education (88%), and healthcare (72%).[113] A recent Uganda study has found that the likelihood of falling below the poverty line falls by 14% for households involved in charcoal production.[114]

In Asia, now dated research from the late 1990s suggests that in key charcoal markets in South Asia (India, Pakistan, Nepal, Bhutan) and Southeast Asia (Myanmar, Cambodia, Lao PDR, Philippines), the woodfuel production and sales business was the main source of income for as many as 10% of rural households, accounting for up to 40% of those households cash earnings.[115] Evidence from Latin America and the Caribbean likewise suggests that charcoal production can be an important source of cash income for poor rural peasants and forest dwellers and, in some cases like Haiti, is the mainstay of rural livelihoods.[116]

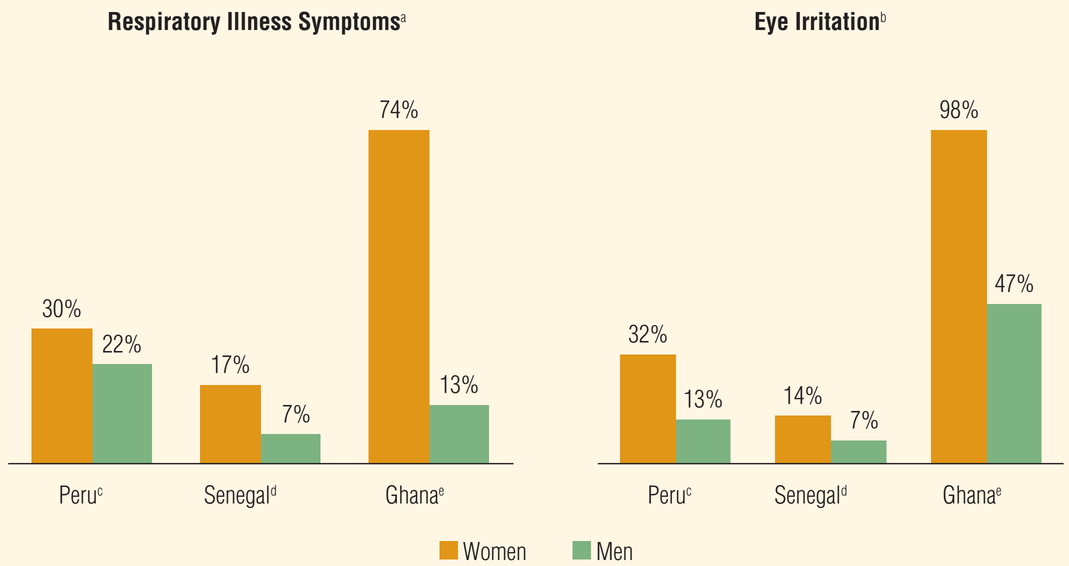
Gender Equity and Related Social Impacts

The negative effects of traditional solid fuel cooking on women and gender equity are clear. Firewood collection, fuel processing (e.g., drying and cutting), cooking, and post-meal cleanup are traditionally female gender roles across the developing world. Women, consequently, bear a disproportionate burden of the negative health, economic, and time-poverty effects of solid fuel consumption reviewed earlier in this report. Because female children are women's main helpers in tasks such as fuel collection and food preparation, they also face a disproportionate share of the harms. At the same time, however, because they are often the primary firewood collectors and woodfuel retailers in many countries, women are also the beneficiaries of the positive rural livelihood impacts of woodfuel value chains.

There is a growing literature on the linkages between gender[117] and access to clean cooking solutions and gender mainstreaming is gaining pace in donor and national improved cookstove programs.[118] The state of knowledge is still at a relatively early stage, however, with minimal investment by sector stakeholders in the systematic collection of gender disaggregated data on the externalities of traditional solid fuel cooking and the gender-specific impacts of clean and improved cooking solutions. Following are a quick overview of the literature and highlights of some of the major gender implications for clean cooking solutions; these are touched on again—where relevant—later in this report.

Gender and health impacts. While there is strong consensus in the literature that negative health impacts of traditional solid fuel cooking are skewed towards women given their greater exposure to smoke from unimproved stoves and the drudgery of firewood collection, there is actually a dearth of robust gender-disaggregated data for most health effects.[119]

FIGURE 2.8:
Gender-Disaggregated Health Impacts



Sources: Senegal (Bensch & Peters, 2012); Peru (Adrianzen, 2010); Ghana (Odoi-Agyarko, 2010); Task Team Analysis.

a Defined as "respiratory illness symptoms" (Peru); "respiratory disease symptoms" (Nepal); and "average of reported cough, chest pain, and phlegm" (Ghana).

b Defined as "eye discomfort" (Peru), "eye problem symptoms" (Senegal), and "eye irritation" (Ghana).

c Symptoms in the past 30 days. Sample size of N=139 adult males in Northern Peruvian Andes.

d Symptoms in the past 6 months. Sample size of N=227 households in the Bassin Arachidier region around Kaolack, Senegal.

e Symptoms at any point in the past. Sample size of N=625 households (152 men and 473 women interviewees) in Bongo district, Ghana.

Evidence from several countries shows that female cooks are exposed to significantly higher particulate matter emissions than men, up to four times men's levels in Kenya and up to double the level of men in South Asia studies.[120] It is not clear that higher exposures necessarily translate into more adverse health outcomes because men's exposure levels also significantly exceed safe minimums,[121] but differential impact on women from the exposure is highly likely. Recent research from Senegal, Ghana, and Peru, for example, demonstrates evidence of greater incidence of respiratory illness and eye disease in women in solid fuel-using households based on self-reported household data (Figure 2.8).

Other HAP-linked conditions with a strong gender component to the disadvantage of women include depression[122] and blindness.[123] Women can be also expected to have much greater incidence of headaches, anemia, and other symptoms of excessive carbon monoxide exposure because the negative impacts of carbon monoxide in women, particularly pregnant women, occur at significantly lower doses than men.[124] Alongside evidence demonstrating these impacts, there is also evidence that while women often recognize the immediate harm from traditional cooking (headaches,

coughing, eye irritation), there is much less recognition of the long-term negative health impacts linked to HAP.

There is also evidence that injuries from firewood collection are endemic in female populations. Rural women transport firewood loads of 10–38 kilograms, with an average of roughly 20 kilograms, and travel between 1–10 kilometers during wood collection trips.[125] There is strong anecdotal evidence that head-loading of firewood and other physical strains related to firewood transport on foot result in headaches and musculoskeletal damage, with attendant symptoms of back pains, neck stiffness, and waist pains. The incidence rates for these symptoms and related physical injuries are significantly higher in women than what is typically seen for men.[126] There are also persistent anecdotal reports of miscarriages and utero-vaginal prolapse[127] linked to firewood collection—which, along with water collection, is among the more physically arduous activities endured by rural poor women.

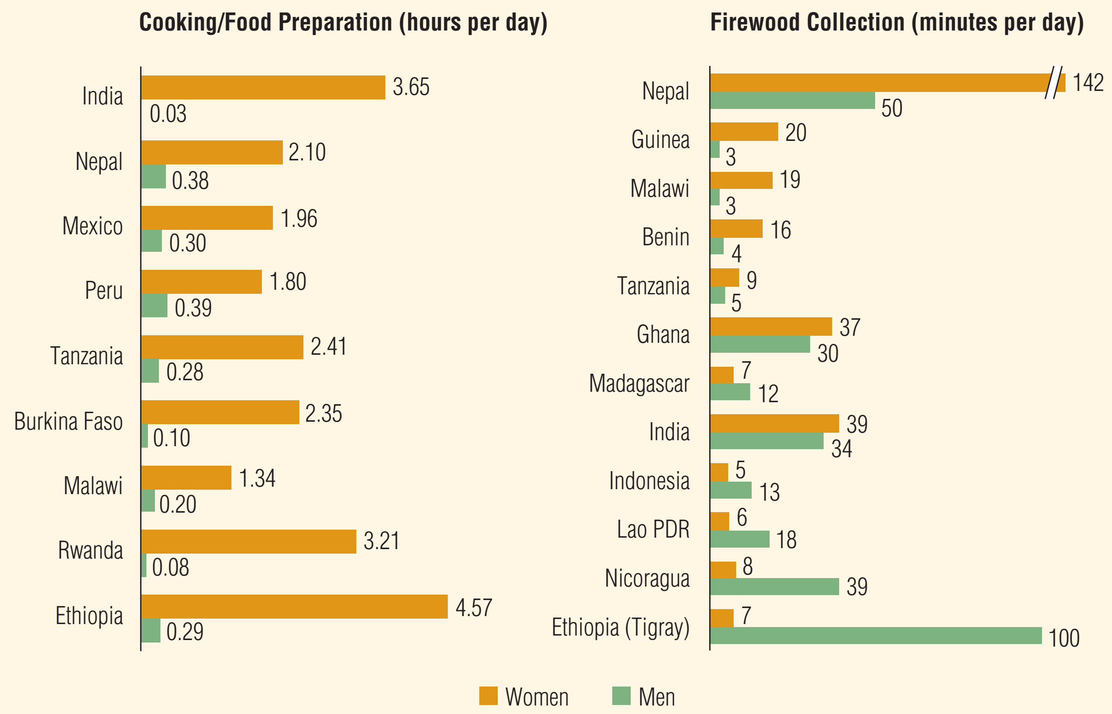
Despite the growing evidence base, local health workers often downplay or fail to incorporate these dangers of firewood collection and HAP in their interactions with women across the developing world,[128] an important issue for future focus by public health practitioners and policymakers.

Gender, time-poverty, and related economic impacts. Aside from the negative health effects, women's involvement in firewood collection and cooking leads to significant time loss and resulting opportunity costs. Household time-use surveys show that women on average spend more time on firewood collection then men, though the gender differential varies across countries due to cultural and historic factors (e.g., cultural norms with respect to hard physical labor, the acceptability of women's work outside of the home in conservative Muslim societies). Women are the primary wood collectors across most of Sub-Saharan Africa and large parts of Asia, for instance in China. In cases such as Madagascar and the Tigray region of Ethiopia in Africa, countries like Indonesia and Lao PDR in Asia, and much of Central America (e.g., Nicaragua, Guatemala, Honduras), men are the main wood collectors.[129] In a number of other countries, like India, fuel collection tasks are a joint family responsibility, with parity between time expanded on such tasks by men and women.[130] In the case of cooking time, however, the disproportionate burden on women is clear across all countries where data is available (Figure 2.9).

The aggregate time loss across fuel collection, traditional biomass cookstove cooking, and related fuel preparation and food processing activities translates into 2–8 hours of effort per day, with a likely average of close to 5 hours daily.[131] This time burden is a major contributor to women's already highly constrained time budgets, or "time poverty" as the phenomenon has been termed by researchers.[132] Aside from the drudgery involved, the time drain of solid fuel cooking restricts women's access to income-generating activities, prevents women from engaging more fully in farming, and reduces time available for childcare, education, leisure, and rest.[133] By reducing opportunities for women's self-actualization and economic autonomy, the time impact of solid fuel cooking also reinforces existing inequitable gender power relationships within the family unit and broader society.

Gender-based violence. Women and girls are exposed to the risks of rape and sexual harassment during the course of firewood collection. The risks are particularly high for refugee women and female

FIGURE 2.9:
Firewood Collection and Cooking Time, by Gender



Sources: World Bank/IEG, 2006; Blackden & Wodon, 2006; Cecelski, 2000; FAO, 2011; Lawson, 2007; Tanzania TUS, 2006; Huba & Paul, 2007; Kiros, 2011; Mexico TUS, 1996; Herrera, 2011; Task Team analysis.

children, who are more vulnerable to sexual violence because of their low status in host communities, inability to purchase fuels, and the resulting daily need to leave their camps (often during predawn hours) in search of wood.[134] In Africa, anecdotal reports of sexual attacks on women linked to firewood collection are omnipresent in refugee camps from Kenya, Northern Uganda, Darfur, Ethiopia, Rwanda, Democratic Republic of Congo, Chad, Liberia, and Tanzania.[135] The incidence of reported rapes in some of these camps is over 50 times that of the host country baseline.[136] Reports of sexual violence during firewood collection have also been noted in South Asia, but are less well studied. The violence need not necessarily be sexual in nature. Household surveys suggest that conflict with private farm or woodlot owners and resulting physical injuries are far more common and affect both refugee populations and local firewood collectors in high scarcity areas.[137]

Though not exclusive to women and girls, there are a number of additional social impacts from solid fuel cooking that often have strong gender dimensions, but tend to be poorly documented.

One commonly noted linkage is the negative relationship between children's natural resource collection and education, though the evidence from this proposition is limited beyond a handful of studies in Africa. A Kenyan study found strong negative associations between the time girls spent on resource collection and the likelihood of school attendance.[138] A similar negative correlation between firewood collection and school attendance has been noted in Malawi and Ethiopia, but in those instances the fuel collection burden and its negative effects fell equally on both genders or primarily disadvantaged boys.[139]

While not fully documented empirically, impaired nutrition is another possible consequence of solid fuel cooking. The effect can stem from the diversion of scarce household resources to purchase fuels or, alternatively, from incomplete food preparation by households when fuel becomes too expensive so that meals are skipped or served cold.[140] This issue is also not strictly linked to gender, but the burden of supplying the family with nutritious meals typically falls on women. The literature also concludes that women and female children are typically the last in the priority queue for the consumption of scarce food resources when families face nutritional shortfalls.

Another important effect is the aesthetic disutility for women of kitchens, dishware, and home environments damaged by solid fuel smoke and soot. The benefits of a clean and "modern" home environment are consistently among the top four or five factors in user satisfaction surveys on perceived clean and improved cookstove benefits across widely varying improved cooking technologies and geographies, including India, Mexico, Pakistan, Tanzania, and Uganda, though this factor is typically of secondary importance relative to household savings, time savings, observable health discomforts (e.g., eye irritation), and convenience.[141]

B. MITIGATION POTENTIAL OF IMPROVED AND CLEAN STOVES

Clean and improved cooking solutions can significantly prevent much of the harm currently created by traditional biomass dependence. The kaleidoscopic complexity of the sector can obscure the fact that a great deal is already known about which of the new cooking solutions hold the greatest potential for impact. There is a strong theoretical case and growing real-world evidence for the benefits of modern fuels, renewable solutions, and—depending on intervention objectives—a range of ICS technologies, with particular promise in the latter case for the new wave of advanced biomass gasifier stoves. Equally important, there is now improved understanding of factors that impede cooking solutions from maximum performance.

Defining and Measuring Impact: Challenges and Lessons to Date

The ability to assess cookstove performance and impact has increased greatly in recent years. Cooking sector stakeholders are in the process of developing ISO standards. The ISO standards will build on the 2012 ISO IWA, which clearly defined performance tiers based on the fuel use of each cooking solution (via thermal efficiency and specific consumption), total and indoor emissions (PM2.5 and CO), and safety. There is increasing sophistication in performance-measurement techniques, such

as stove use monitors and portable exposure monitoring devices; growing reliance on randomized controlled trials (RCTs); and increased investment in data collection and impact research, with dozens of impact evaluations published in the past few years.

As the evidence based on impact continues to grow, the clean cooking sector will have to continue to focus on filling in key data gaps and gaining consensus around methodological frameworks.[142] For example, the sector still needs to harmonize definitions of impact, testing procedures, and reach consensus on effectiveness claims (i.e., whether the technology in question generates impacts) and measures of end-use effectiveness and efficiency (i.e., how well is the specific technology adopted and used by households).

There are also gaps in the knowledge of real-world cooking solution performance and open questions on the precise relationship between emissions, health outcomes, and environmental impacts

The Global Alliance is currently working to standardize some of these methodologies and further build the evidence base by commissioning research, as well as developing frameworks for measuring and defining impacts, including a recently launched initiative to define indicators and methodologies for measuring social impacts.

The theoretical range of performance and relative strengths of the different cooking technologies are already clear.[143] A recently collated sector-wide cookstove performance database with over 3,500 test samples funded by the Global Alliance[144] and earlier performance testing reports,[145] present a fairly comprehensive picture of the theoretical performance potential of most clean and improved cooking technologies under laboratory and controlled field conditions. The data still have gaps with respect to specific cookstove models (e.g., little data on TEG biomass fan gasifiers, TChar stoves, and advanced carbon monoxide-minimizing charcoal stoves) and is subject to inconsistencies stemming from historically poor standardization of common testing protocols such as the water boiling test, the controlled cooking test, and the kitchen performance test.

A certain amount of confusion arises when considering the differences between combustion efficiency, heat transfer efficiency, and thermal efficiency. Combustion efficiency reflects how much of the energy and carbon in the fuel is converted to heat and CO_2 while heat transfer efficiency reflects how much of the heat is absorbed by the pot. The overall thermal efficiency is the product of the first two and shows how much energy in the fuel is absorbed by the pot. Drawing such distinctions is critical in assessing performance and is an important part of drawing up new standards.

Despite these challenges, the testing results clearly show that modern and renewable fuels along with gasifier stoves have the greatest potential for achieving health and environmental benefits. Health benefits appear to be fairly limited from many basic ICSs and, in the case of certain intermediate rocket ICS solutions, poorly designed stoves can actually have adverse health effects when they boost black carbon emissions or hard to track release of little studied small size particles.[146] Renewable solutions such as biogas digesters and solar cookers and—among ICSs—rocket cookstove technologies, and advanced biomass gasifiers, show the greatest potential for household fuel savings.

Data on the performance of improved stoves and clean fuels in real household conditions are less robust, though current evidence suggests that stove field performance approaches laboratory results. A major complication in translating stove performance data into real-world impacts is the gap between stove performance under controlled conditions and actual performance during day-to-day household use. The myriad factors affecting field performance include the skill of the person tending the fire, the size of meal and type of food being cooked, the size and shape of the pot, the use of a pot skirt, heat intensity, cooking duration, and the type and moisture level of the fuel.[147] For HAP exposures, outcomes are affected by additional variables such as the location and quality of airflow within the cooking space, the proximity of the cook and other household members to the fire, and characteristics of the specific fuel.[148]

However, recent trials have shown that the fuel-saving performance of improved stoves in the field is often only moderately lower than the results obtained in the laboratory. Rocket stove testing has shown a reduction from average savings of 50% under laboratory conditions to 40% in the field,[149] and *plancha*-style stoves have better fuel savings in field tests than in laboratory conditions.[150] The fuel consumption performance of popular clay or cement-lined metal "ceramic jiko" stoves appears to be closely comparable across field and laboratory results,[151] and early data from gasifier evaluations suggest that field performance is likely close to theoretical benefits obtained in the lab.[12]

Emissions performance, in contrast, can be significantly degraded in the field compared to laboratory results. This variation in performance has been particularly wide when evaluating portable rocket stoves as shown in Figure 2.10. However, emissions from basic efficient stoves and built-in chimney rocket cookstoves are more comparable between field and lab data. Modern-fuel and new biofuel cooking solutions tend to produce the most consistent results across variable cooking conditions.[153]

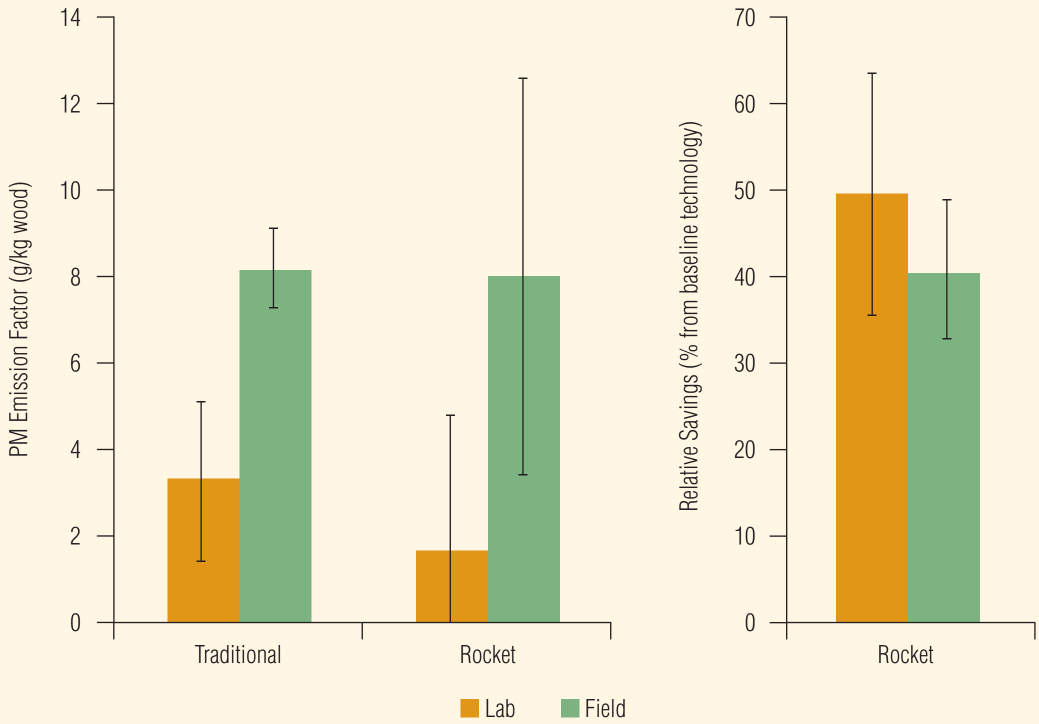
Beyond gaps between theoretical and real world stove-level performance, a bigger challenge is linking cookstove performance to household-level impacts. Ex-post household impact surveys or "before and after" impact assessments have now been conducted for most types of cooking solutions, though, in many cases, the analyses have not been independently validated, pre-intervention baselines are weak, results in many studies depend on self-reported end-user data, and information on new technologies such as advanced biomass stoves is sparse.[154] Randomized controlled trials—the most definitive sources of impact evidence—have only recently been applied to the sector and the very few that have been completed to date have focused on minimally or moderately improved cookstoves.[155]

Impact by Cookstove Technology

Measurable positive economic, health, and environment impacts, while potentially very significant, can vary greatly across cooking technologies.

"Legacy" chimney improved stoves. The advantages of these stoves are that they are designed to be consistent with local cooking practices and are very inexpensive. On average, though, they generate limited fuel savings compared to three-stone stoves, modest (if any) improvements in HAP, and a negligible decrease (sometimes, an increase) in cooking time.[156]

FIGURE 2.10:
Field vs. Lab Performance of Rocket Stoves



Source: Berkeley Air Monitoring, 2012.

The emerging evidence—most notably from a widely circulated and often misinterpreted India chimney *chulha* RCT conducted by the Abdul Lateef Jamil Poverty Action Lab—confirms that minimally improved chimney cookstove solutions of the type traditionally promoted by NGOs and many national cookstove programs often bring few benefits to consumers across most impact dimensions; this is due to both the inherent limitations of the technology and poor or declining consumer use over time.[157] Similar results were obtained in a recent Ghana chimney cookstove RCT.[158]

Additionally, these stoves are generally not durable and depend on ongoing maintenance (e.g., application of new mud layer annually, chimney repairs) that households are often unable or unwilling to provide, leading to performance issues.[159] Our interviews with sector stakeholders suggest that the majority of legacy stoves do not qualify for improved status at all under new ISO performance tiers because of their low thermal efficiency and high particulate emissions.

Basic ICS. Basic efficient charcoal and wood stoves (e.g., KCJ type technologies) live up to their theoretical fuel savings potential (25–35%) under real world conditions, modestly reduce fuel collection times (25–30%), and create moderate environmental benefits via greenhouse gas and woodfuel consumption reductions.[160] The resulting household savings are significant relative to the minimal upfront cookstove costs, but the value proposition beyond economic impacts is limited. Basic efficient stoves have only moderate environmental benefits (deriving from reduced biomass consumption) and few meaningful positive health effects for severe respiratory conditions. Because of their largely artisanal production and the absence of quality standards, the quality of many basic efficient stoves is low, with average thermal efficiency levels in the field significantly below that of the technology's potential.[161] Durability of such stoves is typically a challenge, with average cookstove life ranging from a few months for low-quality products to two to three years for quality-controlled, semi-industrially produced basic efficient stoves.

Intermediate ICS solutions. Built-in or semi-fixed chimney rocket stoves, for instance, can bring significant fuel savings (45–65% in the case of the Patsari and Onil stoves in Latin America, MIRT cookstove in Ethiopia, and the Rocket Lorena cookstove in Uganda) and moderate but measurable health benefits (e.g., 25–30% reduction in severe respiratory illnesses due to a 50–60% reduction in indoor emissions).[162] Such stoves likely have more limited environmental impacts as the rocket cookstove technology does not reduce, and may in some cases increase, net black carbon emissions. Built-in rocket stoves are typically designed in accordance with local cooking practices. Ethiopia's MIRT Stove and Eritrea's Adhanet Mogogo have special surfaces or attachments for baking the staple *injera* flatbread. Such stoves can produce very significant fuel savings (45–70%) via improved combustion and can significantly reduce indoor emissions (with strong emission reduction requiring a chimney). Many stoves of this type are very durable, with some brick and metal models lasting as long as a decade. However, there are drawbacks: depending on materials and location, these stoves can be expensive; cookstove construction can be a significant home improvement project, requiring large investments of household labor and time; performance is highly dependent on the skills of the mason (e.g., cookstove and chimney placement relative to airflow); and most stoves require ongoing maintenance to ensure high quality performance over time.

Portable rocket stoves, including high-end manufactured wood rocket solutions represented in the market by stoves from companies like Envirofit, EcoZoom, Ezy Stove, Grameen Greenway, and Burn Manufacturing, generate significant (though lower) fuel savings, have more indoor emissions than chimney rocket stoves, and have variable black carbon emission performance. While these portable stoves can cut fuel consumption, PM, and carbon monoxide by one-half, their reduction of black carbon is much more limited and some designs can actually release more black carbon then traditional open cooking fires.[163] Moreover, some rocket stoves have low heat-transfer efficiency and inadequate insulation. While some artisanal and semi-industrial variants of rocket stoves can be inexpensive ($ 10–20), the unsubsidized end-user price of industrially manufactured rocket stoves is often high on the ground, ranging from $ 16–20 for domestically manufactured mass produced models to $ 80 for the Save80 cookstove with an integrated pot.

Advanced biomass stoves (ACS). Field evidence for the impact of ACS solutions is encouraging, but cannot be called definitive without further investment in field evaluations and RCTs to measure health, economic, and environmental impacts. An evaluation from Costa Rica, for example, has shown that biomass gasifiers can generate large end-user reported fuel savings (>40%) while significantly reducing emissions. Recent field research from India suggests, however, that emission impacts can vary widely based on the gasifier technology used, with a particularly wide range of performance for natural draft stoves.[164] Most natural draft stoves have the added benefit of producing bio-char as a byproduct, which can be used for fertilizer or for charcoal cooking as part of combined gasifier/charcoal stove (TChar) cooking systems. Other benefits include a more controllable flame to improve the cooking experience, faster cooking times, and cleaner cookware.

As a downside, some (but not all) gasifier stoves require preprocessed fuels, which can add to end-user inconvenience and raise barriers to behavioral change. Although the prices of industrially produced natural draft stoves can be fairly high ($ 25–50), artisanal and semi-industrially produced stoves in this class such as the Greentech rockifier cookstove in Gambia and the Awamu TLUD "Mwoto" cookstove in Uganda are available at the $ 15–20 price range. Fan gasifiers can reduce fuel consumption by over 50% compared to the open fire and also cut emissions by up to 95%, bringing modern fuel performance levels to biomass fuel users. However, fan stoves are relatively expensive ($ 32–120 end-user price) because they have internal fans and electronic components and are made of advanced, lightweight materials.

LPG stoves. Surprisingly few impact evaluations have focused on consumers' use of LPG stoves. Field research also suggests that, while theoretical benefits can be significant (i.e., elimination of most negative health effects of solid fuel cooking), actual impacts are likely to fall far below this potential because of the persistence of baseline cookstove technologies alongside LPG cookstove use.[165] It is important to consider this fuel stacking as impacts are evaluated.

LPG is a clean, non-toxic fuel that emits little particulate matter and burns efficiently.[166] Compared to kerosene, it delivers double the heat for the same quantity used. Additionally, LPG stoves are typically easy to cook with. LPG is, however, a fossil fuel, with moderate release of CO_2 during the cooking process and potentially significant greenhouse gas emissions during fossil fuel production and LPG shipping stages. Moreover, in the absence of a significant subsidy, LPG is more expensive for BoP customers to acquire and use. There are also a fuel supply-chain challenges including supply constraints, periodic shortages, and difficulty serving "last-mile" rural customers. Another concern is the risks of cylinder explosions in the case when LPG distribution is not carefully regulated; accidents are rare, but perception of LPG's danger among consumers is strong in some geographies.

Kerosene stoves. While often categorized as "clean," a large but unknown share of kerosene stoves likely do not qualify as a clean technology in light of the growing evidence on the harmful emissions from kerosene cooking under field conditions. Well documented kerosene hazards include poisonings, fires, and explosions. An increasing evidence base of studies now also suggests that kerosene used for cooking or lighting may impair lung function and increase tuberculosis, asthma, and cancer risks.

However, there are few studies in most regions, quality is varied, and results are inconsistent.[167] Aside from the need for improved evidence, the current state of knowledge already suggests the need to make existing kerosene solutions safer through policy advocacy, standards, and improved design. There is also room for improved fuel efficiency for kerosene cookstove users. While kerosene cooking is inherently more fuel efficient then traditional biomass stoves (30–40% thermal efficiency for kerosene pressure stoves), fuel efficiency levels above 60% are possible, allowing end users to save as much as one-third of their fuel usage. The market for kerosene cooking is not large compared to other cooking fuels (5% of all developing market households), but still substantial in several countries. Companies like Servals Automation from India and Arivi in South Africa have had some success deploying innovative new kerosene stove designs that under field conditions generate significant fuel savings (~30%), reduce the potential for spills and burns, lower carbon monoxide levels, and come near to eliminating particulate matter emissions.[168]

Electric and induction stoves. The potential impacts of the transition to electric cooking have been little studied. The technology has drawn little attention due to the assumption that the use of electric stoves is limited to areas that have access to electricity, which typically excludes rural communities. Furthermore, the high cost of electricity has historically restricted the technology to only the wealthiest urban consumers in the developing world. In reality, this sector warrants more attention for those who focus on clean cooking access in urban environments. Electric cookstoves are the primary fuel for only 5% of urban households across the developing world but are a major cooking technology in select urban markets.[169] Even in those markets where electric cooking penetration is limited, there is evidence of growing uptake of electric and, in particular, electric induction cooking. In India, electromagnetic induction cooking is regionally becoming an important cooking technology with large scale uptake over the past decade in states like Kerala; there is also anecdotal evidence of rapid induction stove sector growth in China.[170]

The primary reason for the growing popularity of this technology is high fuel efficiency and convenience. Electric cooking can lead to fuel savings relative to baseline technologies in those markets where there is reasonable access to moderately priced electricity. Induction stoves, in particular, can reach fuel efficiency levels of 90% in comparison to 60–70% for LPG and electric hot plates, 40% for intermediate ICS, 20% for basic improved stoves, and typically <10% for traditional stoves.[171] At the same time, electric stoves are prohibitively expensive for poor households, ranging $ 15–80 for electric hot plates to $ 25–100 for induction stoves. From a health perspective, the impact of adopting such technologies is likely to be significant. Electric and induction stoves are smokeless at the point of use and do not produce any emissions within a household. From a climate change perspective, however, the benefits of the technology are dependent on the fuel use for electricity generation—in countries with heavily coal-based electricity generation, electric cooking can have negative impacts on the climate. Despite this promise, the overall potential for this solution is still quite limited based on the low rates of electricity access by most traditional stove and fuel users.

Biogas stoves. There is more field evidence for the extensive benefits of biogas digesters, including 60–80% savings in fuel expenditures and firewood collection times,[172] although these savings in

reality need to be adjusted for the annual maintenance costs of biogas solutions and the increased time demands of dung collection. When used on burner-style stoves, biogas produces no smoke or particular matter. Biogas plants are suitable for rural environments and can be used to power single-family homes or entire communities, with the former requiring only the waste of one to two cows or four humans per day.[173] Biogas users benefit from improved indoor air quality, organic fertilizer from the digester residue, and reduced deforestation. Evaluations show notable reductions in HAP exposures and end-user reports of improved health outcomes, though impacts on lung function are not conclusive.[174] However, expensive startup materials, technical construction expertise, and a readily available supply of organic waste often act as barriers to adoption. Moreover, the accidental release of undigested waste from poorly designed plants can threaten local food and water supply and contribute to global warming. A household biogas digester system can cost as much as $ 1,500, although prices are beginning to decrease with low cost portable ($ 350–750) prefabricated units from innovative companies like SimGas in Tanzania and Sintex Industries in India. Similarly, while biogas stoves typically range from $ 50–100, Shenzhen Puxin Technology Company Ltd. (China) produces a biogas cookstove for $ 25 and other similarly low-cost alternatives are available for mass scale deployment.

Biofuels. Field data for biofuels such as ethanol are limited. Evaluations of Project Gaia pilots suggest that ethanol stoves can generate significant emission reductions when operated exclusively. Unlike the laboratory results showing LPG-like levels of emissions from ethanol stoves, data from a Madagascar pilot suggest that field performance has slightly exceeded the WHO PM2.5 emission minimum.[175] Uptake of biofuel stoves relative to baseline technologies under non-pilot conditions is unclear at this point, so the net effects on fuel savings, time savings, and health, while theoretically large, must await verification from the field based on the evaluations of initiatives such as the NDZiLO enterprise in Mozambique, formerly named CleanStar Novozymes.

The stoves are durable and accessible as the flame can be turned on and off with ease. However, ethanol production is dependent upon climate and harvest conditions and patterns. Additionally, some current cookstove designs were made for developed world contexts, and so may not be optimized for local user cooking needs. They are also expensive, and, in some cases, require significant subsidies linked to expected carbon or fuel revenues. Moreover, ethanol has caused a significant number of burns through spills. One solution to bypass this is to convert ethanol into gelfuel, which has a higher viscosity, and so is both safer and easier to use, but has seen limited success to date. Another approach, employed in Dometic AB's CleanCook, a design used by multiple ethanol cookstove enterprises, is the use of fuel canisters that absorb the liquid and so do not spill, thereby significantly mitigating burn risks.

Solar. The data on the impact of solar cookers as standalone cooking solutions are mixed. Before-and-after program evaluations have suggested savings of 25–40% in charcoal expenditure and firewood collection time, on the basis of solar cooker use in Bolivia, Ethiopia, and Kenya. Some evaluations have also shown strong cookstove use over time, with over 90% of solar cookers in Bolivia still being in use 3–5 years after distribution.[176] Basic low-cost solar cookers in Africa have fared less well. A recent mini-RCT of the CooKit solar stove in Ghana has demonstrated ongoing use by less

than one-fifth of treatment households after six months and showed that over 80% of households using solar cookers continuing to use woodfuel stoves in parallel. As a result, this RCT reported no statistically significant reductions in fuel consumption, firewood collection, or health symptoms stemming from HAP exposure.

Because solar cooking depends on sunlight, it is ineffective on cloudy, windy, or rainy days and at night. It also is not appropriate for all cooking tasks: baking flatbreads, for example. For these reasons, solar is most effective as part of an integrated cooking strategy, in which a solar stove is complemented by a retained-heat cooker and a fuel-efficient biomass cookstove. Solar Cookers International's CooKit is a panel cooker that costs $ 25 assembled, or can be built from local materials costing $ 3–7.[177] Composed of cardboard and foil, it directs sunlight onto a cooking pot, which is surrounded by a heat-resistant bag. However, the pot may not be large enough to feed a large family. Parabolic stoves include the Devos Cooker, a safety-focused design that protects the cook from burns and the sun's bright rays.[178]

Retained-heat cookers. Retained-heat cookers, like South Africa's Wonderbag, are insulated containers that fit around a pot. Once the food has been heated on a cookstove to its required cooking temperature, the pot is inserted snugly into the insulated cooker, where it continues to cook until ready. Since the food only needs to be heated on a cookstove to its cooking or boiling point, retained-heat cookers can help conserve fuel and reduce household emissions. Moreover, they can keep the food warm for several hours after cooking is complete. Yet the use of a retained-heat cooker significantly increases the overall food preparation time, and so requires additional advanced planning by the cook.

Household Behaviors

Impact evaluations show that theoretical cookstove benefits become irrelevant if households refuse to use new stoves, discontinue their use over time, or fail to replace the new technology when it fails. Abandonment of improved cooking solutions has been most notable in the case of minimally improved mud and chimney technologies; this is due to quality challenges or poor fit of cookstove designs with household needs. For instance, it is estimated that a significant proportion of improved *chulha* stoves distributed under the earlier incarnation of the India national cookstove program in the 1980s and 1990s are no longer in use and improved *chulha* NGO interventions have suffered a similar fate.[179] The same phenomenon has been seen with Africa mud stoves[180] and is clearly demonstrated in a recent RCT of an NGO-distributed chimney cookstove in Ghana.[181]

The challenge is not limited to legacy stoves, but can also affect renewable fuel and high-end biomass ICS solutions. A significant proportion of early generation biogas digesters distributed in biogas programs in Asia and Africa are no longer being used by households because of maintenance challenges.[182] RCT findings on the ongoing household utilization of basic solar cookers have shown high rates of cookstove abandonment and disuse.[183] Stove abandonment may also be linked to fluctuating fuel prices. Anecdotal reports suggest, for example, that 90% of fan gasifier stoves distributed in the past few years by one manufacturer in India are no longer being used by households

because of a significant run up in the costs of the fuel feedstock and other end-user acceptability issues.[184] A similar fate has been reported for ethanol fuel stoves in certain countries in Africa[185] and fuel price spikes are also responsible for reduced LPG and kerosene use in countries such as Ghana, Nigeria, Senegal, and Tanzania.

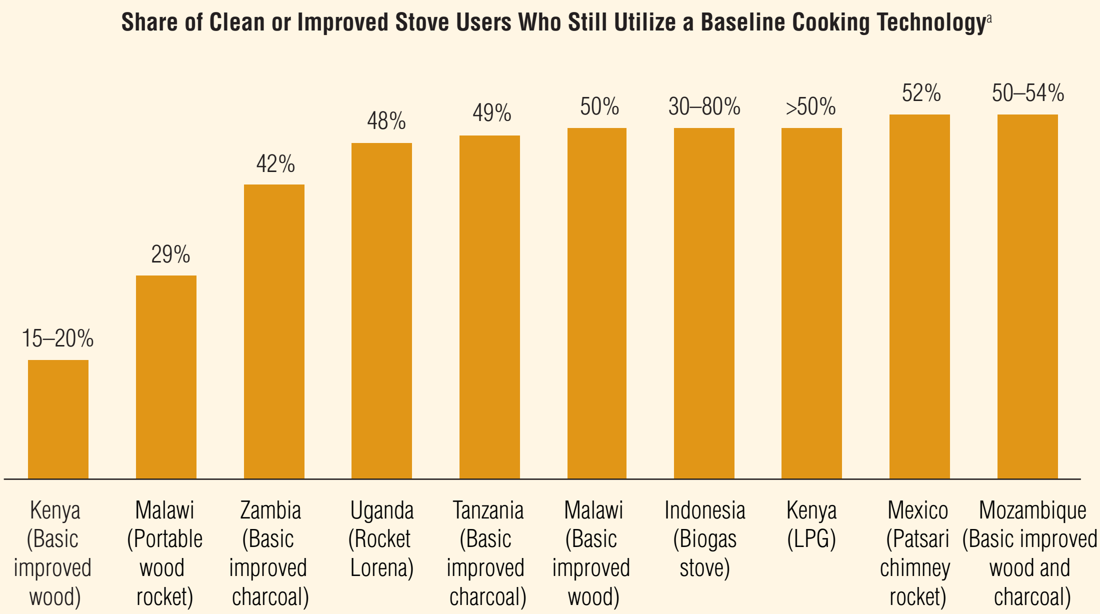
Despite these challenges, in the aggregate, there is incontrovertible evidence of the long-term household adoption and use of many types of improved cooking solutions. Longitudinal data on the use of high-end rocket stoves and gasifiers is at this stage unavailable. Evaluation data for basic efficient wood stoves and intermediate ICS solutions suggests, however, that in most instances ongoing use of improved stoves is high.[186] Ongoing use and sustainability is particularly strong for basic efficient clay-lined metal cookstove technologies (e.g., the Kenya Ceramic *Jiko*), which face a range of quality challenges, but are on their way to being the baseline cooking technology for urban charcoal users in African countries such as Ghana, Kenya, Madagascar, Malawi, Mali, Rwanda, Senegal, Tanzania, Togo, and Uganda. Such stoves are also highly popular for biomass cooking in Asia, including large end-user populations in Lao PDR, Cambodia, Myanmar, and rural Thailand. Global household fuel surveys likewise demonstrate that modern fuel solutions, once taken up, tend to see continued use over the years in the absence of fuel price shocks.

Impact evaluations demonstrate that the biggest disconnect between cookstove performance and impact is the issue of baseline technology persistence or, simply put, the continued use of less efficient cooking solutions by households that adopt clean and improved stoves. The phenomenon, which mirrors and is often related to household "stacking" of multiple fuels for their cooking needs,[187] is reported in nearly all impact assessments (Figure 2.11). Anecdotally, the use of traditional cookstoves in some of the interventions shown in Figure 2.1 has declined over time as users become more accustomed to new technologies. In many cases, the old unimproved technology may be used only very occasionally. The fact remains, however, that baseline technology persistence is the rule rather than the exception for nearly all improved and clean cookstove interventions. Unsurprisingly, the ongoing use of traditional technologies alongside improved stoves can significantly degrade the overall impact of new cooking solutions. This is particularly true with respect to health effects, given the very high sensitivity of health impact to daily emission concentrations and the steep concave shape of the emissions-dose response curve.[188]

Persistence of baseline technologies means that the distribution of improved or clean stoves will often be insufficient to guarantee impact without investment in behavior change. Household rationales for the continued use of traditional technologies include the availability of fuels (in the case of modern fuel stoves), the need for multiple cookstoves and burners to provide meals for a large household,[189] the better fit of certain cookstoves with pot sizes or required heating power levels, the perceived positive impact of smoke on flavor for certain dishes, and the poor quality or performance of some of the improved cookstoves.

Depending on the source of the issue, solutions may range from selling multi-burner stoves or multiple stove unit packages to displace existing technologies, cookstove trade-in programs to remove older cooking technologies from the household when new stoves are introduced, customer education and

FIGURE 2.11:
Illustrative Examples of Baseline Cooking Technology Persistence



Sources: Kenya, Malawi, Zambia, Mozambique, Tanzania – ProBEC M&E reports; Schutze 2010; Indonesia: SNV Indonesia Biogas Users Survey; Kenya LPG: Malla et al., 2009; Mexico: Ruiz-Mercado, 2010; Uganda: Malinski, 2006; Task Team analysis.

a Frequency of baseline technology vs. improved technology or share of cooking (e.g., % of dishes) unknown.

training to explain the downsides of multi-stove use, and—best of all—improvements in cookstove design and fuel supply chain efficiency to make the improved cookstove more "competitive" in the kitchen.

Even under the most positive behavior-change scenarios, however, traditional cookstove persistence may be inevitable as households balance across multiple fuels and optimize across cooking solution convenience, cost, and risks. Our analysis suggests that the best that can be hoped for in the near term is that the use of traditional cooking solutions will be minimized by a combination of improved cookstove design and intensive consumer education, which will lead households to adopt and use a range of maximally efficient solutions for each type of fuel they can access.

The area with the least impact evidence to date is the systemic effects of the adoption of clean and improved cooking solutions. Aside from educated guesses based on aggregated average household impact, we know little about the actual effects of improved stoves on directly measured macro-variables such as biomass scarcity, forest degradation, public health, and aggregated poverty and employment impacts. In part, this is a function of the relatively low market penetration of clean and improved cooking solutions in many countries, which makes it difficult to assess improved

cookstove impacts at the national or subnational levels. It is also difficult to measure some of the important impact variables; aggregate climate impacts, for example, cannot be directly observed. In many other cases, though, analyses have simply not been conducted because the available data are insufficient.

Second order systemic impacts, such as the effects of widespread clean cooking adoption on biomass fuel prices, are even less clear. Theoretically, reduced biomass prices and collection times resulting from improved cookstove use could simply stimulate biomass fuel demand by other households, leaving the net levels of solid fuel consumption unchanged. However, without more robust data and larger sample sizes, any negative net impact of clean cookstoves on biomass consumption and emissions cannot be substantiated.

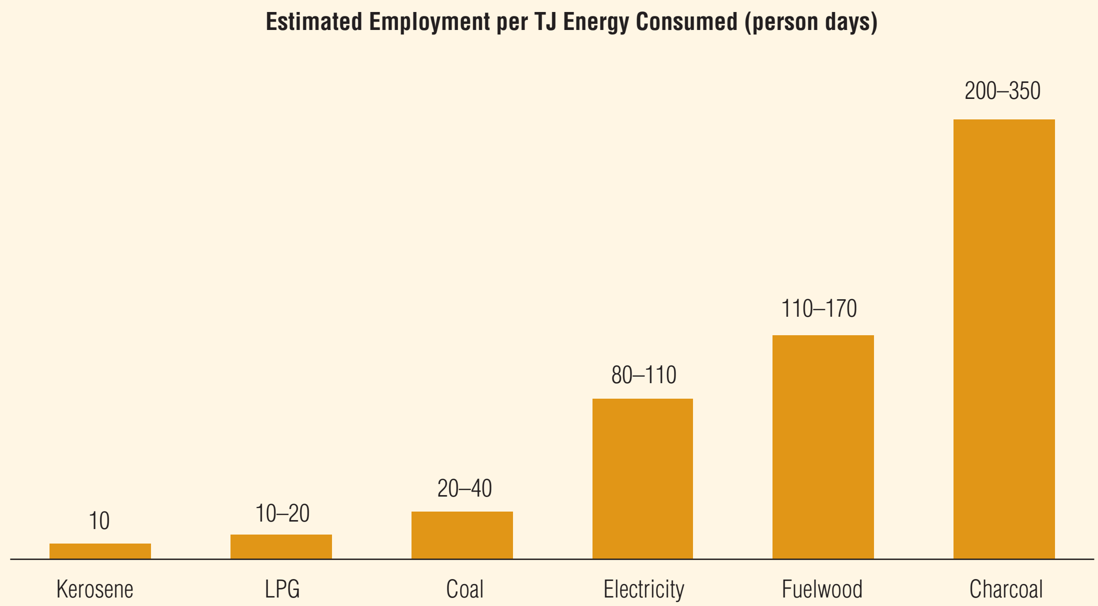
Evidence of Impact for Key Impact Dimensions

Observed impacts vary widely by impact driver. Firewood expenditures and time poverty are the harmful effects most easily addressed by improved solutions, with relatively strong evidence of impact from the field. The livelihood impact of transitioning to clean and improved stoves is likely to be net positive in terms of the number and quality of jobs created, but precise impact will vary by geography and should be managed carefully to ensure sensitivity to potential near-term job displacements in woodfuel value chains. Environmental impacts are more difficult to achieve than economic benefits and are highly variable based on the specific features of the improved or clean cookstove. Positive health impacts are the most difficult benefit to achieve and can only be realized in those cases where the cleanest cooking solutions can displace traditional cooking technologies from day-to-day household use.

Fuel and time savings are the most easily realizable impacts and are the benefits that are most accessible for poor consumers from a cost-benefit standpoint. From a household economics and time-poverty perspective, cooking-fuel expenditures and fuel-collection times can in theory be eliminated entirely via renewable solutions such as biogas and solar or significantly reduced by the most thermally efficient ICS. Impact evaluations suggest that savings on firewood expenditure (or comparable reductions in firewood collection time) of 60–80% are feasible under real-world conditions based on technologies such as biogas digesters and built-in, multi-pot chimney rocket stoves that have a high thermal efficiency and are also the most likely to minimize baseline technology use.[190] Modern fuels such as LPG, renewables such as biofuel and biogas, and select advanced and intermediate ICSs can also generate incremental household time savings by as much as halving total cooking time.

In purely economic terms, the best-performing ICS solutions and biogas digesters have the potential to generate the greatest long-term financial savings for households because modern fuel solutions, such as LPG, electricity, and kerosene, and renewable ethanol stoves all involve ongoing expenditures on relatively expensive fuels. Large economic savings can be generated by relatively cheap ($ 5–20) artisanal ICS. In fact, potential fuel savings from built-in chimney rocket (45–65%) and portable wood rocket (40–50%) stoves can often match or exceed fuel savings from expensive high-end industrial rocket stoves (45–55%) and advanced biomass gasifiers (35–50%).

FIGURE 2.12:
Employment Potential, by Fuel Type



Source: Goldemberg, 2003 (drawing on FAO data).

Although the net effects on employment and livelihood of adopting ICS and clean fuels are most likely positive, interventions should be carefully managed to address potential job displacement. Generally speaking, woodfuel provides the highest employment multiplier compared to modern cooking fuels, so movement up the fuel energy ladder—switching from woodfuel to kerosene, electricity, or LPG—should be theoretically labor saving over time (Figure 2.12).[191]

Theoretically, the adoption of more efficient stoves should also be labor saving. Holding fuel demand constant, the relatively low labor intensiveness of ICS production relative to employment in woodfuel value chains means that jobs generated by ICS adoption are likely to be limited compared to the number of woodfuel jobs displaced.[192] We estimate, for example, that for every ICS stove producer/retailer job created (in the case of artisanal stoves) over 10 woodfuel value chain jobs are eliminated.[193] The displacement ratio is likely to be significantly higher for industrial ICS manufactured at scale.

In reality, the net near-term employment and livelihood effect of ICS adoption are very unlikely to be labor saving. For instance, in Africa, the pace of projected solid fuel demand growth (see Figure 3.5) over the next two decades suggests that, even in the extreme case of total ICS adoption by all solid fuel using households, the *absolute* level of annual woodfuel consumption volume—and consequently

the woodfuel employment impact—is unlikely to fall much below today's levels in the near-to-medium term.[194] The situation in South Asia is comparable. Adding new employment in the ICS sector (likely in the tens of thousands) to the potential millions of jobs created by freeing up household time from firewood collection[195] means that the net employment impact of improved cookstove adoption is likely to be positive for many years to come.

On the biomass fuel supply side, the net livelihood effects are less clear, but also unlikely be labor saving. Promotion of more efficient biomass fuel production technologies such as efficient charcoal kilns can in theory reduce woodfuel sector employment, but rapidly increasing charcoal demand will likely cushion any potential reductions in the near term. Regulations designed to improve the efficiency and sustainability of woodfuel value chains have uncertain employment impacts as they may either raise or lower woodfuel prices (and resulting end-user demand, production volumes, and sector employment), depending on design and implementation. If well designed, such interventions should, in most cases, maintain current woodfuel price levels without effecting overall levels of market demand or employment. Well executed traditional biomass supply interventions should improve the quality of sector employment by creating better-paid, safer, and more sustainable formal sector jobs.[196] Renewable fuel interventions should also contribute to higher quality job creation with emerging evidence suggesting that the promotion of alternative renewable biomass (i.e., briquette and pellets), biogas, and biofuel markets has significant potential for new job creation.[197]

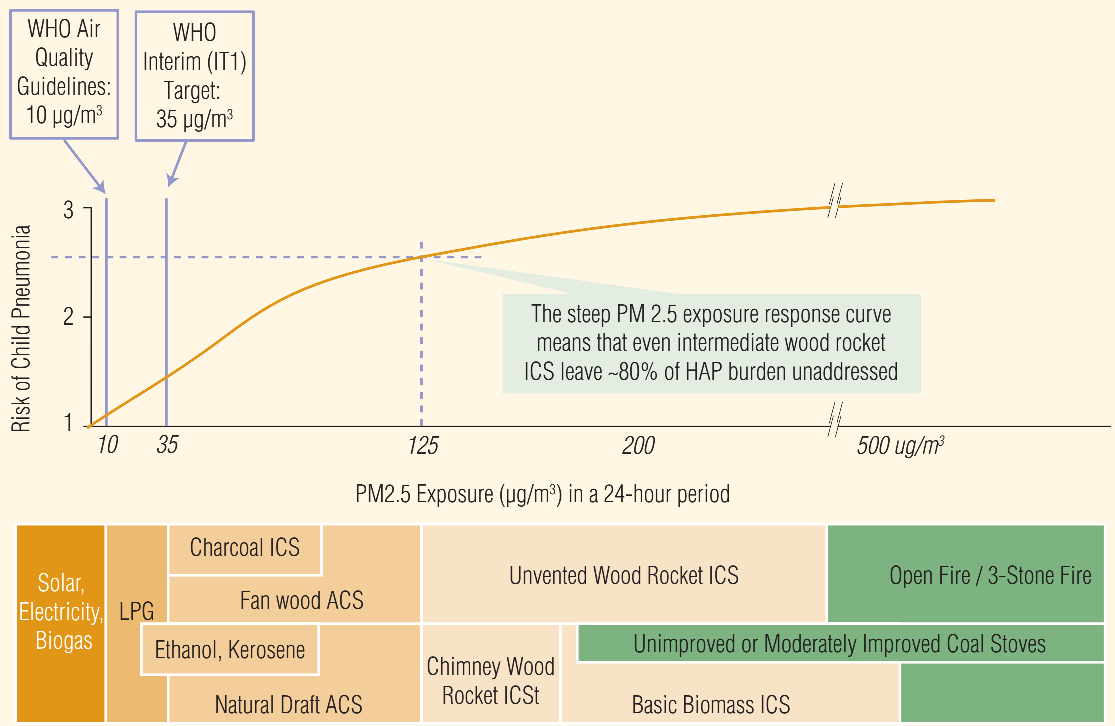
While in most cases the near-term effects of clean and improved cooking solutions are unlikely to displace employment, localized effects may be labor saving. Consequently, interventions should be designed to facilitate the rehabilitation of displaced jobs—by training charcoal producers in briquette/pellet production skills, for example, or transitioning woodfuel retailers to ICS retailing jobs.

Environmental benefits are more difficult to realize. For environmental impact, the "greenest" technologies at the point of fuel consumption are renewable solutions such as solar and biogas, modern fuel stoves, and ethanol stoves, followed by advanced biomass gasifiers. The net climatic impact of modern fuel stoves is complicated by the fact that these solutions rely on potentially unsustainable and carbon-intensive fossil fuel extraction. The environmental benefits of intermediate ICS technologies such as rocket stoves are undermined by their black carbon emissions. Even when they contribute to significant reductions in fuel consumption, many of these cookstove models often do little to reduce and may increase net black carbon emissions.[198] In the case of ICS, all else being equal, the most extensive environmental benefits are possible from those solutions that use sustainable solid fuels such as crop waste briquettes and pellets.

From a health perspective, the cleanest cooking solutions can reduce HAP to levels that approach WHO guidelines, but achieving these benefits under real world conditions is difficult. None of the improved or clean cooking solutions on the market today are likely to eliminate all of the negative health effects of solid fuel cooking under normal use conditions, but adoption of the cleanest stoves and fuels can still save hundreds of thousands of lives. Of the available solutions, the cleanest from a health perspective are renewable technologies such as biogas and solar and modern fuel solutions such as LPG, electricity, and (high quality) kerosene stoves, followed by biofuel solutions

FIGURE 2.13:

Exposure Response Curve for Risk of Child Pneumonia from Particulate Matter



Source: Adapted from Smith et al. (2014); Burnett et al. (2014); Jetter et al. (2012); Grieshop (2011); Task Team analysis.
Note: Comprehensive PM 2.5 µg/m3 data for all stove technologies is not available, so the relative positioning is meant to be directional.

such as ethanol, fan draft gasifier stoves, best-in-class natural draft gasifiers, and, at lower but still measurably improved levels of HAP performance, well-designed chimney rocket stoves.

Improved cooking solutions, assuming full utilization, generate HAP reductions of between 30% for basic efficient wood and charcoal stoves, to up to 60% for rocket stoves, 80–90% for ethanol stoves and natural draft gasifiers, and over 90% for LPG, electricity, high quality kerosene, best in class fan gasifiers, biogas digesters, and solar cookers. Real-world exposure reductions, as is the case for other impacts, are likely to be significantly lower because of the multi-fuel/multi-stove settings for most households.

While the precise links between exposures and health are not yet fully known for intermediate exposure ranges, we do know that the dose-response curve for respiratory conditions such as ALRI and COPD is steeply shaped and concave, meaning that very large exposure reductions (>90%) are needed to achieve significant (>60%) reductions in respiratory illness symptoms.

The Guatemala RESPIRE RCT has shown that intermediate levels of exposure reductions (~60%) lead to moderate observed health benefits (i.e., 25–30% reduction in observed and self-reported respiratory symptoms) and no measurable improvements in actual lung function.[199] Smaller emission reductions obtained by basic efficient (30%) and portable rocket stoves (40–50%), particularly in the case of unvented rocket stoves that increase net black carbon emissions, likely have no or minimal respiratory health benefits.

Although much about potential health impacts is still unknown, the benefits of improved solutions are likely to be greater than what is suggested by emerging ALRI and COPD evidence. We currently have no dose-response data for most HAP-linked health conditions (e.g., low birth weight, heart disease, eye disease), but widespread self-reported improvements in eye irritation and headache symptoms, even with the use of basic ICS models, suggest that the threshold for at least some of the negative health effects of traditional stoves and fuels may be lower than for chronic respiratory conditions. Furthermore, while there is no direct evidence on this point, it is highly probable that basic and intermediate ICS solutions lead to meaningful reductions in firewood collection injuries since such health effects should be directionally proportional to a household's fuel collection time.

ENDNOTES

19 Smith et al., 2011; UNDP and WHO, 2009; IEA, 2011; our global fuel-use database, including coal users, tracks an estimated 3.03 billion solid fuel users for cooking and heating and 2.85 billion solid fuel users for cooking globally.

20 See Chapter 4 for ICS penetration analysis and methodology.

21 For a good overview, see Global Alliance for Clean Cookstoves, World Bank, 2011a.

22 While not directly comparable, a WHO cost benefit analysis using 2004–05 data pointed to a $ 90 billion opportunity cost of solid fuel cooking, assuming the potential to shift 50% of the solid fuel population to LPG (Hutton et al., 2007). See also the CBA analyses in Jeuland and Pattanayak (2012) and Garcia-Frapolli, et al. (2010).

23 Naeher et al., 2007.

24 The most recent WHO HAP mortality estimate (retrieved from: http://www.who.int/phe/health_topics/outdoorair/databases/en/) is a significant upward revision from 3.5–4 million annual deaths estimated in the Global Burden of Disease survey (Lim et al., 2012) and 1.5–2 million deaths estimated in earlier analyses. The proximate causes of these 4.3 million deaths in the latest estimates are stroke (36%), ischaemic heart disease (26%), chronic obstuctive pulmonary disease (22%), pneumonia (12%), and lung cancer (6%).

25 Chafe et al., 2014.

26 Raw GBD data are available at http://www.healthmetricsandevaluation.org/gbd.

27 Dherani et al., 2008; Smith et al., 2004; Ezzati and Kammen, 2002; Smith et al., 2004.

28 Bruce et al., 2000; Kurmi et al., 2010.

29 Lung cancer is of particular importance to the coal-using population, which is small in Sub-Saharan Africa (Mumford, 1987; Smith, 1993).

30 Siddiqui et al., 2005; Pokhrel et al., 2005.

31 For impacts on low birth weights and perinatal mortality, see Misra et al. (2012) and Sreeramareddy et al. (2011).

32 Conditions linked to HAP, but not quantified in current Global Burden of Disease data, include tuberculosis (Sumpter & Chandramohan, 2013); childhood nutritional deficiencies, including anemia and stunted growth (Mishra & Retherford, 2007); blindness (Siddiqui et al., 2005; West et al., 2013); asthma (Schei et al., 2004); maternal depression (Banerjee et al., 2012); cognitive impairment in the young and old (Weuve et al., 2012; Suglia et al., 2008; Perera et al., 2013); upper respiratory, digestive, and cervical cancers (Reid et al., 2012; Bhargava et al., 2004); the exacerbation of the effects of HIV/AIDS (Fullerton et al., 2008); and bacterial meningitis (http://www.nsf.gov/discoveries/disc_summ.jsp?cntn_id=126403&org=NSF&from=news).

33 Eye irritation was a consistent theme in Shell Foundation's 2007 Breathing Space surveys in East Africa. Much of the evidence for solid fuel linked headaches and eye irritation is qualitative, but there is also growing support from peer-reviewed literature from other parts of Africa (Katuwal & Bohara, 2009; Diaz & Pope, 2007; Ellegard, 1997; Matinga, 2010).

34 Lam et al., 2012.

35 Ibid.

36 Wickramsinghe, 2003; Ezzati & Kammen, 2002; Ghana data in Odoi-Agyarko, 2009.

37 See Warwick & Doig (2004) and Ezzati & Kammen (2002).

38 A recent Ghana survey suggests, however, that self-reported morbidity is high, ranging from 20% to 80% for some of these conditions (Odoi-Agyarko, 2009).

39 Derived from consumer segmentation in Section II; >1.4 billion people across the developing world 74 countries, accounting for 98% or solid fuel households with average of 4 people per household.

40 Global Alliance for Clean Cookstoves, 2011.

41 Shell Foundation Breathing Space Surveys, 2007–08.

42 See, for example, insights from cooking consumer research in Tanzania (IDEO, 2012).

43 Total cooking woodfuel consumption is estimated using reported household fuel mix, a standard cooking diet of 320 MJ (see Endnote 224 for details on notional cooking budget assumption), 6 kg of wood per 1 kg of charcoal kiln efficiency, and average wood density of 720 kg/m^3. The total of 1.3 billion m^3 compares with FAO 2010 estimate of 1.8 billion m^3 woodfuel consumption. The estimate is lower due to the exclusion of non-cooking woodfuel and woodfuel use in developed countries.

44 Assumes 880–1,000 kg of coal per household for cooking based on average per household data in Africa and China, and a standard cooking diet of 320 MJ per month (see Endnote 224 on notional cooking diet assumption); the total residential consumption of coal is significantly higher, with 200 MT of coal being used annually in China alone for residential heating in urban areas (Liu & Liu, 2011).

45 Bailis et al., 2015.

46 The top of the range is consistent with the Global Alliance's earlier estimated total Kyoto Protocol GHG emissions of 1 billion MT (Muthiah, 2011).

47 Assumes total global 2011 GHG emissions of 34 billion tons of CO2 based on Olivier et al. (2012).

48 The upper range of our Kyoto GHG estimate assumes a woodfuel non-renewability fNRB ratio of over 50%, the assumption used by the Global Alliance and a number of sector studies. The bottom of the range conservatively assumes an fNRB of 10–15% for wood in line with the IPCC Fourth Assessment position and a fNRB of 50% for charcoal.

49 22–25% of global emissions of 7,530 Gg; total global black carbon emissions from residential solid fuel use reported in Agency (2011) and Bond et al. (2013); these figures include residential heating.

50 Estimated by mapping black carbon emission EC/OC profiles for common Sub-Saharan Africa stove-fuel combinations and charcoal kilns to the annual regional biomass consumption and charcoal production volumes; does not include black carbon emissions from kerosene stoves.

51 Ibid.

52 Grieshop et al., 2011; see also Agency, 2011 Agency, 2011.

53 See recent review of evidence in Bond et al. (2013); in contrast to biomass fuel cooking, there is more certainty around the evidence of positive climate-forcing impacts from coal stoves, although these are used for heating as well, which are not included in this report.

54 Ibid.

55 Praveen et al., 2012.

56 Kilimanjaro glacial melting (Kaser et al., 2004); Rwenzori Range glacial melting (Taylor et al., 2006).

57 European Commission, 2010; World Bank, 2011b; Union of Concerned Scientists, 2011; Hiemstra-van der Horst, 2008.

58 Degradation is here defined as the direct human-induced reduction in forest carbon stocks from the natural carbon carrying capacity of forest ecosystems without a net reduction of forest area (Nature Conservancy, 2009).

59 World Bank, 2011b.

60 Leach & Mearns, 1989; Morton, 2007; Openshaw, 2010.

61 Arnold et al., 2005; Mwampamba, 2007; and van Beukering et al., 2007, cited in World Bank, 2011b.

62 Baland et al., 2010.

63 Kissinger et al., 2012; Baland et al., 2010.

64 Bojo & Cassells, 1995. An older Ethiopia study estimated that if dung had be left in the soil as fertilizer in the mid-1980s instead of being used as fuel, grain production could have been increased by up to 15 million tons (Newcombe, 1989).

65 Ravindranath and Hall (1995) suggested that impact of dung fuel use on soil productivity in South Asia has been Marginal (see also Pimentel, 2006).

66 For localized deforestation and degradation examples in Africa due to charcoal production, see: Zambia – Kutsch et al., 2011; Tanzania – Giliba et al., 2011, Mwampamba, 2007; Ghana – Lurimuah, 2011, Yiridoe & Nanang, 2001; Malawi – Munthali, 2012; Kenya – Bailis, 2005; Burkina Faso – Ouedraogo, 2012, and Madagascar – WWF, 2010. Outside of Africa, notable examples include: Haiti - Williams, 2011; Cambodia – Wyatt, 2013, San et al., 2012.

67 Mwampamba, 2007.

68 Charcoal kiln efficiency varies widely with an average ratio of 6 kg wood to 1k charcoal (Union of Concerned Scientists, 2011).

69 World Bank, 2011b.

70 Chdumayo & Gumbo (2012) and Bailis (2005) suggest that the contribution of charcoal production to degradation is important, but secondary relative to other factors. One recent study has attributed up to half of African degradation effects to charcoal production, 12% in subtropical Asia, and 8% in Latin America (Hosonuma et al., 2012), but this interpretation does not appear to be substantiated by on the ground country-level analysis.

71 See Broadhead et al., 2001.

72 Ghana - Oguntunde et al., 2008, Nigeria - Ogunkunle & Oladele, 2004, multi-geography - Kindt et al., 2008; Kenya - Oyugi et al., 2007; Togo - Kouami et al., 2009.

73 The best publicized instance of such faunal biodiversity threat has been the negative effect of the charcoal trade on the habitat of the of mountain gorilla in Democratic Republic of Congo's Virunga National Park (Nellemann, Redmond, and Refisch, 2010) and there have been anecdotal reports on adverse effects of charcoal production

on other species like the Sifaka in Madagascar, but there is little data on how widespread and representative such effects may be.

74 The proxy used for this variable is woodfuel consumption's share of the country's total above-ground biomass.

75 This variable is estimated as the average annual decline in above-ground biomass from 2000 to 2010 FAO.

76 See for example Westinga et al. (2013), which compares consecutive (1990–2010) census-based FAO Forest Resources Assessments (FRAs) of Rwanda with contemporary fine-resolution satellite images that demonstrate significantly greater deforestation than noted in FRAs. More generally, many scholars have questioned the data quality of FRAs which are typically not triangulated with satellite observation.

77 Broadhead et al., 2001.

78 World Resources Institute's BoP landscape report (Hammond et al., 2007) is based on household survey data for more than 30 developing countries globally.

79 Daurella & Foster (2009) report 7% total of household expenditures going towards LPG, kerosene, and charcoal.

80 Sub-Saharan Africa real incomes, on average, stagnated, with an anemic growth of 1% annually. In contrast, our fuel price analysis indicates real price growth of 2–14% annually for LPG, kerosene, and charcoal over the past decade, depending on the country.

81 Bacon et al., 2010.

82 In Luanda, the lowest urban quintile expenditures were 21% of monthly income (Bacon et al., 2010), urban slumdwellers in Malawi spent over 11% of their incomes on charcoal alone in 2007 (Kambewa et al., 2007). In light of recent price increases, spending on charcoal in Kibera, Nairobi, reaches up to 25% of income for the poorest households on certain months (based on author interviews in September, 2012), though this level of expenditure is unlikely to be sustained on a full-year basis. Asian examples show comparable results—such as a 16% expenditure share going to energy in Thai slums (Shrestha et al., 2008).

83 For a review of the literature on the poverty premium, see Mendoza (2011).

84 Press reports from Cameroon, Uganda, Zambia, Liberia, Tanzania, and Madagascar.

85 World Bank, 2011a; Blackden & Wodon, 2006.

86 See Malawi - GIZ/ProBEC, 2010; Chad - Vaccari et al., 2012; Ghana - Odoi-Agyarko, 2009; Ethiopia – Damte et al., 2011; Kenya - Githiomi et al., 2012; Rwanda - SNV, 2007; Uganda - SNV, 2010, Uganda MOF, 2003.

87 For example, IEA (2006) World Energy Outlook reports collection distances of 1–10 km in Tanzania, depending on the region.

88 Madubansi and Shackleton (2007) show a 14% increase in fuel collection times over 1991–2002 in a set of five villages in South Africa. In Sudan, women's collection times quadrupled in some areas because of increased fuel scarcity (Sass, 2003).

89 Kohlin et al., 2011; Blackden & Wodon, 2006. See also Figure 2.9.

90 Assumes two hours per household of fuel collection time daily and a maximum estimate of 1.5 hours of cooking time savings out of a 3-hour average cooking period per day in the case of a switch to LPG; 8-hour workdays.

91 See Habermehl, 2007 and Jeuland & Pattanayak, 2012.

92 The best data on this issue comes from household surveys in post-intervention impact reports. For instance, 34% of time saved from improved stove interventions in Malawi was used for farming activities GIZ ProBEC 2008, 23% of time saved via improved wood stoves in Mozambique was invested by households in their small businesses or work in fields GIZ ProBEC 2010, 23% of time saved by switching to ethanol cooking was used for income-generating activities in an Ethiopia refugee camp (Egziabher et al., 2006) and 25–40% of time saved by biogas digester users was utilized for income–generating activities in countries like Bangladesh, Nepal, and Vietnam according to periodic biogas users surveys (SNV, 2007–12).

93 Assumes a 25–50% range of time being redeployed for income–generating activities; hourly labor cost of $ 0.30–0.75 per hour equivalent to hourly equivalent of average Sub-Saharan Africa gross national income per capita at top of range and per capita agricultural value added at bottom of range. Using official minimum wages would yield substantially higher figures.

94 World Bank, 2011b.

95 Sepp, 2008, cited in World Bank, 2011b; earlier estimates suggested 200,000 for charcoal production out of a total of over 500,000 (UNDP, 2012).

96 ESD, 2007, cited in World Bank, 2011b.

97 Kambewa et al., 2007 and Openshaw, 2010, cited in World Bank, 2011b.

98 Cited in World Bank, 2011b.

99 15 million people in Sub–Saharan Africa derive their primary cash income from activities like firewood collection, charcoal making, small–scale sawmilling, and woodfuel and timber sales (Oksanen et al., 2003). We assume that the number is likely to have grown by at least 20% in line with the general increase in woodfuel volumes over the past decade to over 18 million jobs.

100 For Philippines, see Remedio, 2012; for India and Pakistan, see Domac et al., 2005.

101 For Brazil, see Domac et al., 2005; for Peru, see Bennet-Curry, 2013, and for Haiti, see Reduondo, 2013.

102 World Bank Central American Clean Cooking Initiative (CACCI) research (forthcoming in 2015).

103 NL Agency, 2010; UNDP, 2012.

104 Press reports from Madagascar and Uganda.

105 NL Agency, 2010.

106 Shively et al., 2010.

107 Schure, 2012.

108 Radounis 2012.

109 ESDA, 2005.

110 IIAM and INBAR 2007, cited in http://ntfp.inbar.int/wiki/index.php/Charcoal (viewed Sept. 1, 2012).

111 PREDAS, 2008.

112 Agyeman et al., 2012.

113 Schure, 2012.

114 Khundi et al., 2010.

115 Bhattarai, 1998.

116 Coomes & Burt, 2005; Bennet-Curry 2013; Reduondo, 2013.

117 For previous general overviews, see the gender sections of Global Alliance for Clean Cookstoves, 2011 and World Bank, 2011a; for in-depth analyses of improved stove and clean cooking energy gender issues, see Kohlin et al., 2011; Clancy et al., 2003, 2011; Carr & Hartl, 2010; World Bank, 2006; and Ramani & Heijndermans, 2003.

118 Kohlin et al., 2011.

119 ibid.

120 Huq et al., 2004 Bangladesh, Balakrishnan et al., 2004 India, Ezzati et al., 2000 Kenya; Smith et al., 2007.

121 For instance, acute respiratory infections incidence for boys is higher than that for girls in India Mishra, 2004.

[122] Banerjee et al., 2012.

[123] Fullerton et al., 2008.

[124] CO exposure displaces oxygen level in blood hemoglobin and women generally have less hemoglobin in reserve than man, with oxygen carrying capacity being a further 20–30% lower in pregnant women in particular Mishra, 2004.

[125] See Warwick and Doig, 2004 and IEA World Energy Outlook, 2006.

[126] See Matinga, 2010; Odoi–Agyarko 2010 reports significantly higher incidence of backaches, headaches, and neck pain for women from firewood collection relative to a low incidence in men. See also Wickramsinghe, 2003 for Sri Lanka data.

[127] For example, see reports from Nepal Earth & Sthapit, 2002 and India Ravindran et al., 2000.

[128] See Matinga, 2010 for criticism of this issue in South Africa.

[129] See following note.

[130] See Cooke et al., 2008 and Kohlin et al., 2011. Geographies with near parity in firewood collection include India, Mongolia, and PNG. Men are the primary firewood collectors in Nicaragua, Guatemala, Lao PDR, and Indonesia.

[131] Our review suggests 0.5 to 5 hours for fuel collection about 2 hours on average and 1.3–5 hours for cooking 2.5–3 hours on average for food preparation based on gender disaggregated data for a dozen developing countries. It should be noted that the average fuel collection times shown in Figure 12 are significantly lower because they benchmark all households rather than just rural poor households actively engaged in firewood collection, for whom the time spent is larger by an order of magnitude.

[132] Blackden & Wodon, 2006.

[133] See Kohlin et al., 2011 Carr & Hartl, 2010, Schlag & Zuzarte, 2008. For evidence that a significant portion of time lost could be used for income generation activities see notes 86 and 87 above and related discussion.

[134] Clancy et al., 2011

[135] Ward & Marsh, 2006; Patrick, 2006; Vaughan, 2011; Bizzarri & Deni, 2010; UNMIL, 2008.

[136] Kenyan press reports the incidence of rape of over 100:100,000 in the Dadaab refugee camp or 358 cases June 2010 to June 2011 out of a total female refugee population of ~300,000 compared to a 2:100,000 incidence of rape in Kenya at large in 2011.

[137] In Uganda's Bushenyi and Kabale districts, for example, 22% of firewood collectors report being beaten by the owners, 24% report being taken to court, and 41% report conflict situations where the wood gets taken away (Malinski, 2006).

[138] Ndiritu & Nyangena, 2010.

[139] Nankhuni & Findeis, 2004; Kiros, 2011.

[140] Cecelski, 2004.

[141] In African surveys, the priority given to the aesthetic appearance of the kitchen is relatively low. For instance, in a Rocket Lorena stove intervention in Uganda, 7.5% of users reported that a notable benefit was that the "stove makes the kitchen look smart" (Malinski, 2006) and 9% of users of an improved charcoal stove in Tanzania likewise reported a "clean kitchen" as a major benefit (Evodius, 2010). The factor of kitchen cleanliness is rated more highly in available Asia and Latin America surveys. One-quarter of users in a Pakistan biogas digester intervention reported clean utensils and a clean household as key benefits (SNV Pakistan Biogas Users Survey, 2011); one-quarter of users reported a clean kitchen as a major benefit in the Patsari chimney rocket stove intervention in Mexico (Masera et al., 2006); and 67% of users reported clean kitchen vessels and walls as a positive benefit of improved chulha stoves in India (Barnes et al., 2012).

[142] A general overview of methodological issues appears in Burwen (2011).

[143] See overview of stove performance by dimension in Chapter 4.

[144] Berkeley Air Monitoring, 2012.

[145] Approvecho Testing Center, 2011; Jetter & Kariher, 2009; MacCarty et al., 2008; for ACS, see Kar et al., 2011.

[146] Just et al., 2013.

[147] Burwen, 2011; Berkeley Air Monitoring, 2012; and multiple stakeholder interviews.

[148] Interview with Kirk Smith; Kar et al., 2011.

[149] See, for example, Berkeley Air Monitoring, 2012, Berkeley Air Monitoring Group, 2010, and Adkins et al., 2010.

[150] Berrueta et al., 2008.

[151] Bensch and Peters (2011a, 2011b) report savings comparable to theoretical 25–35% fuel savings.

[152] Ternes et al., 2008.

[153] For real world performance of built-in or semi-fixed chimney rocket stoves, see Berkeley Air Monitoring(2012); for Ethiopia MIRT stove, see Megen Power Ltd. (2008); for the Uganda Lorena Rocket and RESPIRE data for Patsari stoves, see Malinski (2006).

[154] For field impact evaluations cover full spectrum of ICS, including minimally improved chimney wood stoves in India, see Hanna et al., 2012 and in Ghana, see Burwen & Levine, 2012. For basic efficient charcoal stoves in Senegal, see Bensch & Peters, 2011a; in Tanzania, see Schutze, 2010, and in Mozambique, see Chidamba, 2010. For basic efficient wood stoves in Senegal, see Bensch & Peters, 2011b and in Malawi, see Schutze, 2010. For portable wood rocket stoves in Kenya, see Berkeley Air Monitoring Group, 2010; in Malawi, see ProBEC, 2009; and in Tanzania and Uganda, see Adkins et al., 2010. For built–in chimney rocket stoves in Peru, see Peru Adrianzen, 2012; in Mexico, see Masera et al., 2007; in Guatemala, see Smith et al., 2010, McCracken et al., 2007, Diaz et al., 2007; in Uganda, see Malinski, 2006; and in Ethiopia, see Megen Power Ltd., 2008. For natural draft gasifiers in Costa Rica, see Ternes et al., 2008 and for both fan and natural draft gasifiers in India, see Kar et al., 2011. For renewable and modern fuels key studies include evaluations of ethanol and methanol pilots in Ethiopia - Egziabher et al., 2006; Nigeria - Obueh, 2008; and Madagascar - Practical Action, 2011; LPG stoves in Kenya and Sudan - Malla et al., 2011; biogas digesters in Vietnam, Pakistan, Bangladesh - SNV Biogas Users Reports, and Kenya - Dooho et al., 2012; and solar cookers in Senegal - Levine & Beltramo, 2012, and in Ethiopia, Kenya, and Bolivia - Szulczewski, 2006.

[155] Completed ICS RCTs include evaluations of basic chimney wood stoves in India (Hannah 2012) and Ghana (Burwen & Levine, 2012), a basic efficient charcoal jambar stove in Senegal (Bensch & Peters, 2011a), and the Patsari chimney rocket stove under the RESPIRE program in Guatemala (Smith et al., 2010, McCracken et al., 2007, Diaz et al., 2007, Diaz & Pope, 2007). RCTs of other ICS and ACS are in–progress and include an evaluation of chimney wood stoves in Nepal (Johns Hopkins/Tribhuvan University), efficient improved stove in India (Washington University in St. Louis), Envirofit rocket stoves in Uganda (USAID TRAction Project), BioLite fan gasifier in Ghana (Columbia University), and the Philips fan gasifier in Malawi (CAPS/Liverpool School of Tropical Medicine and Rwanda University of North Carolina).

[156] Hanna et al., 2012; Burwen & Levine, 2012.

[157] Hanna et al., 2012. For criticism, see Grimm & Peters, 2012.

[158] Burwen & Levine, 2012.

[159] Ibid.

[160] ProBEC charcoal stove interventions; Senegal charcoal jiko RCT (Bensch & Peters, 2011a).

[161] Our Kenya interviews suggest that average fuel savings of KCJ in Kenya is near 15–20%, significantly below the potential 30–40% savings possible with well-designed metal-lined ceramic stoves.

[162] Patsari data from RESPIRE evaluations (Smith-Sivertsen et al., 2009), Uganda Rocket Lorena (Malinski, 2006), and MIRT (Megen Power Ltd., 2008).

[163] Berkeley Air Monitoring Group, 2010.

[164] For Costa Rica, see Ternes et al., 2008. For variation in gasifier performance in India field tests, see Kar et al., 2011. More comprehensive RCT evidence for gasifiers is unlikely to be available for several years.

[165] See, for example, Malla et al. (2011) which shows only moderate health and woodfuel consumption impacts in Sudan and Kenya from LPG pilots due to the lack of displacement of baseline technologies.

[166] Smith, K. R., R. Uma et al. 2000. "Greenhouse Implications of Household Stoves: An Analysis for India." Annual Review of Energy and the Environment 251: 741–763.

[167] For the latest research on kerosene stoves, see Lam et al. 2012.

[168] For the Arivi stove, see the data from an independent evaluation by Worcester Institute available at: http://wp.wpi.edu/capetown/projects/p2009/energy/project-components/accomplishments/arivi-safe-paraffin-stove/. The Servals stove has likewise been evaluated by several independent institutions.

[169] See fuel mix data in Figure 3.2 and related text.

[170] Smith 2014. For market prospects in India, a recent report on the Induction Cooktop Market in India: 2012–2016 (Infinity Research Limited, March 2013), has predicted 35% annual growth over the next few years.

[171] Smith, 2014.

[172] 66% reduction for wood and charcoal expenditures and firewood collection time in Lao PDR (Synesis, 2011), 72% reduction in firewood expenditures in Indonesia (JRI Research, 2011), >80% fuel collection time and woodfuel expenditure savings in Bangladesh (iDE, 2011).

[173] Schlag, N. & Zuzarte, F., 2008. Market Barriers to Clean Cooking Fuels in Sub-Saharan Africa: A Review of Literature, Stockholm: Stockholm Environment Institute.

[174] See Dooho et al. (2012) for the results of a recent Kenya biogas assessment.

[175] Practical Action, 2011.

[176] Szulczewski, 2006.

[177] http://solarcooking.wikia.com/wiki/CooKit

[178] http://solarcooking.wikia.com/wiki/Devos_Solar_Cooker

[179] Venkataraman et al., 2010; see also Hanna et al., 2012.

[180] For example, a ProBEC baselining study found that mud stoves distributed under a national program in Malawi in the 1990s were largely abandoned a decade later. Anecdotal evidence from our interviews and press reports suggests a similar fate for chimney mud stoves in Madagascar, Uganda, Rwanda, Zimbabwe, and Tanzania.

[181] For Ghana, see Burwen & Levine, 2012.

[182] The ratio of non–functional or abandoned biogas plants has ranged from 20 to 75% for countries like Kenya, Ethiopia, Bangladesh, Sri Lanka, and India (Bond & Templeton, 2011), though information from new biogas digester programs such as those supported by SNV shows significantly lower abandonment rates at this stage.

[183] See, for exampel, Levine & Beltramo, 2012.

[184] Thurber et al., 2014

[185] Practical Action, 2011.

[186] Evaluations of GIZ interventions in Africa GIZ SUN, ProBEC, and EnDev programs show 70–90% persistence of improved stoves based on ongoing use of or replacement rates across a range of artisanal and semi–industrial ICS technologies. See Schutze, 2010; GIZ/ProBEC, 2010; Evodius, 2010; Chidamba, 2010; Megen Power Ltd., 2008; and Malinski, 2006.

[187] See Masera, 2000; Ruiz-Mercado et al., 2011.

188 See, for example, the impact of partial ICS adoption (i.e., mixed use of Patsari stove and old unimproved stoves) in comparison to full ICS adoption on health outcomes in Michoacan, Mexico (Masera et al., 2007).

189 Evidence from China, Ghana, Guatemala, Kenya, India, Mexico, Mozambique, Tanzania, and Uganda suggests that stove users prefer to use more than one stove. See, for example, Adkins et al., 2010 for Uganda and Tanzania, Concern Universal, 2011 for Malawi, Burwen & Levine, 2012 for Ghana, Schutze, 2010, and Ruiz-Mercado et al., 2011 for multi-geography data.

190 45–65% savings reported from the field for rocket stoves, with the high end representing chimney rocket stoves and 60–80% savings reported from biogas digester interventions.

191 Goldemberg & Coelho, 2003.

192 ICS job creation potential ranges from several hundred stoves per full time employee in artisanal markets (UNDS 2012; IRENA, 2012) to thousands of stoves per job created in the case of industrial stove manufacturing processes. Imported stoves, naturally, create the smallest number of domestic jobs.

193 For ICS jobs, we conservatively assume 500 stoves produced annually per full time artisan (including both liner manufacturers and metal workers) and 1,000 stoves per each full time artisanal stove retailer. The full uptake of 1,000 artisanal ICS stoves would create 3 ICS jobs (1 retailer and 2 artisans) while simultaneously displacing 35 jobs in the woodfuel sector, a ratio of roughly 1:11. For job displacement, we assume that the adoption of 1,000 ICS leads to 240 tons of woodfuel savings (1,000 stoves x 800 kg of charcoal per household x 30%), which translates into the displacement of 10 charcoal makers jobs (2 tons of charcoal or 40 bags of charcoal production eliminated per month), and 25 retailer jobs (25 1-kg charcoal buckets sold by retailer per day).

194 See fuels section of Chapter 3. Net woodfuel consumption volumes are expected to increase 30–40% between 2010 and 2020, so an (unrealistic) reduction in woodfuel demand due to ICS of 30–50% across the board would still mean only 10–30% less woodfuel consumption than today.

195 For example, assuming if just 10% of the time freed up from firewood collection and cooking times is converted into income-generating employment, this would translate into 4 million jobs across Africa (assuming our estimate of a total of 40 million of "wasted" person years on avoidable firewood collection/cooking activities).

196 World Bank, 2011b.

197 UNDP, 2012.

198 A number of common rocket stove models more than double black carbon emissions for each kg of fuel burned, cancelling out the emissions abatement effects of improved fuel efficiency (Berkeley Air Monitoring Group, 2011b).

199 Smith et al., 2010; Smith et al., 2010; Smith et al., 2011.

3

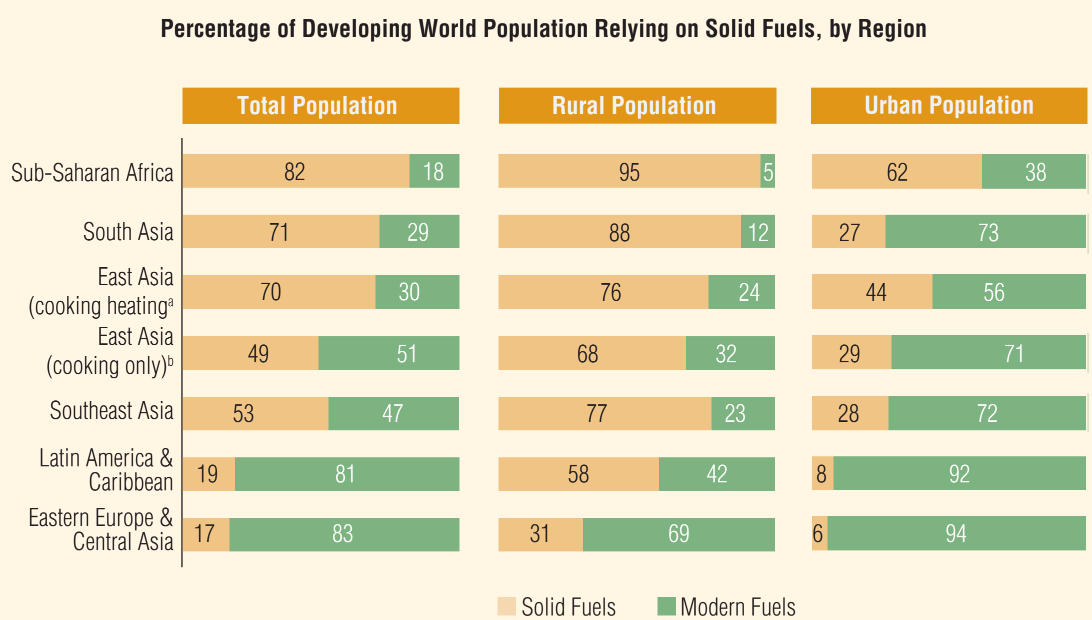
THE DEMAND FOR CLEAN AND IMPROVED COOKING ENERGY

A. OVERVIEW OF GLOBAL FUEL LANDSCAPE

More than 3 billion people—over 60% of the developing world's population and 40% of the global population—rely on solid fuels for their primary cooking needs via open fires or traditional stoves.[200] Of these, about 2.7 billion use traditional biomass like wood, charcoal, animal dung, and crop waste and a further 400 million use coal.

Sub-Saharan Africa has the highest level of solid fuel dependence globally, followed by Asia, Latin America, and Eastern Europe. The latest international and national census surveys, triangulated with parametric estimates for fuel use in geographies where recent data are unavailable, suggest that 82% of Sub-Saharan Africa's population depend on solid fuels for their primary cooking needs. As illustrated in Figure 3.1, this compares to solid fuel reliance by 44–71% in different regions of Asia and significantly lower levels of solid fuel use in Latin America (17%) and Eastern Europe (19%).

FIGURE 3.1:
Solid and Modern Fuel Usage, by Region



Sources: WHO Global Health Data Repository, DHS, MICS, LSMS, National Census data (2005–15); Task Team analysis.
Note: Latest data available on average 2012–13 data; "other" included under solid fuel.
[a] Estimate based on China solid fuel data from WHO Global Health Data Repository data, drawing on CPC UNC China Health & Nutrition Survey data for China.
[b] Bonjour et al., 2014, updated solid fuel cooking only survey data for China based on 2010 national energy census.

The regional split for East Asia has the greatest degree of uncertainty due to variability in historical fuel use data for China and difficulties in disaggregating the country's solid fuel cooking and solid fuel heating figures. We, therefore, show two data points for East Asia to bracket the likely fuel mix range for the region.[201] The more conservative data point, including both cooking and heating solid fuel use in China, is used throughout the other exhibits and text below.

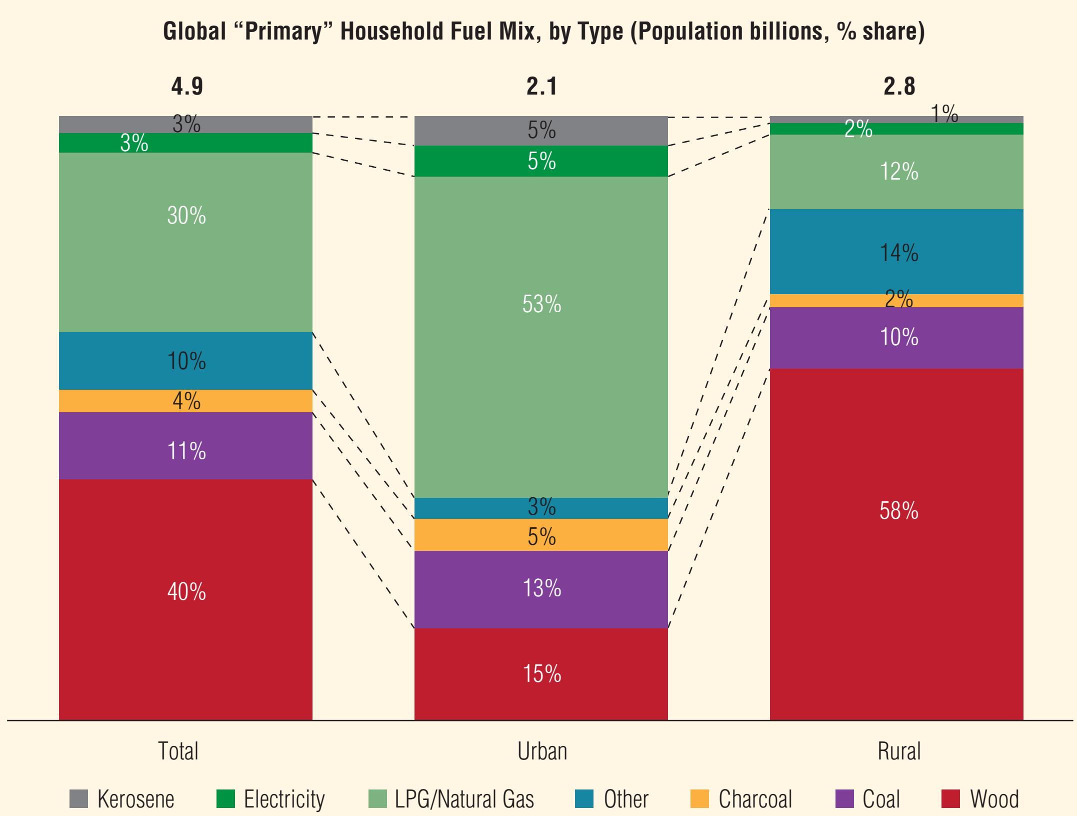
Across all regions, urban populations are far less likely to rely on solid fuel cooking than rural populations. Urban households are wealthier and have better access to new technologies, driving higher adoption of modern fuels. The gap between rural and urban fuel use patterns is most striking in South Asia and Southeast Asia, which are characterized by high levels of rural solid fuel reliance (88% and 71% respectively) and relatively low levels of urban solid fuel use (28–29%). This has important implications for the future. As quickly urbanizing rural populations integrate into the urban environment, the large differential between urban and rural fuel use behavior should facilitate more rapid migration for households up the energy ladder to cleaner, more modern fuels. In contrast, in Sub-Saharan Africa, the rates of solid fuel dependency in rural (95%) and urban (63%) areas are both extremely high. In the Latin America region (including the Caribbean) and Eastern Europe (including Central Asia), due to varying historical reasons, urban populations have almost fully transitioned to modern fuels. In these regions, solid fuel dependence is a problem of rural infrastructure gaps and rural population exclusion.

Wood is the dominant solid fuel overall, with a significant charcoal segment in both rural and urban areas. Wood is used by 58% of rural households as a cooking fuel, whereas in urban areas the use of wood decreases to 15% (Figure 3.2). Wood's dominance in rural areas is due to the population's proximity to forests, grasslands, and agricultural lands. The other major fuel across rural areas is agricultural waste, which largely accounts for the "Other" category in Figure 3.2. In urban areas, while wood is still the main fuel, solid fuel users rely much more heavily on charcoal and coal.

In terms of modern fuels, LPG is the primary modern fuel globally, followed by much smaller electric and kerosene cooking segments. LPG is the fuel of choice for roughly one-third of developing world households. It is the dominant fuel in urban areas (53%) and has a significant (12%) footprint in rural and peri-urban markets. Electricity and kerosene account for the balance of modern fuel use at roughly 3% each of the total fuel mix. While these usage levels may appear negligible at the global level of aggregation, at the country level, the less common fuels can be hugely important. In the case of electricity, for example, electric stoves serve as the primary urban cooking technology for significant portions of the population in select markets in Africa (South Africa, 85% of urban households, Zimbabwe, 73%, Namibia, 67%, Zambia, 39%), Asia (Mongolia, 40%, PNG, 17%, China, 9–13%, Myanmar, 10%), and Latin America (Honduras, 34%, Colombia, 12%).

Underneath these global trends, regional and country level variation is stark. Latin America and East Asia feature large rural LPG populations whereas the fuel is less common in rural South Asia and almost entirely absent in rural Africa (Figure 3.3). Agricultural waste in rural East Asia, captured under the "Other" fuel category in Figure 3.3, and animal dung in rural South Asia, likewise, the major portion of the 24% in the region's "Other" fuel category in Figure 3.3, are mainstream fuels, but are marginal elsewhere in the world. The use of kerosene for cooking in urban areas is somewhat common in Sub-Saharan Africa (14%

FIGURE 3.2:
Urban and Rural Fuel Use in the Developing World

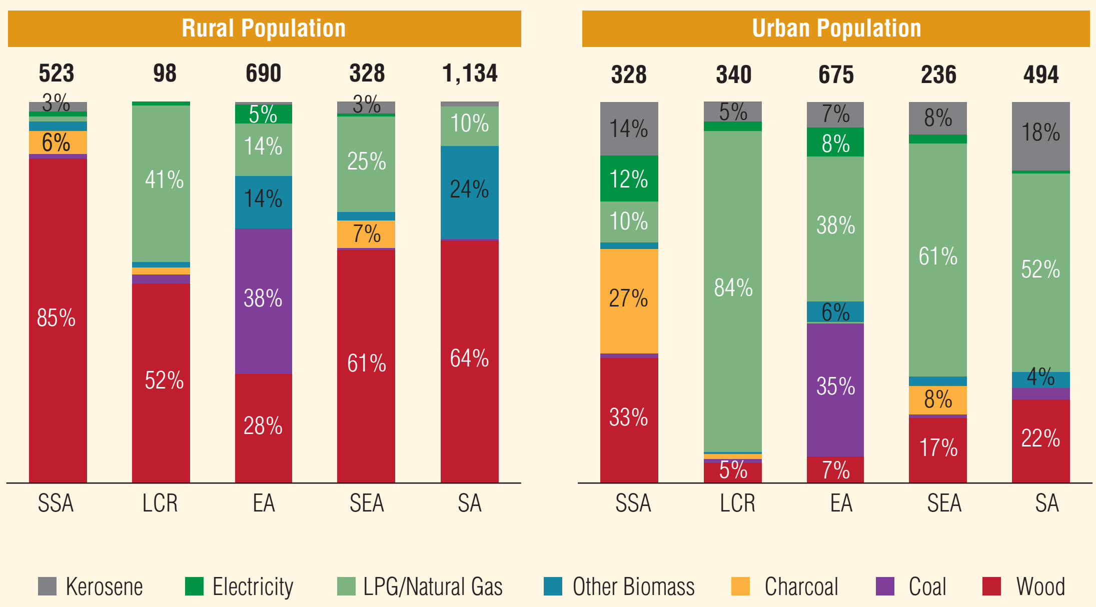


Sources: Global fuel-use data drawing on WHO, DHD, MICS, LSMS; Task Team analysis; national census survey data for 2005–15.
Note: Based on latest year known, which equates to roughly 2012-13, on average, for the global country sample.

of urban households) and South Asia (18%), but is at a relatively low level in urban Southeast Asia (8%), and is absent in other regions. Across both rural and urban areas, the use of coal for cooking and heating is almost entirely an East Asian phenomenon, accounting for one-fifth of households in the region, with rare exceptions elsewhere (e.g., 18% of all households in Sudan, 14% of households in Paraguay).

There is similarly dramatic variability at the country level within regions. Figure 3.4 shows the diversity of fuel use patterns within regions, as can be seen by comparing South Africa with Liberia in Africa, Pakistan with Bangladesh in South Asia, China with North Korea in East Asia, Thailand with Lao PDR in Southeast Asia, and Brazil with Haiti in Latin America and the Caribbean. The major implication is that while it is important to consider regional strategies and trends, cooking fuel preferences are a highly local phenomenon that requires tailored and nuanced approaches to addressing solid fuel dependence challenges within each region.

FIGURE 3.3:
Global Urban and Rural Fuel Use, by Region (population, millions)



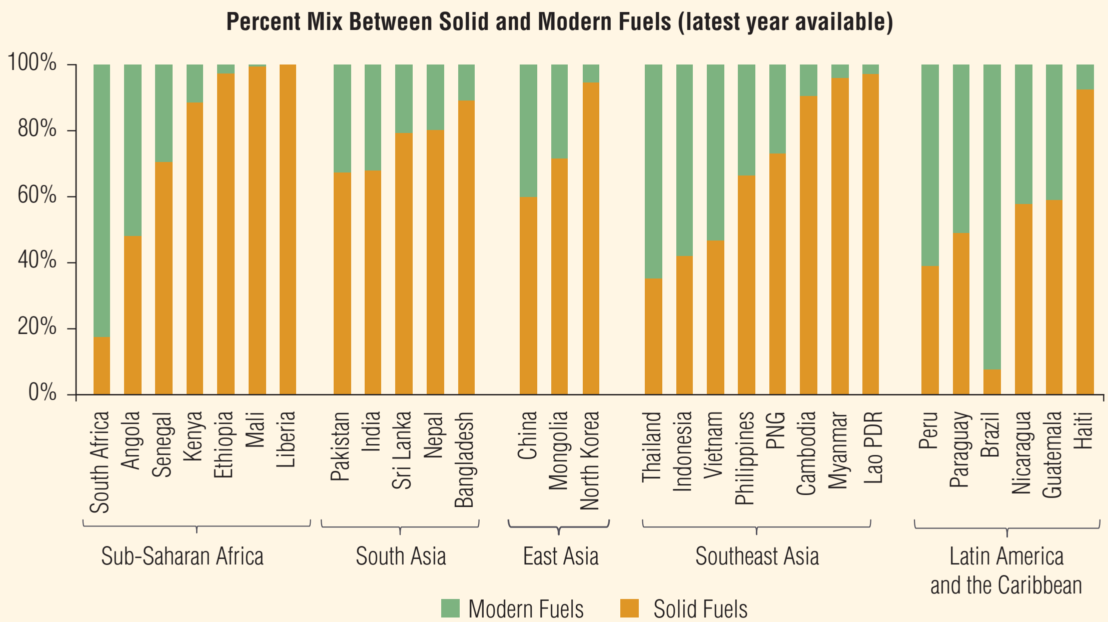
Sources: WHO Global Health Data repository and national household surveys; Task Team analysis.

Forward-Looking Fuel Adoption and Consumer Income

Current trends point to the increase in the overall number of solid fuels users globally over the next decade. Rapid but deescalating population growth, increasing urbanization, and rising middle-class incomes in the coming decades will be the major demand-side shaping forces for cooking fuel mix. Population growth will have its most dramatic impacts in Africa, where the region's population has grown at an annual rate of 2.5%, and is predicted to double by 2036.[202] Slower but still rapid population growth in other regions (1–1.5%) will likewise continue to drive solid fuel demand. The two countervailing pressures of urbanization, with urbanizing households adopting more urban patterns of fuel use due to lifestyle shifts, and income growth, which accelerates the movement of households up the energy ladder, will not be sufficient to significantly brake the demographic engine for solid fuel adoption.

Extrapolating from past experience, our estimates and comparable analyses from Global Energy Assessment and OECD/IEA suggest that, even in moderate scenarios, Africa's solid fuel population will grow by 200 million people to 850–900 million by 2020 (Figure 3.5).[203] South Asia will increase slightly to 1.2 billion solid fuel users, with the slowing growth in India counterbalanced by increases in solid fuel use in countries like Bangladesh and Pakistan. In contrast, the solid fuel population in East Asia is projected to decrease significantly given the strong trend of migration to modern fuels across all

FIGURE 3.4:
Use of Solid and Modern Fuels, by Country

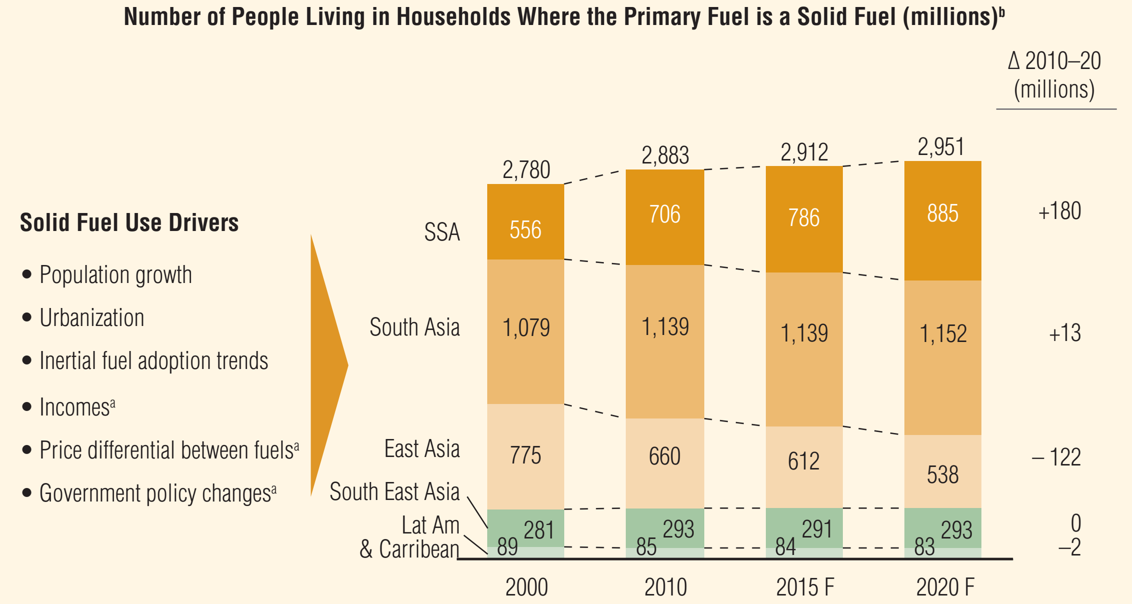


Source: Global fuel-use data drawing on WHO, DHD, MICS, LSMS, Task Team analysis and national census survey data (2005–12).

segments in China, combined with rapid urbanization in that country. In Latin America and Southeast Asia, increasingly urban and modern fuel-oriented middle-income economies of leading regional nations are continuing to decrease these regions' solid fuel footprints. Cumulatively, we forecast a stagnant global solid fuel population, culminating with 3.1 billion solid fuel users by 2020.

Based on historical trends, adjusted for projected population growth and rural-to-urban migration, the fuel mix across the developing world will still primarily depend on solid fuels by 2020. Historical trends (2000–10) suggest that the overall use of solid fuels for cooking and heating will decline from over 60% of primary fuel users to just over half (50–52%) over the developing world population (Figure 3.6). Most of the gains in modern fuel use will come from the growth in LPG use, increasing from 23% in 2000 to nearly one-third (30–33%) of primary fuel users by 2020. The use of electricity will also see strong growth in relative terms, from under 3% to up to 9% of the population.[204] Renewable fuels like biogas and solar will continue to increase in share, though the trajectory of this change is difficult to predict in light of poor data on these segments and, in absolute terms, the share of such fuels will continue to remain small. These increases in modern and renewable fuels will come at the expense of wood (43% to 35%) and coal (11–14% to 6–9%). Charcoal consumption, however, is not expected to decline, in relative terms, given the strong demand growth for the fuel in urbanizing

FIGURE 3.5:
Forecast of Solid Fuel Users, by Region



Source: 2000–10 data based on WHO, DHS, MICS, LSMS, and national survey data; projection based on inertial penetration trends adjusted for changes in urban/rural mix.

[a] Factors considered qualitatively, but not modeled directly for the forecast.

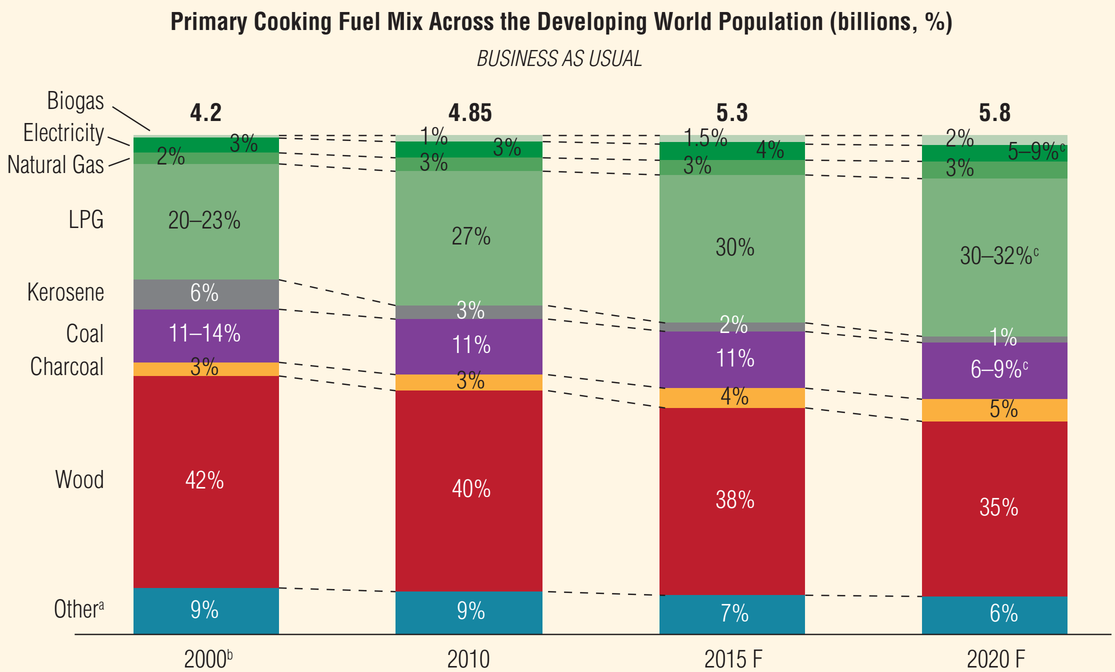
[b] Data set covers 82 countries accounting for 98% of solid fuel users globally; the actual number of solid fuel users was likely close to 3.1 billion in 2010.

Africa. This forecast is consistent with recent research that estimates that with every 1% increase in urbanization, there is a resulting 14% increase in charcoal consumption.[205]

Countries have already individually begun to transition away from wood fuel to other forms of energy. Figure 3.7 provides a country-level view of the net change in energy use from 2000–10 in each country, by type of fuel. The vertical axis reflects the proportion of each country's population currently dependent on a given fuel for their primary cooking needs, while the horizontal axis shows the net change in the usage of each fuel type over the past decade. The size of each bubble represents the absolute number of fuel users within the national market.

A majority of the countries profiled saw a reduction in their reliance in firewood over the decade. Over the same period, many countries experienced growth in charcoal, showing the net shift from firewood to charcoal in urban areas for solid fuel users. Charcoal use declined strongly in China. For modern fuels, LPG use grew quickly in share in middle-income countries such as Brazil, China, India, Indonesia, Vietnam, and Mexico—all of which have also relied on significant LPG subsidies over this time period. Reliance on kerosene has been decreasing, though causal factors are unique to individual

FIGURE 3.6:
Evolution of Primary Cooking Fuel Mix



Source: Fuel mix analysis and projection; forecast based on historical fuel mix evolution, population growth, and urbanization; Task Team analysis.

[a] Primarily consists of other biomass fuels like dung and crop waste.

[b] Due to challenges with the China data set (variance in survey data), overall numbers for coal and LPG for 2000 are represented as a range.

[c] Variability in the China fuel usage data leads to a range of results for the forecast of Electricity, Coal, and LPG use in 2020.

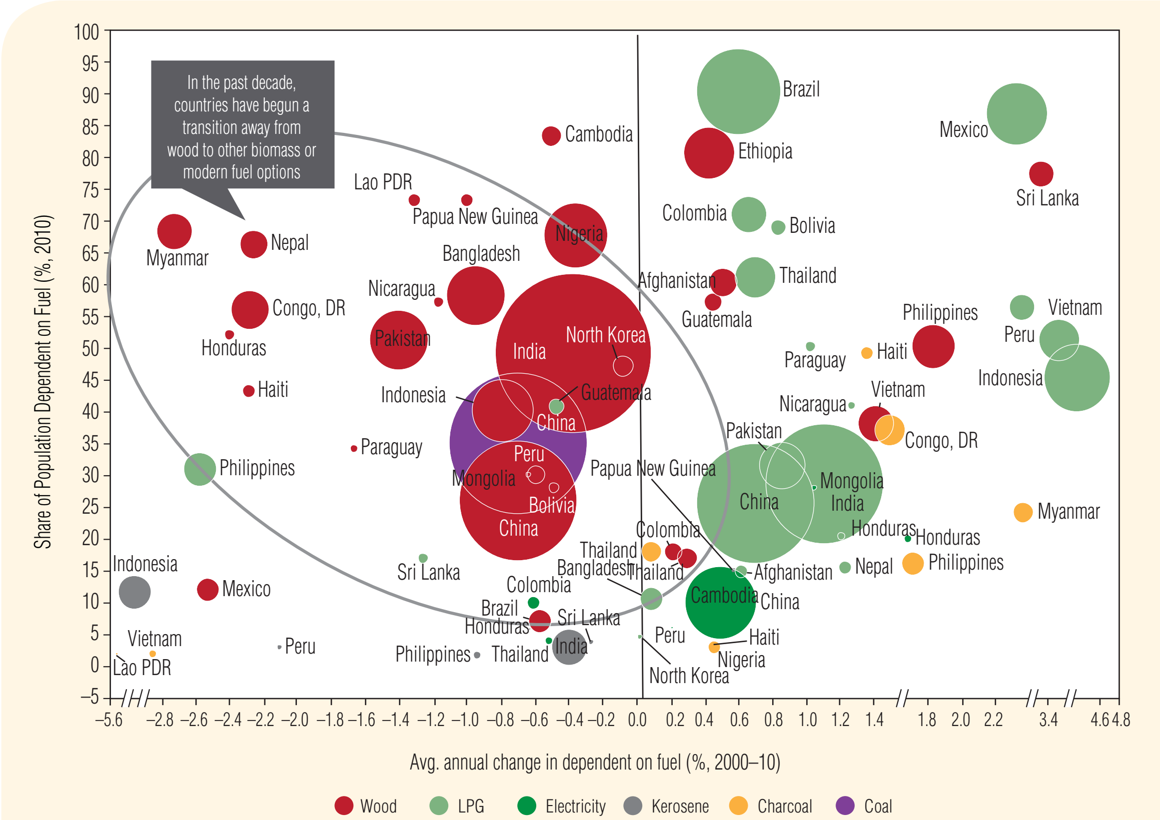
countries. Indonesia's subsidy policies, for instance, have explicitly promoted transition from kerosene to LPG fuel, resulting in a rapid increase in LPG uptake and pronounced decline in kerosene use in recent years.[206]

Absolute and Relative Fuel Costs

Over the past decade, prices for many fuel types have steadily increased. In the past few years, culminating in 2012–13 alone, South Asia has experienced double-digit annual increases in the prices of LPG, charcoal, and wood; Sub-Saharan Africa, on average, has seen similarly rapid price growth (Figure 3.8). This tandem growth in fuel costs provide households less incentive to switch to modern fuels, which remain up to 10 times more expensive than biomass alternatives. This obscures the fact that smaller increases in the prices of charcoal and wood represent significant annual percentage

FIGURE 3.7:

Solid and Modern Fuel Usage, by Region (2010)



Source: Historical fuel mix database drawing on WHO Global Health Depositary and other national and regional household survey resources for 82 countries; Dalberg analysis.

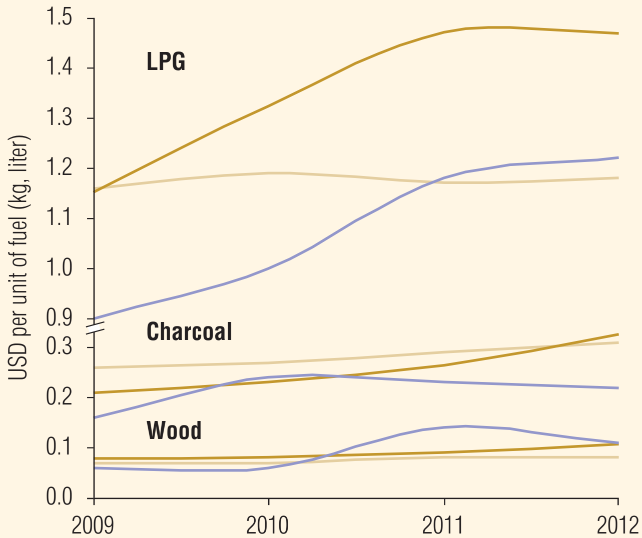
Note: China trends shown from 1991–2009 due to data comparability challenges for the 2000 national survey data (cooking only vs. cooking and heating for 2009).

growth in prices; according to regional averages, the unit cost of charcoal and wood has risen as fast or faster than LPG prices across all profiled geographies. This average data cannot speak directly to national or subnational price trends, which reflect government policies, access to vendors, and other unique cost factors. These macro-level trends, though, indicate that latent consumer demand for fuel-efficient cooking solutions is global, and likely to remain high while fuel prices continue to increase.

Reported fuel spending at the household level shows greater competitiveness between biomass and modern fuels in urban areas because of "poverty premiums." The urban poor often do not pay the same unit price for fuel as middle-class and upper-class consumers, even for the same types of fuel, because they purchase fuel in small quantities. The additional per unit "premium" the poor must

FIGURE 3.8:

Nominal Average Price Trend for Key Cooking Fuels (2009–12)



Corresponding Compound Annual Growth Rates

	LPG	Charcoal	Wood
Sub-Saharan Africa	+8%	+16%	+11%
Southeast Asia	+1%	+6%	+5%
South Asia	+11%	+11%	+22%

Sub-Saharan Africa — Southeast Asia — South Asia

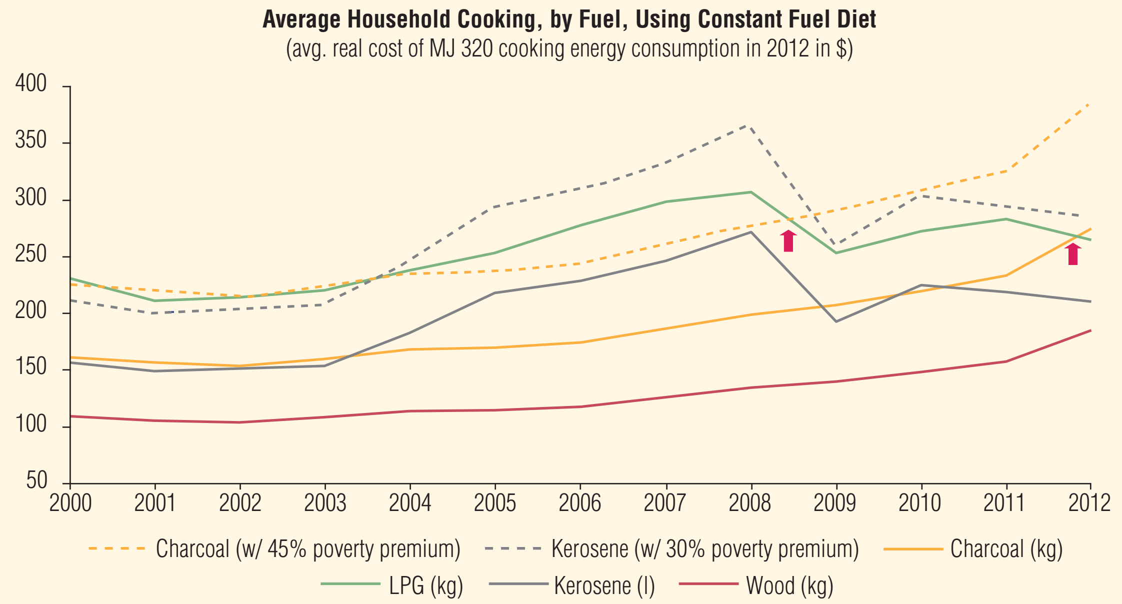
Source: Fuel price database for >70 markets globally based on publicly available sources and press searches; Task Team analysis.

pay because they cannot buy from distributors in bulk can be substantial—anywhere from 25–100%, depending on the locality. Taking this into account, the real cost of charcoal in an area sometimes becomes competitive with unit prices for modern fuels.

Fuel use data for Africa, based on a comprehensive data set for the continent, is an excellent illustration of this point (Figure 3.9). Aggregate market and household data suggest that, in the Sub-Saharan Africa region, the average real cost of charcoal exceeded the price of LPG for the first time in 2012. For the poor urban consumers reliant on frequent high-cost purchases of subscale packages of charcoal, the implicit poverty premium for woodfuel consumption has actually meant that this crossing point happened earlier, at some point in 2008–09. Naturally, this calculation does not reflect issues of relative access (i.e., LPG availability) and upfront equipment costs, but the trend does amply illustrate that, on average, modern fuel cooking is already cheaper in many parts of the world than reliance on high-cost biomass, a trend that will likely continue to accelerate in the coming years. This means that there is now increased potential for modern fuels, backed by quality infrastructure, to compete with woodfuel in low-income areas that may not otherwise be considered high-potential markets. For those consumers that cannot afford modern fuels, this trend of escalating woodfuel costs means that fuel savings ICS solutions will appeal to an ever-increasing number of consumers.

FIGURE 3.9:

Historical Fuel Cost for the Average Household in Sub-Saharan Africa



Source: Fuel price database (22 countries for charcoal, 11 for LPG, 45 for kerosene); Task Team analysis.

B. UNDERSTANDING THE CONSUMER

Segmentation Rationale and Methodology

Although understanding of the end user is critical to increasing clean cooking adoption, consumer demand has not been sufficiently studied in either a qualitative or quantitative fashion. The Global Alliance for Clean Cookstoves and the World Bank, among others, have begun to address this with in-depth country-level market segmentation analyses supported by a rising volume of ethnographic and human-centered design research on consumer behavior and preferences.[207] To date, however, these insights have not been integrated into a comprehensive segmentation of the global cooking consumer. In this section, we draw on existing segmentation methodologies, fuel-mix data, and consumer survey findings to make a first attempt at such a global segmentation. While many data gaps persist, this macro view of the cooking consumer sheds light on important demand drivers, including the very different preferences and needs of various segments, as well as the links between consumers' ability and willingness to pay for cleaner stoves and fuels and the size of the market that can be addressed with commercial or hybrid clean and improved cooking solutions.

Understanding consumer segmentation and related drivers of demand is crucial to achieving scale. The clean and improved cookstoves sector is by its very definition not monolithic. Households

TABLE 3.1:

Developing World Cooking Consumer Segmentation

	SIZE	SEGMENT PROFILE	SEGMENT CHALLENGES
Non-Wood Biomass Collectors[a]	~400 mil (<9%)	• 17% BoP<500, 80% BoP 500–1500 • 86% rural, 14% urban	• Use very dirty fuels; largely dung and crop waste • In most cases, lack access to more efficient fuels and stoves alongside other barriers like affordability and tradition
Poor Wood Collectors	503 mil (10%)	• BoP<500 • 94% rural, 6% urban	• Lack of disposable income to move up ladder • Long collection times/biomass scarcity • High health burden, but minimal awareness
Mid-Income Wood Collectors	859 mil (18%)	• 95% BoP 500–1500, 5% BoP 1500+ • 94% rural, 6% urban	• Lack of awareness of harms, but more sensitive to time burden of collection/cooking • No access to quality improved solutions
Poor Wood Purchasers	96 mil (2%)	• BoP<500 • 46% rural, 54% urban	• High fuel expenditures relative to income • Lack of awareness of harms or access • Cannot afford modern energy
Mid-Income Wood Purchasers	478 mil (10%)	• 85% BoP 500–1500, 15% BoP 1500+ • 60% rural, 40% urban	• Urban: Cannot afford to move up the energy ladder to available solutions • Rural: Lack awareness and access
Charcoal Users	174 mil (3.4%)	• 10% BoP<500, 58% BoP 500–1500, 32%>1500 • 68% urban, 32% rural	• High premiums for charcoal paid by urban poor • High share of income for urban buyers, but mid-income cannot afford to move up energy ladder • Rural/peri-urban have access to cheaper fuels
Coal Users	545 mil (11%)	• 56% BoP 500–1500, 28% BoP>1500 • 48% urban, 52% rural	• High health burden, especially for certain common coal types • Low quality of most available stoves
Modern Fuel Users	1734 mil (<37%)	• 75% BoP>1500 • 75% urban, 25% rural	• Danger of moving down energy ladder due to rising modern fuel prices/shortages • Lack awareness of solid fuel harms

Source: Dalberg consumer segmentation database.

a Primarily dung and crop waste collectors, but segment also includes a small population (<1% of consumers) of dung and crop-waste purchasers.

that use solid fuel cover the full socioeconomic spectrum. Their living arrangements range from densely settled urban slums to remote rural settlements; they eat a broad variety of cuisines based on dozens of staple foods; they employ an immense variety of cooking techniques, with sub-regional and intra-country variation; and they vary significantly in their consumption patterns and behaviors, such as the number of people eating a meal, frequency of meals, cooking methods, and kitchen settings.

While any generalization at the global scale necessarily obscures regional and country level variation, it is nonetheless illuminating to divide the developing world cooking consumer into eight segments based on a combination of income levels, urban vs. rural status, fuel use preferences, and fuel procurement approaches (Table 3.1). These segments fall into several broad groups: wood and non-wood biomass collectors (labeled in shades of red in the table), wood purchasers (blue), charcoal users (yellow), coal users (purple), and modern-fuel users (green).

Consumer segmentation based on primary fuel use must not obscure the need to look across multiple consumer segments, fuels, and stove technologies given the phenomenon of "stacking". The consumer segmentation methodology in this report focuses on the household's primary fuel use, but fuel choice is rarely an "either/or" decision. Households often employ "fuel stacking"—use of multiple fuel types, sometimes simultaneously—in the completion of daily tasks. Fuel stacking is a sensible practice for protecting against fuel price volatility and unreliable supply; use of multiple fuels can also reflect taste preferences.

In Africa, higher income households who use modern fuels commonly use charcoal as a backup option or for preparation of particular foods. In Senegal, for instance, households using LPG still use as much or more charcoal in total than households that only use charcoal.[208] In China, recent large-scale household surveys show that it is not at all uncommon to find 4–5 stoves and 3–4 fuels in any given rural Chinese household.[209] In remote areas, Chinese households that have access to agricultural residue will use straw and other crop residue after the harvest season. However, straw and other crop residues are not as heat efficient as coal. Therefore, in winter months households in provinces with access to coal will switch and purchase coal for heating, a phenomenon that cuts across income categories. In urban China, anecdotal evidence suggests that there is similar stacking behavior between LPG and coal. Using a Latin America example, in Mexico, fuel stacking behavior has similarly been observed with fuel switching not being unidirectional depending on circumstances and LPG not completely substituting fuelwood even as consumers up the income ladder.[210]

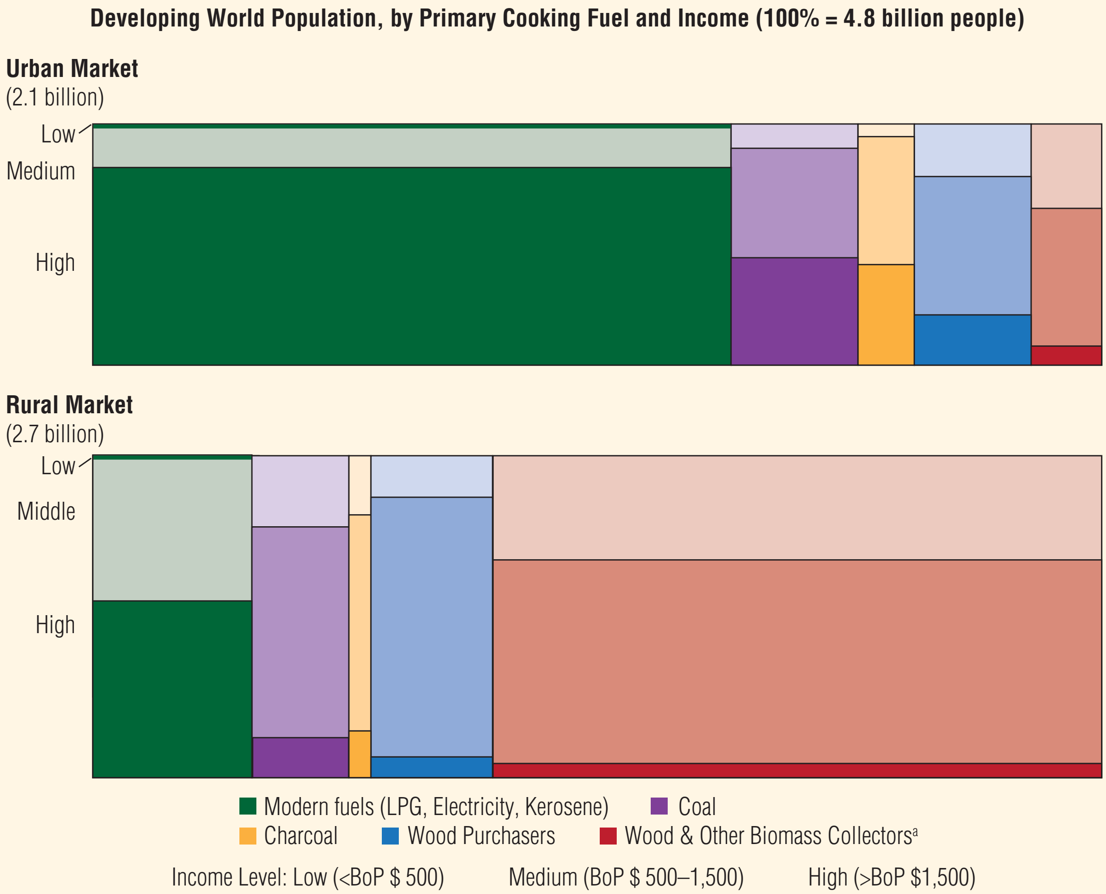
As such, the hypothesis of the "energy ladder" that suggests complete fuel substitution with increased income is not entirely representative. Successful clean and improved cooking interventions and business models should serve demand from multiple market segments in order to hedge against variable preferences within those segments, as well as geographic variance across and within global regions.

Consumer Segmentation Insights

As summarized in Table 3.1 above and reviewed in more detail in Figure 3.10 below, the specific challenges to cleaner cooking adoption and, therefore, the appropriate technological solutions and business models will vary widely across these segments.

Fuel collectors, accounting for ~37% of the total population, are primarily rural (>90%) and poor, though there is also a substantial lower middle-income (BoP 500–1500) fuel collector segment in some regions. As many as one-third of all fuel collectors are indigent subsistence farmers who live largely outside of the cash economy. These very poor (<BoP 500) fuel collectors are the most difficult segment to address with improved and clean cooking solutions since such consumers are typically unable to afford any but the most basic ICS. Even more important, unlike all other segments, fuel collectors see little direct economic value from more efficient, fuel-saving stoves since they do not currently spend money on fuels and typically undervalue the indirect economic benefits of reduced fuel collection and faster cooking time. Other barriers for fuel collectors include very limited physical access to cleaner cooking solutions due to their remote locations, limited awareness of the harms of traditional solid fuel cooking, and often substantial cultural and behavior change barriers due to the constraints of traditional lifestyles.

FIGURE 3.10:
Cooking Consumer Segmentation, Rural vs. Urban

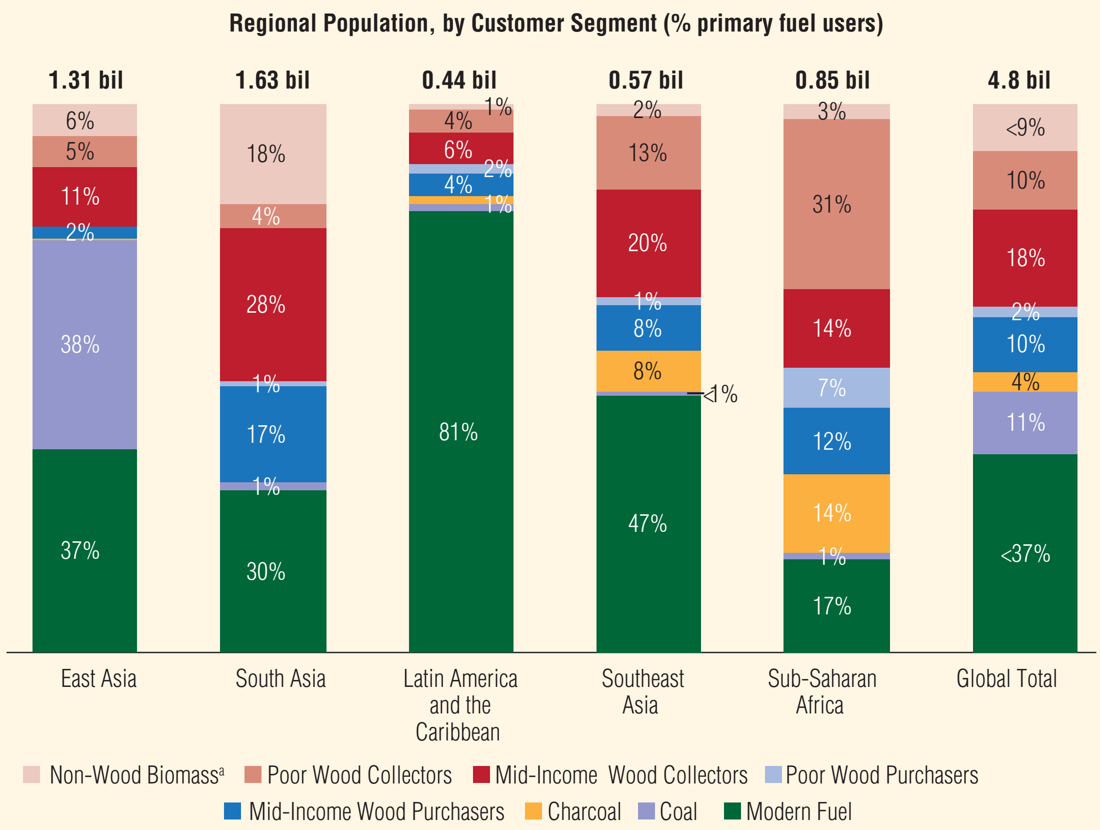


Source: Dalberg consumer segmentation database.
a Primarily wood collectors (76% of wood/biomass collector segment), but also many dung and crop waste users. Small share of crop waste/dung users pay for fuels.

The severity of these various obstacles lessens as one moves up the fuel ladder to **wood buyers** (12%). Because wood buyers already face moderate economic pressures from fuel costs, they are often more willing to consider efficient stoves. A surprising number of wood buyers are also urban or peri-urban, roughly half of the total, particularly in Africa and parts of Asia, which means that they, in theory, have greater physical access to distributors of cleaner stoves and fuels. Nonetheless, behavior change challenges for these segments are often substantial.

Economic incentives for cleaner fuel and stove adoption are even stronger for **charcoal and coal users** (<15% of total). Assuming the availability of appropriate solutions, the primary barriers to adopting cleaner stoves for this segment are an inability to afford the upfront costs of high performing

FIGURE 3.11:
Consumer Fuel Segmentation, by Income and Region



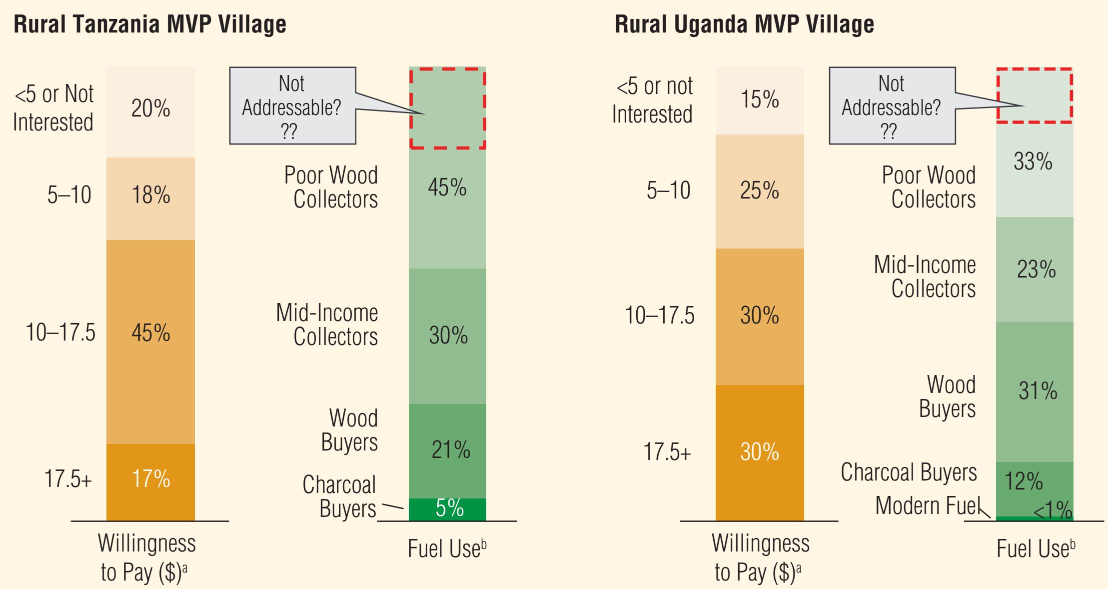
Source: Dalberg consumer segmentation database.
Note: Uses 2010 as baseline year to ensure meaningful cross-regional comparison.
a Primarily consists of dung and crop waste collectors, but also includes a small population (<1.5%) of biomass purchasers.

stoves without financing; high modern fuel costs which often, though not always, exceed the cost of traditional fuel alternatives on an annual basis; and limited consumer awareness of the broader benefits of clean cooking.

Finally, **modern fuel users** (37% of total) are the most able and open to adopting clean and more efficient cooking solutions, but are often under significant economic pressure due to the rising costs of clean fuels. The biggest challenges for this segment is ensuring that they do not slip lower on the energy ladder and, from a health and environmental impact standpoint, reducing the use of less clean secondary household stoves and fuels by such households.

A segmented view of the global cooking consumer highlights the vast gulf separating rural and urban users and the relationship between income and fuel use. Figure 3.11 maps these

FIGURE 3.12:
Rural Household Willingness to Pay for Improved Cooking Solutions



Sources: Atkins et al. 2010; GVEP 2010; Task Team analysis.

a Data extrapolated from Atkins, et al. (2010) and reflects willingness to pay for improved rocket stoves.

b Data for specific MVP villages not available. Uganda and Tanzania collector data based on GVEP assessment of rural areas in each. Country mid-income collector share set at 40% to reflect 30–50% range in studies of wood collector demographics in Chad/Sudan/Nepal/Guatemala.

consumer segments by fuel type and income, scaled to the share of these segments in the overall cooking population. This visualization points to a number of important trends. The urban market is dominated by modern fuel users and has a large proportion of consumers who regularly purchase costly solid fuels like charcoal and coal. The rural market, in contrast, is dominated by fuel collectors who constitute over half of the 2.7 billion rural cooking consumers. This mapping also shows the close links between income and fuel use. Wealthier consumers are heavily concentrated among modern fuel, coal, and charcoal users, particularly in urban areas. Wood and biomass users have the highest share of very poor cooking consumers.

The pattern across consumer segments differs a great deal by region (Figure 3.12). While both globally and regionally, fuel purchasers are in the majority overall, in Africa fuel collectors constitute nearly half of all cooking consumers, but the share of collectors is 22% in East Asia and under 11% in Latin America. Likewise, among solid fuel users, the population mix is highly variable across regions. For instance, the majority of wood collectors in Africa are very poor (<BoP 500), whereas with comparable levels of overall wood fuel reliance, the majority of wood collectors in South Asia fall into the lower

middle income category (BoP 500–1500). South Asia (17%) and Sub-Saharan Africa (12%) have relatively sizeable middle-income wood purchaser segments and Sub-Saharan Africa (14%) and Southeast Asia (8%) have many charcoal users. These segments can readily benefit from (and likely afford) more efficient stoves, whereas in East Asia—in contrast—commercial biomass markets are underdeveloped so nearly all biomass users are fuel collectors, with the result that the commercial opportunity for efficient and clean stoves is primarily linked to coal users, unless a commercial market for processed biomass (i.e., pellets) is established at scale.

Consumer Demand: Ability and Willingness to Pay

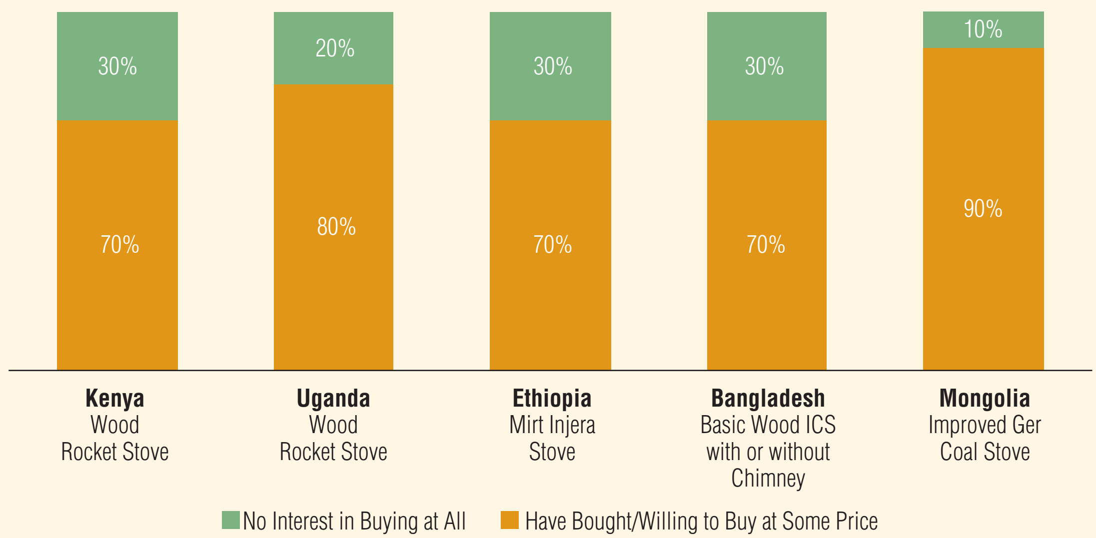
While the specifics will vary by fuel type and geography, the global cooking consumer segmentation sheds light on questions of ability and willingness to pay for clean and improved cooking solutions. Ability to pay is influenced mostly by trends in income and availability of financing. Willingness to pay is influenced by a more complex constellation of factors, including the fit of cooking solutions to consumers' needs and preferences, physical access and experience with clean and improved solutions, consumer awareness of potential clean cooking benefits, and consumer trust in the vendor and confidence in the advertised benefits of the technology. These two dimensions of demand are often confused.

A lack of willingness to pay for improved and clean cooking solutions is a major demand constraint across most stove technologies and end-user segments. Consumers at all income levels have rejected improved and clean stoves even when they have been made available to them for free or at a nominal cost. For instance, there are sizeable non-adopter populations in African cookstove program pilots, with up to 30% of target ICS end users (Figure 3.13) rejecting stoves that were provided to them at no cost or expressing no willingness to purchase these products at ***any*** price after an initial trial period. This proportion of non-adopters is similar to the experience of other global ICS distribution efforts in countries like Bangladesh, India, and Mongolia. There is less quantitative evidence for non-biomass improved and clean cooking technologies, but anecdotal reports from sector stakeholders suggest that similar non-adoption issues apply to clean modern fuels (LPG), biofuels, and biogas. This evidence suggests that separate and apart from any affordability issues, willingness to pay and somewhat related issues of technology fit and behavior change barriers are major constraints.

At the same time, there is significant evidence that where affordable and appropriate clean and improved stoves exist, adoption has been rapid and widespread; the ceramic *Jiko* stove has become baseline cooking technology among urban populations in Africa; intermediate ICS solutions, particularly highly efficient charcoal and coal stoves, are experiencing very strong market-driven sales in urban markets across Asia and Africa; and modern fuels and stoves have seen massive increases in adoption in those cases where such fuels have been subsidized. Even within rural markets, there is evidence that customers appreciate the time and cost savings associated with efficient stoves. Surveys conducted in Tanzania and Uganda, for instance, suggest that 80–85% of rural village residents are interested in paying for ICSs starting at $ 5, including 85% of wood collectors (Figure 3.14).

FIGURE 3.13:

Interest in Using Improved Cooking Solutions at any Price Point



Sources: Shell Foundation Breathing Space Survey data; GiZ 2011 MIRT evaluation; Miller and Mobarak (2011) for Bangladesh, ADB /New Dawn Engineering (2010) for Mongolia.

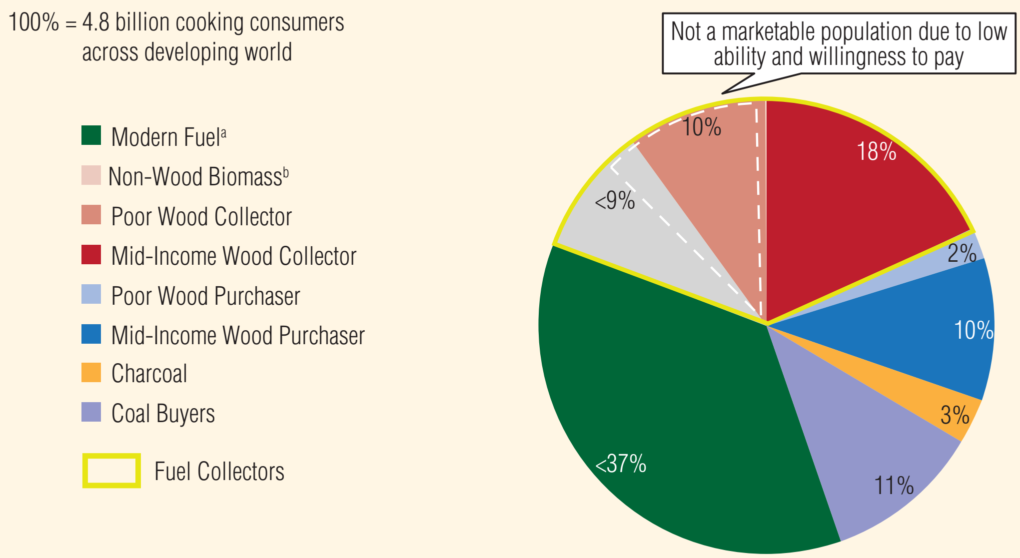
Even when initial willingness to pay is constrained, there is extensive evidence that familiarizing customers with ICS products through product demonstrations (see Box 3.1) leads to large increases in willingness to pay. The best evidence for increased willingness to pay with exposure currently comes from comparable products like solar lanterns, but there is increasing data on a similar phenomenon for cookstoves—a recent study of wood and charcoal improved stoves (intermediate ICS) in Uganda, for instance, demonstrated a five to six times improvement in uptake (20–30%) after a one-week trial relative to an upfront post-demonstration sale offer.[211]

Although most consumers can theoretically afford at least basic improved cooking solutions, high costs are a critical obstacle for the poor and impede the overall growth of the market. The nature of the affordability challenges varies greatly by cooking technology and consumer segment. Paying for cooking fuel and stoves is not an unfamiliar concept to the BoP, as 63% of all developing country households, including nearly half of all solid fuel users (<45%), already pay for their cooking fuels. Of the 37% who do not currently pay for their fuels, more than half are middle-income wood or biomass collectors who should have the ability to afford at least a basic ICS.

This segmentation suggest that the truly "unadressable" market segment where users have absolutely no ability or willingness to pay for any improved product is likely very small (Figure 3.14). The vast majority of consumers (75–95%, depending on country)—including many of those who fall below the

FIGURE 3.14:

Mapping Ability and Willingness to Pay, by Cooking Consumer Segments



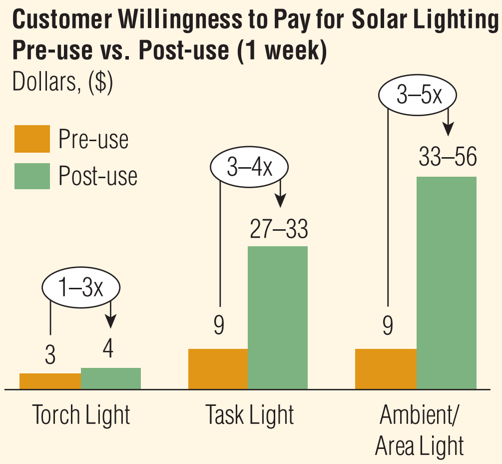
Source: Dalberg consumer segmentation database.

[a] Includes LPG (27%), natural gas (3%), electricity (3%), and kerosene (2.5%). Biogas is also included in this category (<1.5% of households).

[b] Primarily consists of poor biomass users of dung and crop waste (95% are dung and crop waste users; of these <10% purchase the fuels).

BOX 3.1:

Lessons from Marketing of Solar Lighting



Evidence from research conducted for the International Finance Corporation's (IFC) Lighting Africa report suggests that product demonstrations can have a great effect on uptake of new technologies. In this study, BoP consumers were up to five times more willing to pay for solar lighting technologies after one week of consumer education and hands-on use than they were before the demonstration. While this seems intuitive, it reinforces the importance of consumer services to technology distribution campaigns. Future ICS initiatives can increase focus on consumer education and demonstrations to aim for similar results.

Source: IFC/WB, *Lighting Africa* (2011).

FIGURE 3.15:

Barriers to Adoption, by Consumer Segment

	Non-Wood Biomass Collectors	Poor Wood Collectors				Charcoal Users	Coal Users	
Segment Size	400 mil (<9%)	503 mil (10%)	859 mil (18%)	96 mil (2%)	478 mil (10%)	174 mil (3.4%)	545 mil (11%)	1.7 bil (37%)
Current spending Monthly fuel (stove) cost	n/a	n/a	n/a	$1–10/mo. ($0–5)	$5–25/mo. ($0–5)	$5–35/ mo. ($1–12)	$1–10/mo. ($5–70)	$5–30/mo. ($10–70)
Household Income • BoP < 500 • BoP 500–1500 • BoP > 1500	 17% 80% 3%	 100% — —	 — 95% 5%	 100% — —	 — 95% 5%	 10% 58% 32%	 17% 56% 28%	 <1% 24% 75%
Location of Consumer	14% urban, 86% rural	6% urban, 94% rural	6% urban, 94% rural	54% urban, 46% rural	40% urban, 60% rural	68% urban, 32% rural	48% urban, 52% rural	75% urban, 25% rural
Awareness of solid fuel health harms/risks	◔	○	◔	◔	◑	◑	◔	◑
Awareness of improved fuels/stoves	◑	◔	◔	◔	◑	◑	◑	◕
(Physical) access to improved products	◔	○	◔	◔	◔	◕	◕	●
Ability to afford improved solution	◑	○	◑	◔	◑	◑	◑	●
Access to finance	○	○	◑	◔	◑	◑	◑	●
Cultural resistance to new technologies	◑	●	◑	◕	◑	◑	◔	◔

Sources: Various end-user surveys, Shell Foundation, Global Alliance Market Assessments; Dalberg customer segmentation database; Task Team analysis.

BoP 500 income tier (less than $ 1.25 per day)—are able to afford paying $ 3–10 for basic ICS once they have access to improved stoves and are convinced of the quality and utility of the product.

While the majority of the developing countries and regions can be reached with basic ICS, intermediate ICS and clean cookstoves costing $ 15–30 will likely be affordable to fewer consumers globally. For the 37% that consume modern fuels (Figure 3.14), stoves in this price range have already been purchased and we can assume that most would continue to have the ability to purchase such stoves in the future. Similarly, such stoves should be affordable and attractive, particularly with financing, for the 15% developing world households that use charcoal and coal and will see immediate and substantial economic benefits from switching to cleaner and more efficient

stoves and fuels. Finally, there is evidence that improved stoves in this price range are attractive and, with appropriate financing, affordable for a portion of the 12% of consumers who are relatively poor wood purchasers in rural and urban areas. For instance, the number of consumers willing to pay over $ 17 for an intermediate ICS in rural Tanzania and Uganda pilots suggests that such stoves are appealing for as many as half of wood buyers in rural areas.

There is little empirical evidence to suggest the ability and willingness of biomass collectors to pay more than a few dollars for improved stoves, though anecdotal reports from stove distributors in Africa, Asia, and Latin America confirm some paying ability and demand, particularly from wealthier biomass collector households. In sum, the global consumer segmentation suggests that intermediate ICS ($ 15–30) are a viable option for at least **60%** of developing world households.

The affordability challenge is especially problematic for higher-end cooking appliances and modern fuels where high upfront costs ($ 75–100 for biomass fan gasifier stoves, $ 50–100 for LPG and electric stove kits, $ 500–1500 for biogas) severely limit the clean cooking market's potential for the bottom half of the market. The challenge is not limited to upfront costs; for modern fuels like LPG and electricity, the ongoing costs of the fuel can be 4 to 10 times more expensive on an annual basis than purchased firewood; when compared to more expensive biomass fuels like charcoal, however, modern fuels, in some cases, can be competitive, even when unsubsidized.

Anecdotal stove manufacturing interviews and analogous data from WB/IFC's Lighting Africa program for the solar lantern industry suggest that consumers are willing to spend the equivalent of one to two month's fuel expenditures on an improved appliance. With this as an assumption, stoves in the $ 30–100 price range are only affordable to the highest income segment of BoP consumers (earning more than $ 1,500 per capita), an equivalent of approximately 34% of the global population.

Historical purchasing behavior also shows the importance of this constraint. Few developing world consumers today have spent more than $ 20–50 on their primary cookstoves. Shell Foundation surveys in Kenya, Tanzania, and Uganda, for instance, show that only **10–20%** of households in these countries purchased ***any*** consumer durable item costing more than $ 30 over the course of a year. The adoption of an intermediate ICS solution in the $15–30 range implies a significant re-allocation of budget priorities for an average household. The challenge is even greater for clean cookstoves since the average prices of clean stove appliances like LPG and biomass fan gasifiers range from $ 50 to 100.

In light of this data, it is likely that only the **wealthiest one-fifth to one-third** of consumers in the near term can afford cash purchases of the highest cost clean cooking solutions ($ 50–150) without major saving mobilization or major shifts in consumer preferences. This is a major challenge as cleaner and, generally, more expensive solutions are needed to reach optimum health and environment benefits.

ENDNOTES

200 In this report, data from 82 developing countries with a combined population of 4.9 billion has been used in the fuel mix analysis. This represents 70% of the global population and ~98% of the 3.1 billion global solid fuel users tracked in the WHO Global Solid Fuel data repository. The data for these 82 countries was corrected to: (i) reconcile urban and rural fuel mix data; (ii) update fuel mix estimates with the latest Demographic and Health Surveys (USAID), Multiple Indicator Cluster Survey (UNICEF), Living Standards Measurement Study (World Bank), or national energy household survey data; and (iii) eliminate other data inaccuracies such as inconsistent categorization of fuels (e.g., inclusion of natural gas in LPG category, mischaracterization of charcoal as coal). The latest year of data available, ranging from 2007 to 2012, with an average year of mid-2009, was used for each country to compute current aggregate and regional fuel mix totals. For most tropical countries, solid fuel cooking and heating data is identical, but the numbers differ significantly in countries with more temperate climates. Where possible, we use only cooking data. As an exception, for Asian countries like China and Mongolia, we use both cooking and heating data since the two cannot be disaggregated with great certainty across multi-year time series. Cumulative results were triangulated with an independent analysis of 2010 global fuel use (~3.1 billion solid fuel users) from Dr. Daniel Polsky and Ms. Caroline Ly, which combined WHO's parametric solid fuel estimates (WHO World Health Statistics Report) and the latest data available from the World Bank's World Development Indicators Database. The analysis was also triangulated with the Global Energy Assessment for a Sustainable Future, a report developed and validated by a network of 300 international researchers (GEA, 2012), which estimated a global solid fuel population of 2.9 billion.

201 Our conservative East Asia fuel mix estimate is based on national energy census data for China captured in the WHO fuel mix database (2009–10), this data indicated a solid fuel share of households of nearly 60% in 2009, up from 53–56% in 2000, largely due to increasing coal use. The 2009 data captured all solid fuel users without disaggregating between households using solid fuels for cooking and heating. More recent estimates suggest that these numbers may significantly overestimate the population relying on solid fuels for cooking. Estimates from (Bonjour et al., 2014) show China solid fuel use for cooking declining from 53% in 2000 to 43% in 2010, with much of the change due to a dramatic decline in coal use in urban areas. Even more recent preliminary survey data from the CRAES, the Chinese National Environmental Related Human Activity Survey of 91,000 households across 31 Chinese provinces (cited in Zimmerman et al., 2014), suggests an even more dramatic decline of primary solid fuel cooking households to 41% by 2013–14, with solid fuel cooking reaching a low of 61% of rural households and 20% of urban households, down from 67% of rural households and 41% of urban households in 2000.

202 United Nations Population Division. World Population Prospects: The 2010 Revision. Retrieved from: http://www.unescap.org/stat/data/syb2011/I-People/Population.asp.

203 Our forecast methodology uses a linear extrapolation of 2000–10 fuel-use trends, adjusted by overall population growth and urbanization. Income effects are accounted for within the historical rural-urban migration trends and fuel mix within urban and rural zones, but are not explicitly modeled. GEA (2012) and IEA (2011) estimates using comparable methodologies, but based on a smaller number of country data points, reach comparable solid fuel counts.

204 The baseline projection gives electricity a 5% share in 2020, but recent survey data from China (the 2013–14 CRAES) suggests that the country's urban areas are undergoing a dramatic shift to electric stove use (Zimmerman 2014) and corresponding declines in urban coal use. If this pattern holds through the end of the decade, the overall developing world fuel mix will be much more heavily skewed to electricity (9%). The fast growth of the electric convection oven market in urban India in recent years (30%+ annually) likewise suggests that the electric cooking segment may be growing more quickly globally then is indicated in lagging national survey data.

205 World Bank. Charcoal in Tanzania. Retrieved from: http://siteresources.worldbank.org/EXTCC/Resources/PolicyNote_Charcoal_TZ_08–09.pdf.

[206] International Institute for Sustainable Development, 2011.

[207] See Global Alliance market assessments in http://cleancookstoves.org/resources.

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[210] Masera et al., 2000.

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4

THE SUPPLY LANDSCAPE

This chapter provides an overview of the clean and improved cooking solution space, including the current status and market penetration of various fuel and stove technologies.

A. TYPOLOGY

The new ISO IWA guidelines offer a path forward to much greater terminological clarity. Recently, a coalition led by the Global Alliance reached an important milestone in their development of uniform performance metrics. In February 2012, an ISO IWA—unanimously affirmed by stakeholders from 23 countries—for the first time provided a set of globally agreed-upon guidance for rating cookstoves on four key performance indicators: fuel use (efficiency), emissions (carbon monoxide and PM 2.5), indoor emissions (carbon monoxide and PM 2.5), and safety (Figure 4.1). In the near future, three additional performance indicators are slated to be included—climate impact, durability, and field testing. The IWA represents a first step and is continuing to be improved through the ongoing international standardization process, including the formalization of an ISO standard and the formation of ISO Technical Committee 285 for clean cookstoves and clean cooking solutions in mid-2013.

The IWA ISO quantitative performance Tier definitions are designed to provide flexibility for stakeholders to target improvements in terms of the environmental, health, or economic impacts of cooking solutions according to their priorities. By using the IWA's harmonized and quantitative terminology, the goal is to replace terms like "clean" or "improved" that may be used differently by different donors or implementers.

As it stands, IWA is the first step towards arriving at a fully fledged consensus on global standards. It will take some time for testing capacity to be ramped up and for sufficient numbers of stoves to be tested against agreed protocols. Progress is already well underway with scaling up activities at many testing centers around the world, including 13 centers that are supported through grants provided by the Global Alliance. A further several years are required before the formalized ISO proposed "tier" system for categorizing stoves can fully take effect. Meanwhile, concerns around combining multiple metrics to provide an aggregate value and the implications of using current protocols to establish ranges within the tier system still exist. While the proposed ISO tiers aim to be representative of different indicators, there is a possibility of more granular nuances around stove performance being lost. Because stoves are often used for specific tasks, it might be worth considering how different models perform on more specific metrics, such as thermal efficiency, indoor air quality, and general emissions.

The level of thermal efficiency is a highly important metric when considering both economic savings for consumers and environmental impacts in terms of climate change and forest degradation. Improvements lead to better heat transfer to cooking equipment and more efficient fuel usage, though measuring thermal efficiency does not necessarily imply that these outcomes have been achieved and other factors are also relevant. Figure 4.2 shows the relative thermal efficiency of major stove types. On

FIGURE 4.1:

ISO Technical Committee 285 on Clean Cookstoves and Clean Cooking Solutions – Ongoing Progress

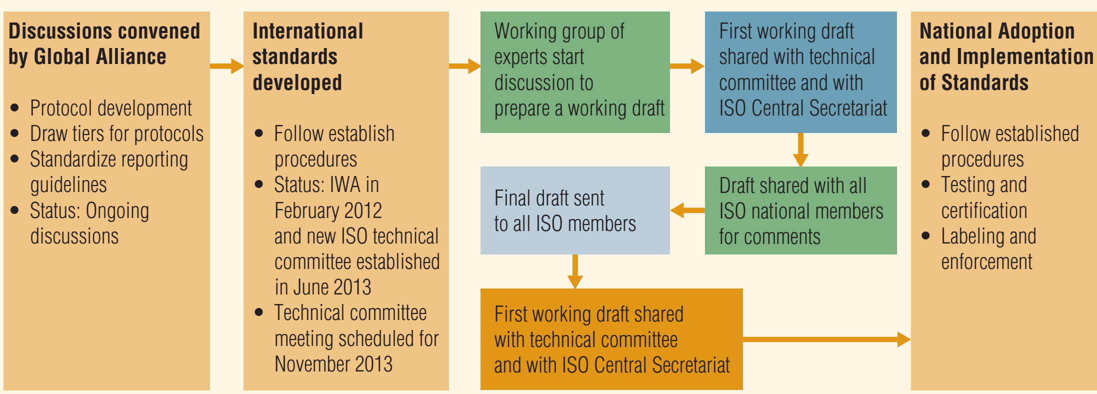
International Organization for Standardization Technical Committee (ISO/TC) 285, the key body that will develop and approve standards, was approved in June 2013. Kenya and the United States will serves as Co-Secretariats of the committee. The committee will be comprised of experts from participating national committee and external liaisons. The first ISO/TC 285 meeting was held 4–8 November 2013 in Nairobi, Kenya.

Additional Testing Activities in 2012

Developing a global network of centers for stove testing to catalyze regional activities. In fall of 2012, the Global Alliance awarded grants to over a dozen institutions in developing countries to build capacity as Regional Testing and Knowledge Centers. These institutions are strengthening their staff and equipment to be able to provide testing and knowledge-sharing services to catalyze regional cookstove activities. Beyond these institutions, the Global Alliance has also been working to establish a broad global consortium of testing organizations to share best practices and standardize results through regular in-person training workshops and webinars.

Integrating and sharing data about technology options. The Global Alliance has compiled stove performance data for laboratory and field testing performed over the last few decades and developed the Clean Cooking Catalog, a global guide to clean cooking solutions. This online resource has prices, performance, and characteristics of over 60 stove models and over 500 test results, and integrates information from manufacturers and testing organizations.

Standards Development Process

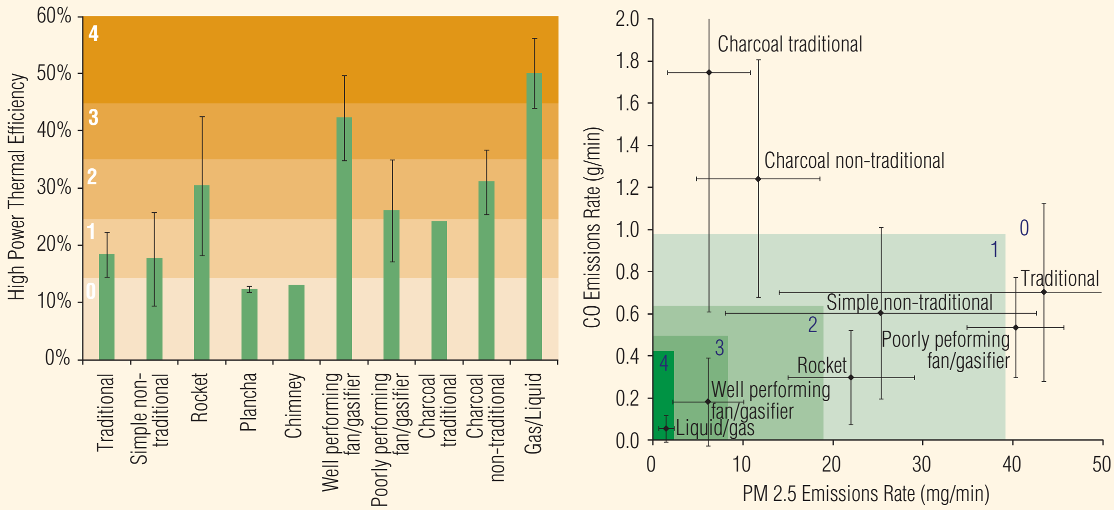


Source: IWA.

the one hand, many basic improved stoves do not achieve great improvements in thermal efficiency with scores under 25% that are analogous to certain traditional stoves. On the other hand, thermal efficiency scores above 30% are possible with advanced technologies, such as gasifiers and market-leading rocket stoves. It is important to recognize that different models of a particular cookstove type may vary significantly in their performance. In Figure 4.2, for example, rocket stoves achieve low emission scores, but their performance ranges across bands 1–3 in terms of thermal efficiency.

FIGURE 4.2:

Thermal Efficiency and Emissions Ranges, by Stove Type



Source: Global Alliance for Clean Cookstoves/Berkeley Air Monitoring Stove Performance Inventory Report (October 2012).
Note: Emissions and thermal efficiency performance for key cookstove/fuel classes across the IWA Tiers for the Water Boiling Test based on over 400 test sets.

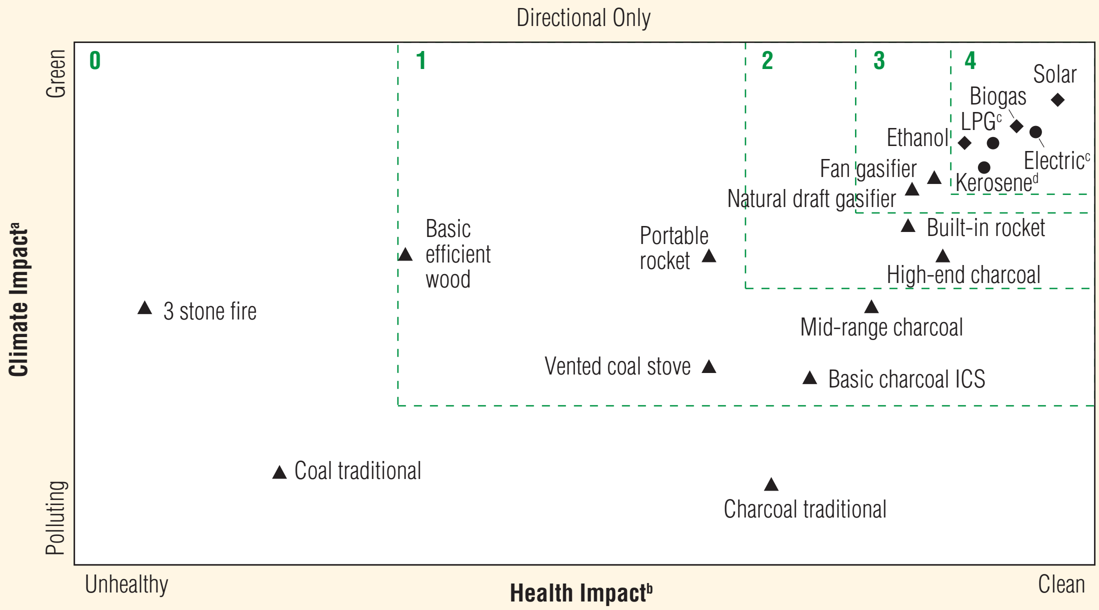
Beyond thermal efficiency, it is important to consider both the health and environmental impacts of improved cookstove designs. Health impacts stem from measures of particulate and other harmful substance emissions, such as carbon monoxide. Environmental impacts unrelated to fuel collection activities, such as deforestation, are measured through greenhouse gas emissions. These metrics are indicators relevant for climate and health impacts, but do not measure climate and health impacts directly. Both of these metrics are captured in Figure 4.3, which measures “climate” and “health” impacts based on composite scores. Modern fuels such as solar, LPG, kerosene, ethanol, and electric scores emerge as clear top performers on both these metrics. Meanwhile, biomass cookstove performance ranges widely by stove type along both the climate and health axes. Clear gradations of performance emerge between traditional, basic efficient, and advanced model stoves—although, as previously mentioned, numbered tiers have not yet been agreed upon and the figure includes only the likely classifications of different stove types.

In Figures 4.2 and 4.3, a hierarchy of stoves emerges based on the evaluation of “average” stoves against the performance metrics. However, different stoves within each category give rise to highly variable performances above and below these average scores, as seen earlier in Figure 4.2.

The metrics to consider for any cookstove typology extend beyond those linked to health, environmental, and economic impacts. While several of these highly important metrics have been

FIGURE 4.3:

Indicative Health and Climate Impact, by Stove Type



Source: Berkeley Air Monitoring Stove Performance Inventory Report 2012; Grieshop et al. 2011; Stove Database; Task Team analysis.

Note: The ISO tiers indicated by the dotted lines correspond roughly to the ISO IWA Tiers for emissions.

a Index on scale of 1–10 based on stove emissions of tons of GHG CO_2-eq including all particles from fuel combustion and charcoal production weighted at GWC100; assumes fNRB of 0.5

b Index on scale of 1–10 of daily PM 2.5 intake per person and CO concentration, weighted 80/20 to reflect the more deleterious effects of particulate emissions relative to CO

c Climate impact of electric and LPG stoves only includes CO and particulate emissions at point of fuel consumption; production of these fuels may have significantly negative climate effects (e.g., in the case of electricity production from coal combustion, but such climate costs vary across countries and are difficult to estimate)

d Kerosene stove results reflect measured PM and CO emissions and do not incorporate potential kerosene carcinogen effects

reviewed previously, there are many others worth considering. Potential customers will also consider other factors such as cost, design, life span, safety, and cooking times. Publicly available information on these factors is now available from an online resource developed and maintained by the Global Alliance for Clean Cookstoves.[212]

Figure 4.4 provides a high-level evaluation of major stove types against a broader range of metrics that include some of these other factors. This view draws important attention to some of the drawbacks of stoves that have performed well in the previously mentioned categories. Most notably, while modern stoves and biomass gasifiers perform very well on environmental and economic indicators, affordability is a very important drawback.

It is evident that there is a wide range of metrics that a particular consumer or stakeholder might care about. Moreover, a cookstove's performance cannot be forecast based on type alone. Having provided an overview of stove performance indicators, we now turn to a detailed description of stove types, including their advantages and challenges.

FIGURE 4.4:
Various Performance Metrics, by Stove Type

Category	Stove Type	Affordability	Fit w/ Custom	Life/Durability	Safety	Fuel Savings	Cooking Time	Environment	Health	Employment
ICS	Legacy Stoves	●	●	◔	◔	◔	○	○	○	◔
ICS	Basic Efficient Stoves	◕	●	○	◑	◔	◔	◔	◔	◕
ICS	Chimney Rocket	◕	◑	◕	◕	◕	◑	◑	◑	◑
ICS	Portable Rocket	◑	◕	◑	◕	◑	◔	◑	◔	◔
ICS	Advanced Charcoal	◔	◕	◑	◕	◕	◑	◑	◑	◔
ICS	Natural Draft Gasifier	◑	◔	◑	◕	◑	◕	●	◕	◑
ICS	Fan Gasifier/Jet	◔	◔	◑	◕	◑	●	●	●	◔
Modern	LPG	◑	◑	●	◑		●	◕	●	◔
Modern	Electricity	○	◑	●	●		◕	◕	●	○
Modern	Kerosene	◑	◑	◕	◑		◕	◕	◑	◕
Renewable	Ethanol	◑	◔	●	◑		◕	◕	◕	◑
Renewable	Biogas	◔	◔	◕	◕	◕	●	●	●	◑
Renewable	Solar	◑	◔	◑	●	◔	○	●	●	◔
Renewable	Briquettes/Pellets	◕	◑		●	◑		●		◕
Renewable	Retained Heat Devices	◑	◔	◑	●	◑	○	●	●	◔

Source: Stakeholder interviews; literature review; Task Team analysis.

B. TECHNOLOGY TRENDS

While some cookstove models have been based on the same basic designs for decades, many of the new models are subject to ongoing fuel and cookstove design innovation with several exciting trends in technology innovation across the full spectrum of cooking technologies.

Basic and Intermediate Stoves

There is continuing innovation around in-built and portable basic ICS. Multi-stakeholder initiatives like EnDev and ProBEC, working alongside national cookstove programs and NGOs such as GERES in Africa and Southeast Asia and HELPS in Central America, have made meaningful advances in emissions performance and durability by introducing new construction materials and improved technical designs for basic ICS and intermediate rocket stoves. There are now more

form factors, greater standardization in quality, and—particularly important—increased design customization.

While the latter is a long-standing trend, the past 5 to 10 years have seen a marked acceleration of design innovations targeting basic ICS. There is, for instance, continued evolution in the design of *plancha* style stoves across Central and South America, with stove models being replicated across national borders and adapted for different patterns of tortilla production, family sizes, and secondary dish preferences. The MIRT cookstove in Ethiopia and the Adhanet Mogogo in Eritrea, which have seen large-scale sales in the past 5 to 10 years, offer unique, customized designs because they enable regional users to simultaneously bake *injera*, a local flatbread, while cooking or boiling food without using additional fuel. Similarly, in recent years, radical adaptations have been introduced by UN Environment Programme (UNEP) and US Agency for International Development (USAID) for the *tandoor* stoves in Afghanistan, which are designed for both bread baking and the underground heating of living quarters. Improved Ger district stoves in Mongolia share similar principles, combining both cooking and space heating features.

The sector has also seen, in the past decade, a dramatic proliferation of basic portable stove designs, with hundreds of stove models now on record. For example, stoves distributed in Africa and Latin America under the EnDev program are highly customized at the regional and country levels with dozens of models, including adjustments in materials used, stove appearance, and functional characteristics like pot holder size and thermal properties.[213] GERES, an NGO which has seen major success at scale for basic ICS distribution, also extensively modifies its stoves (e.g., New Lao Stoves) to local conditions. Social enterprises like ILF in Africa and Microsol in Central America likewise focus on stove "localization" and end-user focus design.

We anticipate that this proliferation of designs will continue in the basic ICS sector in the next decade given the ongoing demand for basic, low-cost ICSs and the immense diversity of poor rural consumers' needs. In markets where basic ICS have become (or are becoming) baseline cooking technologies (e.g., Kenya), sector stakeholders report that the most important innovations in basic ICS design will be ones that focus on scalability of production and quality control since durability is a perennial issue. In distinction to the rural end-user segment, market experts observe increased convergence in stove designs due to the greater commonality of needs and preferences for urban consumers (e.g., convergence in urban portable charcoal ICS designs across East and West Africa).

The global intermediate ICS sector, dominated by industrially and semi-industrially manufactured solutions, is an even more active point of design innovation. Leading the way in developing a range of intermediate ICS technologies globally is Envirofit, which has a diverse selection of wood and charcoal cookstove models (10+) designed for different cooking needs and contexts. In a similar fashion, many of the more innovative and successful players in the intermediate ICS sector (e.g., EcoZoom, EzyStove, Burn Design, Grameen Greenway Infra, and Prakti Design) emphasize localization of design as an important competitive differentiator.

Aside from the general trend to customization, there are also several novel technological innovations in design and materials for intermediate ICSs such as:

Low-cost design. One example, I EzyStove, designed by Swedish firm Ergonomidesign, is a very low-cost portable wood rocket cookstove. The stove's combustion chamber is suspended within a wireframe exoskeleton. The stove is designed to be flat packed, and can be assembled by a local worker with basic tools. Ergonomidesign says the stove, despite its stripped down architecture, reduces fuel consumption by 40% and particulate emissions by 70%.[214] Flatpack designs have been utilized with some success by other ICS manufacturers like WorldStove (e.g., Lucia Stove), and is increasingly being adapted by new players looking to adapt stoves with more advanced features (e.g., natural draft gasification) to artisanal manufacturing processes.

Climate appropriate design. The Berkley-Darfur cookstove, distributed by the Potential Energy NGO, has been adapted with a tapered wind guard for the sandy and windy conditions of the Sahel. The stove, modified from the Indian-developed Tara stove, is also redesigned for Darfur's unique style of cooking and food.[215]

Durability. Envirofit's $CH_4$400 Charcoal cookstove has a combustion chamber composed of a patent-pending alloy that prevents deterioration and increases the durability and warranty of the stove's chamber. Highly durable materials have also been adapted by newly designed stoves like the *Jiko* Poa and *Jiko* Koa being sold by Burn Manufactaring in Africa.

Modular cooking attachments. Envirofit offers a variety of add-on products alongside their stoves, including a pressure cooker, a grill attachment, pot skirts, and a double pot attachment accessory with a chimney. While the inclusion of a pot skirt, which EcoZoom also sells with their cookstove, increases thermal efficiency and significantly reduces emissions, there is significant anecdotal evidence that usage of a pot skirt is low among BoP households.

Non-cooking functions. The BioLite HomeStove combines electricity generation via a thermoelectric generation unit (TEG) with cooking, and its manufacturer is planning to sell stoves with bundled LED lighting. It also has an onboard data-logging system, enabling field recording of data on a range of key usage metrics (such as frequency and duration of stove use, firepower, and charger usage) in a cost-effective and non-intrusive manner. Such a technology may have important research benefits in the context of both developing a better understanding of stove-usage and fuel-stacking strategies, and making the carbon-monitoring methodology more accurate and less expensive.

High-Potential Newcomer: Gasifier Stoves

The most exciting technological trend in the biomass cookstove sector is the growing range of forced draft and natural draft gasifier stoves. These stoves have shown the greatest potential to improve health and environmental outcomes, at least under laboratory conditions. Early models were unsuccessful because the complex construction made stoves expensive, fan draft stoves required an external electricity supply, and users had to significantly modify their cooking habits to operate them. For instance, many gasifier stoves required additional fuel preparation (chopping wood into small pieces), preprocessed fuels, and potentially inconvenient top loading.

Recent technological innovations mean these traditional gasifier shortfalls are no longer characteristic of the sector. New side-loaded designs are able to dramatically reduce emissions without tediously requiring the user to prepare the fuel or remove the pot to add additional fuel. Moreover, these stoves do not need to be prohibitively expensive. Thanks to low-tech "frugal design" and manufacturing innovations, inexpensive cookstove varieties are now available. The Gambia Greenstove Rockifier cookstove costs just $ 15, although the user needs to buy briquette feedstock fuel. Similarly, there are now low-cost, semi-industrially manufactured natural draft stoves, including the Awamu (ABE) Mwoto ($ 16–20) and the Peko Pe.[216]

At the very apex of cookstove technological innovation are fan gasifiers and fan jet stoves such as the Philips Smokeless Fan Stove manufactured in Lesotho by Africa Clean Energy and the BioLite Homestove currently entering into commercialization in India and Africa. In the case of BioLite, as previously mentioned, through its patented Direct Conduction Thermoelectric System, the HomeStove converts the heat of the flame into electricity. This technology enables the stove both to autonomously power an internal fan and to generate surplus electricity to charge mobile phones and LED lights. There is early evidence that the bundling of a cookstove with an electricity source may increase stove adoption, particularly among households that do not see value in purchasing a stove alone.[217] Other enterprises are exploring such TEG-linked designs, but have not yet released them on the market.

These gasifier technologies have great untapped potential. Whereas six or seven years ago gasifier technologies were highly experimental, now there are more than a dozen existing stove models in this category. However, the commercialization of advanced biomass stoves is still at a very early stage and more field testing, including longitudinal randomized control trials of health outcomes, is necessary to build on initial field testing results and prove the health and environmental benefits of these stoves.

Modern Fuels and Stoves

Among modern fuels, there generally has been less innovative activity relative to other cookstove types, though some companies are investing in updating LPG and kerosene cookstove design. A kerosene cookstove developed by Servals burns with about a 64% thermal heat efficiency and includes a "toppling-safe" feature, increasing safety for the consumer.[218] Arivi has a similarly innovative product in South Africa. New LPG cookstove designs have been developed with significantly higher fuel efficiency (about 90%) than traditional models (about 55%).[219] However, many of these models are quite expensive and not oriented to the BoP. There is, however, potential for entrepreneurs to design new LPG, electricity, and kerosene stoves for the BoP. The one-kg stoves promoted by Gulf Energy (Pima Gas) in Kenya and the three-kg cylinder stoves sold by Oando (O-Gas) in Nigeria have integrated burners, eliminating the need for separate cookstove purchases. They are also partly refillable, allowing for low-cost "top ups" that match BoP household income streams. Reducing cylinder size is not a new innovation, but the interest of large local gas distributors in expanding its marketing reach is an encouraging trend. GenteGas in Guatemala, for example, has similar business model adaptations for driving LPG adoption among the poor.

Renewable Fuels and Stoves

For renewable fuels, the cookstove market is embryonic. These stoves are typically expensive, including models that are designed for and manufactured in the developed world. When these technologies have been brought to the developing world, they have not been adapted to local conditions, and so have not yet gained significant traction in most markets. As the technology to adapt and improve performance improves, there is a real opportunity for entrepreneurs to design renewable fuel stoves for the BoP.

For **biogas digesters**, outside of the mass-scale biogas household plant program in China, there is innovation occurring around cost reduction, quality standardization, and more kit-based models. For example, the 'Plastic Bag Digester' is an inexpensive, prefabricated plastic biogas digester designed for farmers in developing countries. The device, which is UV-resistant and composed of recycled plastic, can be manufactured locally and installed in a day. Even more promising is the model of SimGas Tanzania, a partnership between the Dutch SimGas BV and Silafrica Tanzania, which manufactures and sells small-scale, environmentally sustainable manure-fed biogas digesters and stove systems custom designed for the East African farmer. Other examples of portable modular biogas digesters are in development; according to promoter data, these may lead to significant (50%) price reductions in the upfront cost of biogas digester systems, with comparable levels of field performance.

In the **solar cooker** space, the wealth of designs has not yet translated into large-scale sales with the exception of China. Nonetheless, important innovations are emerging, such as the recent release of the Sol Source 3-in-1, a parabolic cooker that not only cooks food, but also serves as a heater and electricity generator.[220] While the heating and electricity generation modules are still at a nascent stage of technology development, the concept holds promise. Other solar cooking innovations include the CooKit low-cost solar stove ($ 20–30), which brings the potential for solar cooking within reach of many more households as a supplement to traditional cooking solutions.

Innovation in Fuel Production

Innovations have also been occurring in technologies for processing plant oil. Project Gaia, which runs an ethanol-for-cooking program in Ethiopia, is currently building a micro-distillery plant to make ethanol from sugar cane. The project, with funding from the World Bank, will be able to produce 1,000 liters per day of ethanol from molasses feedstock. These micro-distillery facilities can be designed sustainably as cogeneration plants powered by the same biomass inputs.[221] Another promising geography where pilots have been launched is Madagascar. The largest scale effort on ethanol fuel production for cookstoves globally was in Mozambique as part of CleanStar Novozymes ethanol cookstove project, but did not see success.

Additionally, industrial scale manufacturing of renewable solid fuel pellets and briquettes is becoming more affordable, enabling entrepreneurs to expand their production exponentially. Biomass pellet cooking fuel manufacturing is present at scale in India—over 250 factories—though largely with a commercial and industrial client focus rather than a household cooking energy. China has a

large briquetting industry focused on coal and biomass, with 500–1,000 biomass briquette factories. Africa likewise has growing activity for green biomass briquette and pellet production with cooking applications, with large facilities launched in recent years in Kenya (e.g., StarDust), Uganda (e.g., KJS), Tanzania (e.g., EA Briquette Company), Rwanda (Inyenyeri), Ethiopia (e.g., African Briquet Factory), and Senegal. At the micro-entrepreneur end of the market in Africa, organizations like GVEP, Harvest Fuel, and the Legacy Foundation are supporting the migration of micro- and small-scale entrepreneurs from manual extruders to low-cost, locally fabricated, motorized briquette machines.[222] Artisans can manufacture briquettes manually with a capital investment of just $ 30–40.[223]

There have also been advances in briquette and pellet manufacturing processes. Torrefaction, for example, is a new thermochemical process in which biomass is mildly heated to dry out the solid biomass and deplete it of oxygen. The net result is a dehydrated product that is lower weight, greater energy density, and does not rot. The torrified material can then be compacted into briquettes or pellets (see Box 4.1). Through these processes, the fuel is easier to transport and store.

Charcoal production technologies are also seeing rapid innovation in design. Industrial gasifier retort kilns and a variety of lower cost intermediate solutions (e.g., ICPS retort kiln) now offer the potential of relatively clean charcoal production with reduced emissions and high charcoal production efficiency

BOX 4.1:

Emerging Fuel Technologies: Renewable Briquettes and Pellets

Biomass briquettes and pellets are created by compressing loose biomass and animal waste into a dense, solid form. There is a range of briquette-making processes that vary in their equipment requirements, capital intensity, and production capacity.

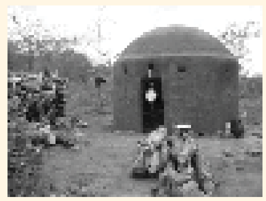
Advantages and Challenges

Their density allows briquettes and pellets to burn longer, and output heat more reliably, than fossil fuels. Briquettes and pellets are particularly useful in top-loaded stoves, as the user would otherwise need to chop the biomass into small pieces to fit inside the combustion chamber. Additionally, briquettes and pellets can be a renewable fuel source, if the raw materials are sourced from agricultural waste residue or sustainably harvested.

However, briquette and pellet production requires careful quality controls and technical knowledge (e.g., optimizing the ratio of agricultural residue to binding agents like molasses). Moreover, it requires its own fuel supply chain, including a consistent supply of agricultural waste feedstock. Since some forms of feedstock are volatile commodities, there may also be pricing challenges.

Micro-entrepreneurs can produce up to two tons per year by hand using inexpensive, simple tools. Small-scale entrepreneurs, by using manual extruders costing $ 150, and can produce up to 20 tons per year. Medium-size entrepreneurs use automated electric-screw extruders, which are nearly 10 times as expensive ($ 1350) but produce 10 times the yield (200 tons). Semi-industrial factories use imported machines, such as piston extruders and roller presses, which can make 2,000 tons annually but cost $ 50,000 to $ 100,000. Large-scale factories use hydraulic presses, which are very expensive (approximately $ 2 million) but can process 20,000 tons per year.

FIGURE 4.5:
Overview of Charcoal Kiln Technologies

	Traditional Kilns	Modern Kilns	Improved Kilns
	Range of technologies from earth mound kilns to crude brick kilns	Artisanal and semi-industrial kilns including brick and metal designs	Industrial and semi-industrial retort and gasifier kilns
			
Efficiency	**8–20%**	**12–30%**	**20–50%**
Emissions (in g per kg charcoal produced)	CO_2:450–550 CH_4:~700 CO: 450–650	→	CO_2:~400 CH_4:~50 CO: ~160

Source: World Bank, 2011b; Sepp, 2008; Task Team analysis.

(e.g., 30–50%, or 2–3 kg of wood per 1 kg of charcoal, up from 6–9 kg of wood per 1 kg of charcoal with traditional charcoal kiln technologies) at increasingly affordable price points for medium-scale charcoal producers (i.e., less than $ 5,000). More advanced biochar systems promise greater efficiency alongside the ability to produce biochar.[224] The current set of charcoal production solutions appears in Figure 4.5. The newness of the technology, the costs involved, lack of secure land tenure, and other regulatory challenges in most areas have led to limited uptake of such improved charcoal production solutions, but there is increasing attention being paid to the sector by donors and social entrepreneurs.[225]

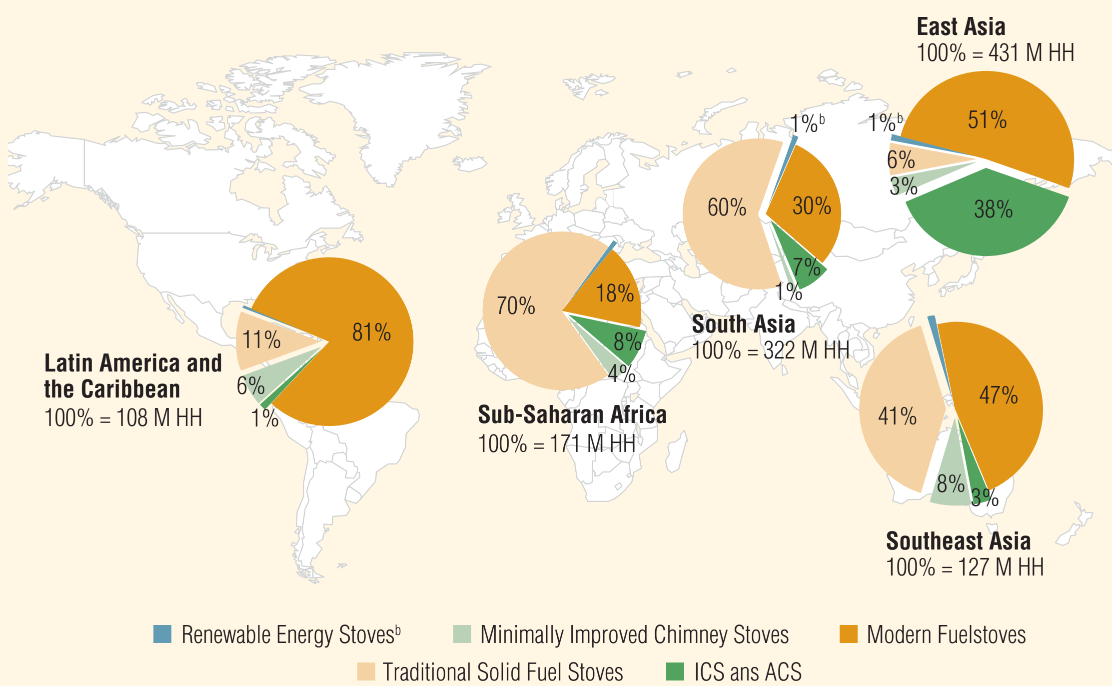
C. CURRENT MARKET STATUS

Basic, Intermediate, and Advanced Biomass Stoves

Despite the size of the opportunity, the market penetration of improved stoves and clean fuels is still limited. Out of the almost 700 million global households reliant on solid fuels (~3 billion individuals), we estimate use of roughly 200 million ICS units in 2012–13, which represents 30% of solid fuel-using households or 17–18% of all households. In terms of modern fuels, there is a great deal of variability across regions; modern fuels users (i.e., household using modern fuels as their primary

FIGURE 4.6:
Cooking Technologies, by Regio

Biomass Cooking Technology Mix, by Region (% of households)[a]



Sources: ICS penetration database with data for 72 countries from national program, donor, CDM, and individual manufacturer data; WHO chimney stove penetration database; Global Alliance Market Assessments; Task Team analysis.

Note: Data estimated for 2012 baseline year using 2010–14 source information at country level; aggregated up and triangulated to remove duplication. This is an upper bound estimate since, in absence of survey data for many countries, the analysis assumes one stove per household, an overly conservative assumption for portable improved stove technologies.

cooking fuel) represent up 80% of the cooking fuel market in Latin America, but are a minority of total households in most other developing regions (Figure 4.6). The largest shares of traditional unimproved solid fuel stove users appear in Sub-Saharan Africa (71%), South Asia (66%), and Southeast Asia (41%). Renewable fuel stoves (biogas and solar) are a significant segment only in China where the rapid expansion of biogas use and a traditionally robust solar market account for this segment's size.

When biomass stoves are disaggregated by stove type (Table 4.1), the biggest shares are made up of basic chimney stoves for which we have very limited information about levels of improvement (22%) and basic ICS (69%), which feature only some improvements. Intermediate ICSs that burn biomass more efficiently using rocket chambers (e.g., Envirofit, EcoZoom, Burn Manufacturing, Ezy Stove, Grameen Greenway) and built-in or semi-portable rocket style stoves (ONIL, Rocket Lorena, Patsari) constitute the next largest category at 8%. Finally, the advanced ICS segment than can reach or exceed ISO Tier particulate emissions standards is still at an early stage with a very small share

TABLE 4.1:

Regional Segmentation of Solid Fuel Improved Cooking Solutions (2012)

Millions of Households with Improved or Clean Solid Fuel Stoves

	SUB-SAHARAN AFRICA	SOUTH ASIA	EAST ASIA	SOUTHEAST ASIA	LAT AM & CARRIBEAN	TOTAL
Minimally Improved Solid Fuel (includes legacy)	**6.3**	**3.8**	**14.4**	**10.00**	**6.6**	**41**
Basic ICS	**9**	**23**	**150**	**4**	**0**	**186**
Basic Efficient Biomass (chimney)	0	9.2	122.1	0.0	0.0	131
Basic Efficient Biomass (non-chimney)	4.3	13.8	—	0.4	—	18
Basic Efficient Charcoal	4.7	—	—	3.6	0.05	8
Basic Efficient Coal (chimney)	<0.1	—	12	—	—	12
Basic Efficient Coal (non-chimney)	<0.1	—	16	—	—	16
Intermediate ICS	**4.5**	**0.25**	**13.5**	**0.1**	**1.33**	**20**
Built-in Biomass Rocket	3.5	<0.05	—	—	1.28	5
Portable Biomass Rocket	0.5	0.2	3.50	<0.05	<0.1	4
Intermediate Coal	—	—	10.09	—	—	10
Intermediate Charcoal	0.5	—	—	<0.05	0.01	1
Advanced Cookstoves (i.e., gasifier)	**0.05**	**0.5**	**1.0**	**0.02**	**0.01**	**2**
Biomass Gasifier	<0.1	<0.5	0.7	<0.05	0.01	<1.5
Coal Gasifier	—	—	0.3	—	—	<0.5
Total ICS/ACS	**14**	**24**	**165**	**4**	**1**	**208**
Total ICS/ACS with Minimally Improved	**20**	**28**	**179**	**14**	**8**	**249**

Source: Database of improved and clean cookstove penetration for more than 70 countries based on self-reported manufacturer and program data triangulated, where possible, with household surveys on clean fuel and ICS penetration; Task Team analysis.

Note: Difficult to esTmate split between minimally improved and basic efficient biomass chimney stoves; for conservaTsm, where stove quality is unknown (e.g., for unbranded improved plancha stoves in Central America) stoves are assumed to be minimally improved.

(<0.5%) of total market penetration. This category includes advanced biomass ICS such as natural draft gasifiers (e.g., TLUD) and forced-draft stoves (e.g., BioLite).

In terms of fuel, most improved stoves (~68%) rely on wood or other forms of biomass, such as crop waste. The coal cookstove market, consisting largely of users in East Asia, makes up the next largest portion (27%). The balance consists of charcoal stoves (5%).

These numbers must be interpreted carefully, as the analysis relies on a broad definition of "improved" cookstoves that includes legacy chimney stoves. Such stoves, typically built-in mud stoves made from local materials by skilled or semi-skilled masons, have been distributed in the millions since the 1980s, often through subsidy-based and NGO-driven approaches. There are examples of well-designed and quality-controlled projects promoting built-in stoves in recent years; one is the GIZ Hera program, which distributed 250,000 Rocket Lorena stoves in Uganda in 2008–10. The wide variety of built-in plancha style rocket stoves in Central America (Patsari, ONIL) fall into the same category. The distinction is important because RCT evidence shows that legacy built-in chimney cookstove variants often have limited impact on fuel efficiency and emissions and have suffered from the weak quality controls inherent in many earlier cookstove distribution programs.[226]

Regional Differences in Traditional and Improved Biomass Stove Preferences

Under this categorization scheme, it is important to note that the different regional biomass cooking markets are characterized by dramatic differences in stove styles and preferences.

Africa. Sub-Saharan Africa is predominantly a market of portable stove users with the three-stone fire serving as the traditional firewood and crop waste cooking solution, and the metal brazier or bucket stoves historically serving as the baseline charcoal cooking solution. Built-in stoves do have a tradition in some countries on the continent like Ethiopia (fixed stoves for *injera* cooking), Uganda, Kenya, Rwanda, and Nigeria, but the vast majority of built-in and semi-portable stoves have been introduced over multiple generations of improved stove programs. Chimney stoves are used occasionally, but are unusual. Given this pattern, it is unsurprising that the vast majority of ICSs in Sub-Saharan Africa (whether basic, intermediate, or advanced stoves), follow in the mold of traditional technologies—portable, typically chimneyless, single-burner stoves designed to handle woodfuels, crop waste biomass, or a combination of solid fuels. The vast majority of ICSs are artisanally produced. Stove prices across the continent are moderately high due to the high costs of labor, materials, and poor distribution infrastructure for basic stoves ($ 5–10), and high import duties, taxes, and transport costs for industrial ICS solutions that are mostly imported ($ 25–100).

South Asia. While characterized by massive intra-regional variation, the traditional South Asian biomass cooking market is predominantly built on *chulha*-style stoves, typically featuring multiple pot holders and chimneys. Most stoves utilize firewood, crop waste, and animal dung, the latter a regionally important fuel; charcoal and coal are of subregional importance in select geographies. The use of unimproved chulhas is often combined with basic three-stone fires or, more rarely, primitive clay stoves that offer the household flexibility for cooking stew-based dishes and bread preparation. Most of the unimproved chulhas are self-built by owners. A large swathe of the region requires specific cooking adaptations for the preparation of staple rice dishes (Indian rice belt, Bangladesh, Sri Lanka) and beans (dhal). The chulha culture can be traced across key regional geographies like India, Pakistan, Nepal, and Bangladesh. The improved stove culture mirrors these preferences with the dominance of fixed, chimney-based improved stoves, although portable stoves also have seen uptake.

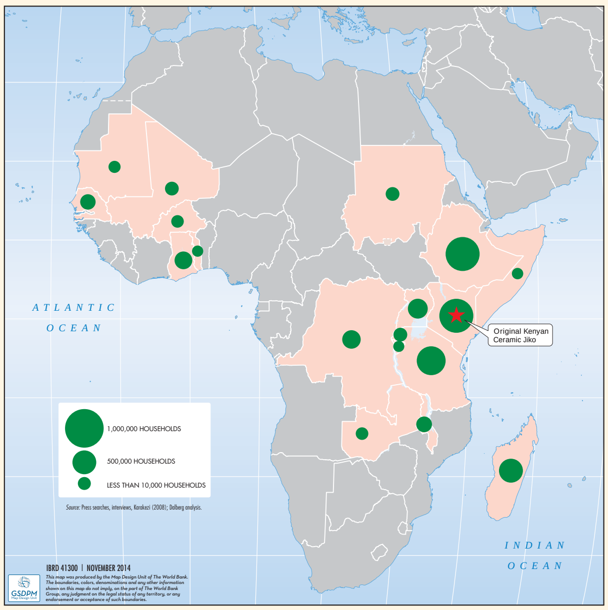
Portable ICSs are particularly important in markets like Sri Lanka (e.g., Anagi stove). The vast majority of improved stoves are artisanally produced, often on location by skilled artisans or constructed by owners with some external support. Stove costs, across all manufacturing modes, are relatively low ($ 5–40)—typically below the cost of improved stoves in all regions other than Southeast Asia.

East Asia. This region, dominated by China, differs significantly both in terms of solid fuel preferences and traditional stove features. China is the world's largest coal cooking market. Correspondingly, coal stoves (basic coal stoves or improved stoves distributed via the National Program and now replaced through more commercial mechanisms) and coal fuel supply chains (coal briquettes) are major features of the market. The vast majority of coal stoves feature chimneys and many are built to provide space and water heating, another important general feature of the China market explained by the large share of the population living in cool climates. Aside from coal cooking, the China market also has a large biomass cooking segment, which is split into crop waste cooking (20–50% based on region) and firewood users. As with coal stoves, most biomass stoves are built in and often feature space heating features. The legacy of the China improved stove program and its historic reach (up to 180 million households at peak) has meant that most of the stoves in China are either industrially or semi-industrially produced. An important implication of this mode of production, and the fact that many stoves are built in, is that ICS solutions in China tend to be at the higher range of costs globally alongside improved stoves in Central America (i.e., $ 30–150).

Southeast Asia. This region features very different cooking cultures, but has some common trends, including the regional importance of charcoal as a cooking fuel (e.g., Philippines, Vietnam, Myanmar, Cambodia), the use of coal in a number of countries with cultural and economic linkages to China (e.g., Vietnam), common cooking behaviors linked to the staple rice crop, and a strong overall preference for portable, unvented stoves. The dominant biomass cooking technologies across the region are portable unvented cookstoves. The vast majority of improved stoves in the region are produced through scaled, semi-industrial production models (i.e., GERES). The cost of improved stoves is typically low, with some of the lowest prices for basic ICSs globally ($ 1–5 in countries like Cambodia, Lao PDR, and Myanmar).

Latin America and Caribbean.[227] The distinguishing feature of solid fuel stoves markets across much of Central America and South America is that the prevalence of tortilla-making necessitates that a *plancha* (griddle) be included in ICS design, which leads to larger, heavier, and less portable stoves. Cooking is done traditionally using open fires or with rudimentary stoves, with or without a chimney, that are usually home-built with help from outside labor and, in the case of improved stoves, often relying on standardized, semi-industrially produced parts. In addition to cooking, like in China and Himalayan South Asia, stoves in this region often serve other functions, including heating water for drinking or bathing and space heating. A rocket elbow in the combustion chamber, plancha, and chimney have become standard elements of the design for most ICS available in the region. The costs of producing such stoves, whether in situ or premanufactured industrial stoves, with these elements is high, the highest across ICS solutions globally ($ 60–200). Portable and typically lower cost stove solutions have seen much less uptake in the regions, with the exception of relatively uncommon

FIGURE 4.7:
Distribution of Ceramic *Jiko* and Comparable Models in Sub-Saharan Africa



Country	Local Name
Kenya	Kenya Ceramic Jiko
Rwanda	Canamake
Sudan	Canunel Sarour
Uganda	Ceramic Sigiri/Usika
Tanzania	JikoBora
Malawi	KCJ/Ceramic Mbaula
Ghana	Gyapa
Senegal	Jambar/Diambar
Zambia	Ziko
Ethiopia	Lakech
Mali	Sewa
Burundi	KCJ
Burkina Faso	Diambar/Sewa
DRC	Butembo/KCJ
Madagascar	Fatana Mitsitsy
Somalia	Kenya Jiko
Mauritania	Sewa

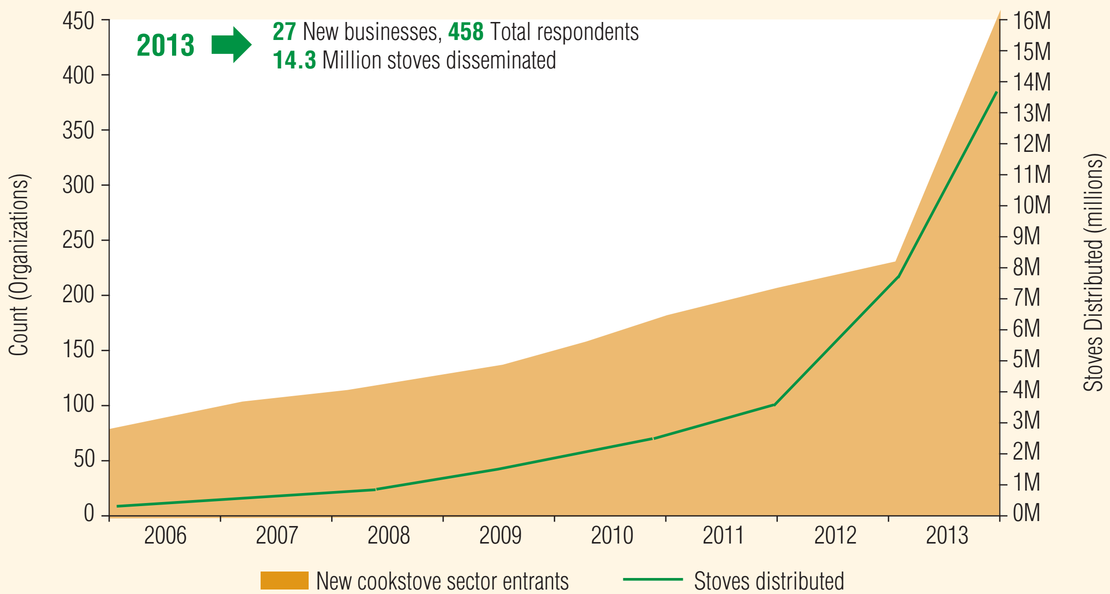
Source: Press searches, interviews, Karakezi (2008); Dalberg analysis.

portable *plancha* models (e.g., Nixtamal and Ecocina in Guatemala) and the majority of stoves in Haiti, where improved charcoal ICSs are the dominant form of improved stoves.

Stove Production and Sales Trends

From a production standpoint, although the market penetration of industrially produced stoves is growing quickly, the biomass ICS sector is currently dominated by artisanal and semi-industrial stoves. Excluding basic vented biomass and coal stoves, which are often self-constructed by users, our analysis of the global ICS market suggests that the majority of the 200 million ICSs in use around the globe today have been produced by artisanal methods in local workshops or on location by trained builders. Semi-industrial stoves, featuring greater scale, some mechanization of production, prefabricated standardized parts, and improved quality controls represent 25–40% of households. Industrial stoves produced with mechanized methods, using precision-tooling and higher performing materials, are being utilized by <2.5% of ICS-owning households (4–5 million) by late 2013. The situation is particularly stark in Africa where underdeveloped, semi-industrial ICS markets mean that artisanal solutions account for over 90% of improved stoves in use. In markets like China, in contrast, the vast majority of improved and clean stoves are industrially or semi-industrially produced.

FIGURE 4.8:
Stoves and Organizations Tracked by the Global Alliance for Clean Cookstoves



Source: Global Alliance for Clean Cookstoves.

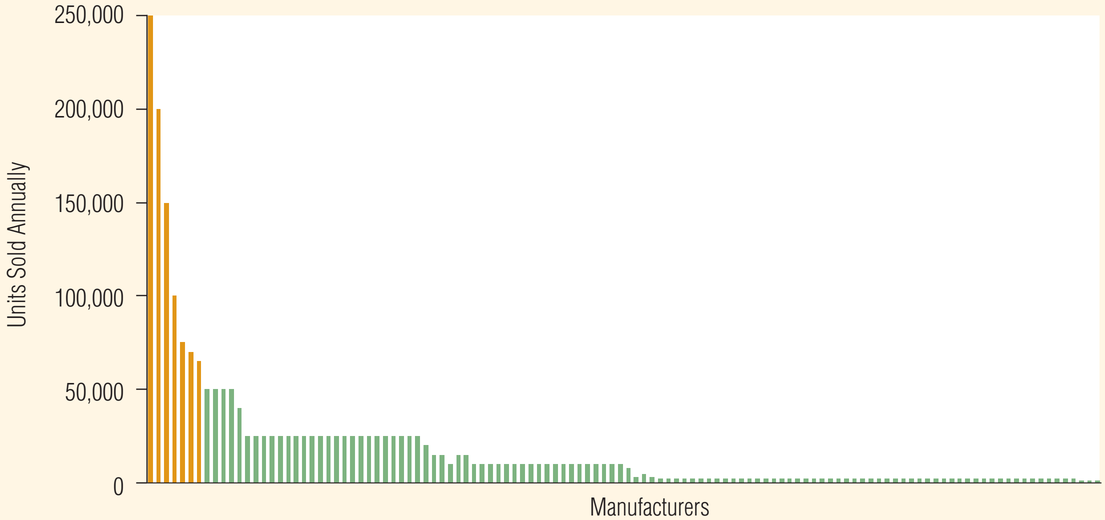
Note: Data prior to 2012 tracked by PCIA, function now taken over by the Global Alliance for Clean Cookstoves. Latest data (2013) reflects responses from 458 organizations, which represent under half of Global Alliance's membership base.

The prevalence of artisanal ICS models is well illustrated in Figure 4.7 with the map of Kenya Ceramic Jiko-type technologies for wood and charcoal cooking present across Sub-Saharan Africa today, a footprint of over 25 million households across the continent.

Sales growth has been rapid across all ICS technologies and methods of production. Annual growth in cookstove sales based on the self-reported data from Global Alliance for Clean Cookstoves partners, and building on the legacy data of the Partnership for Clean Indoor Air (PCIA), has exceeded 50% over the past decade (2003–13), quadrupling from 3.6 million units distributed and sold in 2011 to 14.3 million units in 2013 based on the latest partner survey (Figure 4.8).[228]

Self-reported global manufacturer and cookstove program data available to the report team, a larger universe of data points, suggests that sales of industrial and semi-industrial stoves have risen much more rapidly (50–300% annually) than the artisanal sector (10–50%) over the past five years, albeit from a much lower base. ICS sales from industrial and semi-industrial manufacturers serving the Chinese market, for instance, grew tenfold over a six-year period ending in 2011, now likely approaching 2 million units annually by 2013. The fast global growth of industrial ICS is reflected in the rising number of industrial and semi-industrial manufacturers. For instance, of the 35–40

FIGURE 4.9:
Annual Sales of Industrial and Semi-Industrially Produced Stoves



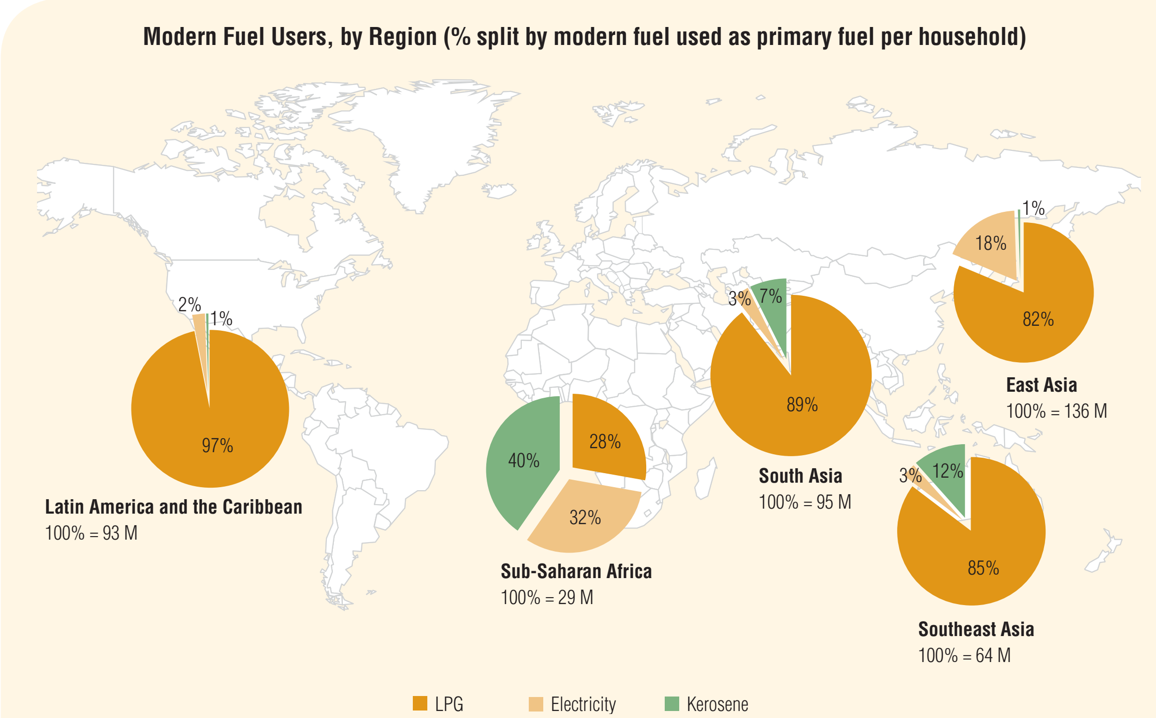
Source: Task Team analysis of data from 50 improved biomass stove manufacturers. This list includes most of the top global manufacturers and relies on both self-reported and estimated data, triangulated through industry interviews.
Note: Excludes coal stove manufacturers in China.

semi-industrial and industrial players active in Sub-Saharan Africa today, roughly 33% started their operations in the past 2 years, and 80% did not exist 5 years ago. Globally, there are now over 10 global industrial ICS manufacturers with annual sales of over 100,000 units and over 40 with annual sales above 20,000 units, a major leap in scale and sophistication for the sector, though the sector is still heavily fragmented with many small players (Figure 4.9).

Modern Fuels and Stoves

The market penetration of modern fuel and renewable fuel stoves varies significantly by region. Globally, 36% of all developing world households—more than 1.7 billion—rely on modern fuels (LPG, kerosene, or electricity) as their primary fuel source. Most households use several fuel sources, basing their choices on relative fuel pricing, availability, and local cooking practices—for example, using modern fuels for warming meals and traditional fuels for preparations involving lengthy cooking time. In terms of modern fuels, LPG may hold the most promise because of its clean-burning qualities and relatively low cost. Yet, demand for LPG is highly linked to the price of local fuel, which is subsidized in some economies and taxed in others. Countries rich in this form of energy tend to promote it through financial incentives, driving affordability for this fuel in response to consumer

FIGURE 4.10:
Regional Segmentation of Modern Fuels



Source: Global ICS and clean fuel penetration database; Task Team analysis.
Note: Relies on DHS/MICS/National Survey data from 2005–15; average year of data for global sample is roughly 2012–13.

TABLE 4.2:
Estimated Penetration of Renewable Cooking Technologies (2015)

TECHNOLOGY	HOUSEHOLDS REACHED	KEY GEOGRAPHIES FOR STOVE/FUEL
Biogas Digesters	> 50 Mil[a]	China, India, Cambodia, Nepal, Vietnam, Bangladesh
Ethanol / Ethanol Gel	> 350 k	South Africa, Ethiopia, Malawi, Nigeria, Mozambique, Zimbabwe, Botswana, Haiti
Solar Cookers	> 2 Mil	China, Haiti, India, Nepal, Guatemala, Thailand, Vietnam, Sri Lanka, Mongolia
Briquettes / Pellets	>1.4 Mil	India, China, Indonesia, Kenya, Tanzania, Rwanda, Ethiopia

Sources: Publicly reported program and manufacturer data; global fuel and ICS penetration database; Task Team analysis.
a Includes biogas digester households not using biogas as their primary fuel; primary biogas using household figure is significantly lower (<20 mil).

demands. Multiple local distribution channels distribute cylinders to remote consumers; these channels are difficult to regulate.[229]

In terms of the breakdown among modern fuels, LPG is the dominant fuel type in most regions, making up over 70% of modern fuel use in all regions, except Sub-Saharan Africa (Figure 4.10). In some regions, the figure is higher than 90%.

Renewable Fuels and Stoves

Relative to improved solid fuel cookstoves and modern fuel stoves, usage of renewable alternative fuel source stoves is even more limited. As shown in Table 4.2, an estimated 45–50 million households worldwide rely on biodigesters, with the vast majority located in China (over 40 million) and India (about 5 million). There are estimated to be over 2 million solar cookers worldwide, about 1.5 million of them in China, and fewer than 50,000 liquid biofuel (e.g., ethanol cookstove) users.

ENDNOTES

212 See the Clean Cooking Catalog available at: catalog.cleancookstoves.org.

213 See EnDev at http://www.endev.org. EnDev is a multi-donor program, spearheaded by GIZ, that has been the biggest donor program in terms of improved stoves delivered globally over the past 10 years.

214 Ezy Stove: http://www.ezylife.com/shop/ezystove

215 http://cookstoves.lbl.gov/darfur.php

216 http://www.mwotostove.com/; http://www.pekope.info/stove.html

217 Mobarak and Grant, 2011.

218 http://servalsgroup.blogspot.in/2008/06/energy-efficient-kerosene-stoves.html

219 Personal interview with Alex Evans, Global LPG Partnership, New York, October 2012.

220 http://solarcooking.wikia.com/wiki/SolSource_3-in-1

221 http://www.projectgaia.com/blog/2012/10/05/new-gaia-annoucements-ethiopia-haiti-madagascar/

222 http://www.gvepinternational.org/sites/default/files/briquette_businesses_in_uganda.pdf

223 http://www.gvepinternational.org/sites/default/files/briquette_businesses_in_uganda.pdf

224 Mercer et al., 2011.

225 World Bank, 2011b.

226 Hanna et al., 2012.

227 Discussion of Central and Latin America region stoves draws on Wang et al. (2013), the Global Alliance market assessment reports on Peru, Mexico, Guatemala, Colombia, and Brazil, regional interviews, and web searches.

228 Global Alliance for Clean Cookstoves, 2014a.

229 World Bank, 2011c.

THE COOKING APPLIANCE SUPPLY CHAIN

This chapter provides an overview of the supply chain for clean and improved cookstoves, highlighting key trends, challenges, and opportunities across components.

The cookstove value chain is composed of a number of activities, including research and product development, production, marketing, distribution, and after-sales service. Underpinning the whole value chain are the financial and regulatory systems that enhance both supply and demand. With this as the basic framework, the rest of the chapter is devoted to understanding the variation in the actors involved at each stage and the different models employed.

A. RESEARCH AND DEVELOPMENT

Research and development is an essential component of the cooking appliance value chain, especially as players attempt to mainstream their products in frontier markets. A wide variety of customer segments exist for cookstoves based on characteristics and price points. While competition and the attractiveness of the growing markets will incentivize research and development (R&D) investment, strategic engagement in the R&D process by donors and other actors may facilitate even greater expansion in this crucial component of the supply chain.

Although R&D in the cooking appliance sector lacks focus, three successful primary models for product development and research have emerged. These models are based on local designs, international designs, or hybrids. Different players in the cookstove ecosystem have opted for different R&D approaches. These are outlined in Table 5.1, alongside some of the key players.

Each of the three models comes with unique challenges and advantages. Locally designed stoves are created with a better view of the market in mind, but often lack the finance or capacity to develop high quality models. By contrast, international stoves may use high-end materials and yield greater benefits to consumers, but they are often poorly adapted to the local user, especially in terms of price. Hybrid models seek to take advantage of the best of both worlds, but are difficult to execute in practice given multiple remote designers.

B. PRODUCTION MODELS

As with the research and product development phase of the cooking appliance value chain, the production process can also be broken down into several subprocesses. Each subprocess can be organized in different ways. As illustrated in Figure 5.1, the production phase comprises raw material purchase, labor, and manufacturing. This is followed by a post-production phase, involving shipping (if applicable), government charges, and all costs associated with distribution and retailing. This value chain has been generalized in order to parse out the differences between different production processes and technologies. Although its construction is most relevant to the supply of biomass

TABLE 5.1:

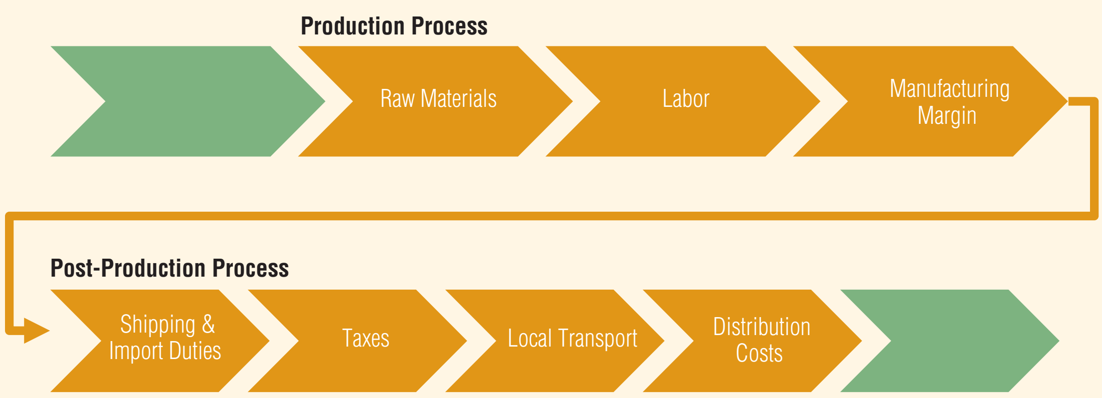
Research and Development Models

R&D MODEL	DESCRIPTION	EXAMPLE
Locally Based Design	Design and development specific to country context by local players	Microsol, EnDev, Practical Action, EnterpriseWorks/VITA, geres
International Stove Design	Design and development in international setting introduced in markets in standard formats	ecozoom, Philips, Envirofit, BioLite, Greenway
Hybrid Adaptive Design	Design and/or component development conducted in international setting but modified and adapted based on local needs and preferences	burn, Pro Leña, Prakti, Helps

Source: Program documents; Task Team analysis.

FIGURE 5.1:

The Production and Post-Production Value Chains



Source: Task Team analysis.

cookstoves, the underlying drivers are also relevant for other cooking appliances such as LPG and ethanol stoves. To a great extent, different methods of production will drive the relative significance of each component in the production process. The main production methods to consider are **industrial, semi-industrial,** and **artisanal**.

As Figure 5.2 shows, we can conceive of the three models as existing on a continuum of mechanization and scale, with additional "sub-models" existing within each.

The industrial model involves a highly mechanized production process, a high degree of centralization, and large scale. This model is growing significantly within the sector, with several variants identified.[230] Some models are mass-produced and pre-assembled in locations, such as in

FIGURE 5.2:
Illustrative Production Models and Sector Actors

Decreasing Mechanization and Increasing Decentralization →

Industrial		Semi-Industrial	Artisanal
International Mass Scale Industrial Manufacturers	**Regional Industrial Manufacturers**	**Low Tech Integrated Production/Assembly**	**Producer Networks & Individual Artisans**
High tech, mass scale automated manufacturing with modern QC methods, skilled workers, sophisticated in-house design and extensive R&D capacity	Moderate automation, high quality standardized components, may use imported machined parts, rigorous QC processes and R&D capacity	Semi-industrial tools (folding, drilling, welding), typically local materials/components, may work with artisans, but typically salaried staff; may focus on flat-pack assembly	Minimal automation, individual artisans/collectives, typically with facilitating institutions for training, and QC; may share workshop space
PHILIPS, Dometic, BioLite, ecozoom, EZY STOVE, ENVIROFIT	Prakti, Greenway, KOPERNIK, ENVIROFIT, Save 80, burn	CookClean, Helps, PRO LEÑA, STOVE TEAM	geres, EnterpriseWorks/VITA, PRACTICAL ACTION, GVEP International, EnDev

Sources: Interviews; press searches; Task Team analysis.

China, India, or Europe, in order to serve export markets. They meet a high standard of production and performance. A second variant of the model involves having some or all of the core components centrally manufactured for export and then assembled in the recipient country. The last variant is wholly "local" industrialized production whereby factories are established within the country of final sale. With this final model, some raw material inputs may still be imported, but the component manufacture and final assembly are all centrally integrated.

The semi-industrialized model involves cookstove production in a centralized setting, but with fewer mechanized tools and processes than in a factory or industrialized approach. The model may involve workshop-based production, using molds and similar tools for standardization, and hand assembly, or may involve a network of individuals centrally coordinated and all using similar designs, tools, and processes. Production scale of these semi-industrial models can range from a few hundred to a few thousand stoves per month.[231]

In the artisanal model, which is a further step down on the mechanization and centralization spectrum, stoves are made locally by artisans or small enterprises. This model draws on existing trade skills (potters, tinsmiths, blacksmiths) and is based on an existing design for both portable and fixed/built-in stoves. Although scale is typically quite small (fewer than 5,000 stoves per year), artisans are often well embedded in their communities, which eases distribution challenges and facilitates after-sales support and repair. In addition, aggregation and adequate support can lead to larger scale. To date, this production process has been far and away the most common one for manufacturing stoves used in Sub-Saharan Africa, Southeast Asia, and South Asia.

C. DISTRIBUTION

Once the cookstove has been produced, the next phase of the value chain is the distribution. In many contexts and for many products, including stoves, this is the key bottleneck to scaling up adoption. The stoves must be taken from the transporter or manufacturer, cleared through customs (if they are being imported), and then transported to wholesalers or retailers. From this point, a variety of models exist for taking the stoves to the household level.

Although distribution models are still emerging and stand to be improved, several have already demonstrated success, especially in the South Asian and Sub-Saharan African markets. In each model, producers are attempting to facilitate linkages that maximize their exposure to consumers while minimizing their costs of doing so. This is an especially tough challenge when seeking to penetrate Africa's thoroughly dispersed rural market, where many traditional appliance distribution networks do not reach, and institutional distribution channels and NGOs also frequently have limited capacity and footprint. Part of the challenge is picking production location and achieving scale. Artisanal models are generally produced close to their markets and none of the producers interviewed spent more than $ 3 per cookstove on distribution and retailer margins. For industrial stoves, the costs were much higher and a great deal more variable, ranging from $ 5–15 per cookstove, with international producers incurring the highest

costs.[232] For this latter group of producers, the variability reflects a market where production is often far from the consumer and best practices are yet to be established.

Manufacturers and distributors are currently experimenting with a number of different distribution models. Figure 5.3 gives an overview of these models and they are described further below. While precise sales figures across these distribution channels are unknown, if artisanal and semi-industrial stoves are included in the equation, the vast majority of biomass ICSs and modern fuel solutions distributed via private sector models have been distributed through direct sales channels, including individual stove entrepreneurs, salaried sales forces directly under the distributor's control, and village-level entrepreneur models that utilize commission-based sales forces trained by the stove manufacturer or distributor. Institutional sales and sales via social sector partners naturally are a major feature of government-driven stoves programs.

FIGURE 5.3:
Illustrative Emerging Distribution Channels for Clean Cookstoves

Direct Sales Channel	3rd Party Dealer-Distributor Networks	Micro-Franchisees	Social Sector Partners	Institutional Sales
Manufacturer staff, commission-based door-to-door agents, proprietary stores	Distributor/dealer networks, inc. both large and small retailer formats	Micro-franchisee agents empowered and incentivized to distribute products	Sales/order fulfillment via MFI/NGO/gov't extension agents	Bulk purchases and redistribution by institutional clients (e.g., relief agencies)

Sources: Interviews; press searches; Task Team analysis.

The mix between these channels differs dramatically between different markets. In Africa, the private sector channel is likely the dominant mode for stove distribution, with most industrial stove sales utilizing the direct distribution or third-party distribution model. In China, most stoves sales directly or indirectly involve government involvement, though in many cases the ultimate distribution is executed by private sector players. A recent large-scale survey of biomass ICS manufacturers in China shows that half of all sales involve third-party distribution through wholesalers (42%) and retailers (11%), one-fifth of sales are direct to consumers (19%), and nearly one-third are institutional sales to regional and city governments (28%).[233] Likewise, in Latin America, the picture is heavily dominated by institutional and NGO-based distribution with a limited commercial component. In Peru, for example, the Global Alliance's market assessment report estimated that half of stove distribution is managed through government channels and the balance is largely accounted for by NGO distribution (47%), with the private sector accounting for only 3% of stoves installed annually.

D. CONSUMER MARKETING

Levels of consumer awareness of the general benefits of improved cooking appliances, as well as of particular stove products, are key determinants of successful scale-up. In general, consumers are largely unaware of the negative impacts associated with traditional cooking practices, and do not highly value improved stoves. Marketing and education, thus, have an important role to play in generating and sustaining consumer demand and can be incorporated into both distribution channels and financing mechanisms within the cookstove value chain.

Marketing approaches (in both the development sector and the sector for commercial consumer products) can be either "above-the-line" or "below-the-line." Above-the-line approaches include traditional mass media such as TV and radio advertisements. Below-the-line channels include less traditional mechanisms such as road-shows, community theatre and folk songs, demonstrations, and direct door-to-door marketing. Local and national government partners can also be engaged, as can community health workers affiliated with government clinics. Such actors are well respected within the community. They can be trained and enlisted to disseminate information about improved cooking practices and technologies along with their other activities.

The biggest challenge in this section of the value chain has been the lack of investment in large-scale consumer marketing. This largely results from the fact that the returns from any such investment are largely public and not private. In this case, any company that invests in raising consumer awareness about the benefits of improved stoves may increase the demand for these products, but cannot be assured that consumers will buy from *them* rather than from a competitor. This is a classic coordination failure around providing a public good. Many governments and agencies recognize this, as well as the need for them to fund consumer awareness. The marketing challenge seems to be of greater concern for the high-cost, high-performance second- and third-generation stoves—more so than with the locally produced artisanal stoves. For these products, because the price point is so much higher and the benefits are much less tangible, the depth of education and awareness raising required is more costly and more difficult.

E. AFTER-SALES SERVICE

Unlike major consumer durable goods purchased by upper-middle/upper quintile consumers, most improved stoves available today do not provide much after-sales support, if any. Both price points and the relative scale of the industry impose limitations on the ability of manufacturers to provide economically efficient after-sales service. This lack of after-sales support has three key implications for adoption and use of improved stoves:

- Customers may be deterred from original purchase if there is uncertainty around how/when/if they will have access to repairs or support.
- Without adequate after-sales training for consumers on proper use of the stoves, customers may believe that stoves do not work properly, hurting brands, and the market as a whole.
- Lack of after-sales support makes tracking and monitoring of cookstove distribution and use very difficult. This is a particular challenge for projects/programs that are using carbon financing, as continued accreditation and receipt of carbon revenues is dependent upon monitored and continued use of the stoves.

That said, there are a few models that have begun to incorporate after-sales support to cookstove users. These include services covered by formal warranty agreements and the services provided by artisans that produce stoves for local consumers.

F. PRODUCT ECONOMICS

Differences between specific technologies and production processes give rise to different cost structures. In this section, we consider how each value chain component contributes to the final price of a product—the choice that consumers ultimately face. As discussed previously, the three main production processes employed for stoves are artisanal, semi-industrial, and industrial. Within these processes a variety of different stove types can be produced. The differences between these methods are demonstrated in general terms in Figure 5.4 and explored in more detail later in this chapter.

Producer and distributor margins for improved and clean stoves are moderate but positive in most cases. Accounting for indirect subsidies (i.e., seed grants, scale-up grants) and carbon finance revenue streams, most major industrial cookstove producers feature modest but positive profit margins. Several of the large global ICS manufacturers interviewed for this report self-reported profits in the 3–15% range. Chinese industrial biomass stove manufacturers (89 players) recently surveyed by the World Bank reported profits that were 10–15% of the stove price.[234] Semi-industrial stove manufacturer profit margins are comparable, albeit much smaller in absolute terms.

Costs of production and their impact on final selling prices should always be viewed through the lens of quality. Final product quality varies considerably in terms of environmental and health impacts, as well as in terms of longevity and operating cost. These variations are driven by the design of cooking appliances, designs that may rely on more sophisticated raw materials and manufacturing techniques. Figure 5.5 shows both relative pricing and total usage costs of different appliances

FIGURE 5.4:
Distribution of Costs along the Improved Stove Value Chain, by Production Process

Production Process

Process	Research & Development	Raw Materials	Labor	Manufacturing Margin
Artisanal		30–50%	15–25%	Included in "Labor"
Semi-industrial		20–40%	10–20%	10–15%
Industrial		15–40%	5–15%	5–15%

Post-Production Process

Process	Shipping & Import Duties	Taxes	Local Transport	Distribution Costs	Price Subsidy
Artisanal	0%	0%	10–25%	10–30%	0%
Semi-industrial	0%	10–15%	10–20%	5–15%	0–50%
Industrial	0–40%	10–15%	5–15%	5–20%	0–50%

Source: Global, Africa, and India manufacturer interviews (5–10 data points per stove type); Task Team analysis.

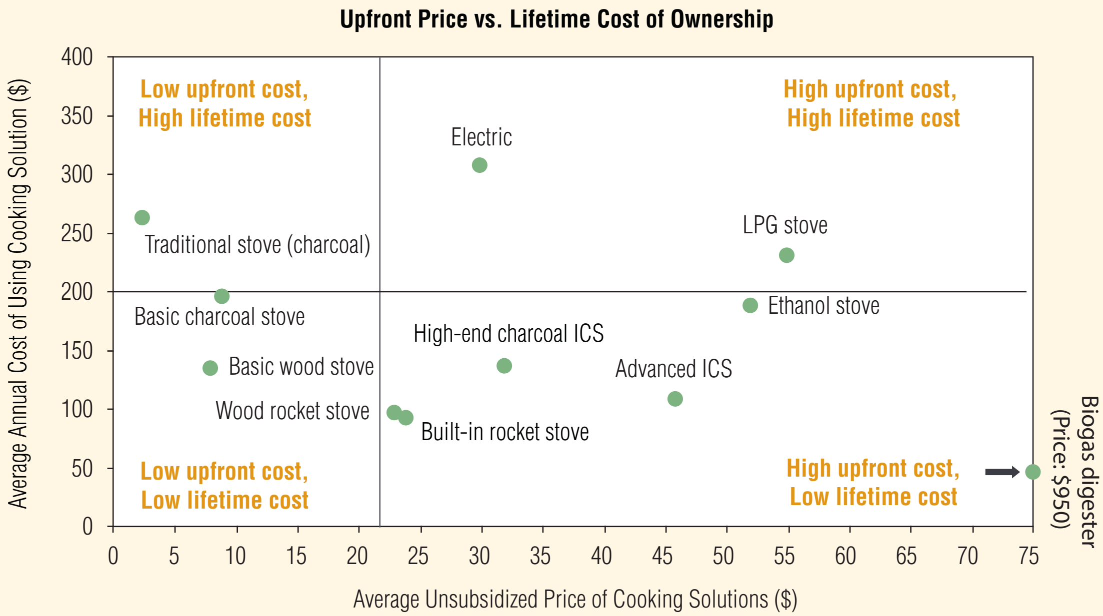
illustrating this. Advanced biomass stoves or biodigesters, are priced considerably higher than basic biomass stoves, 3 times as much for the former and 40 times as much for the latter.

However, considering price alone can disguise the fact that many products with high upfront costs, such as biodigesters and high-end biomass stoves, have significantly lower operating costs. When operating costs are considered, given a notional monthly cooking budget of 320 megajoules (MJ) per household,[235] these options often turn out to be significantly cheaper in terms of total cost. While biogas digesters require the highest upfront costs of any model, their total annual cost is lower as a result of their long life and free access to fuel (animal manure). Other advanced stoves also have lower total operating costs—as much as 50% lower than the cheapest stoves on the market—which offer limited consumer benefit.

Both costs and cost drivers vary widely by cookstove design and local conditions, so it is misleading to identify a universal set of cost components. There are also limited data points for drawing a scale curve for each technology type, which could be vital in understanding the trade-off between scale and customization. Nevertheless, on the basis of interviews, we have developed cost breakdowns for different technologies and under differing geographies and scale.

FIGURE 5.5:

Price and Annual Average Cost for Various Cooking Appliances



Source: Manufacturer interviews and press searches; Task Team analysis.

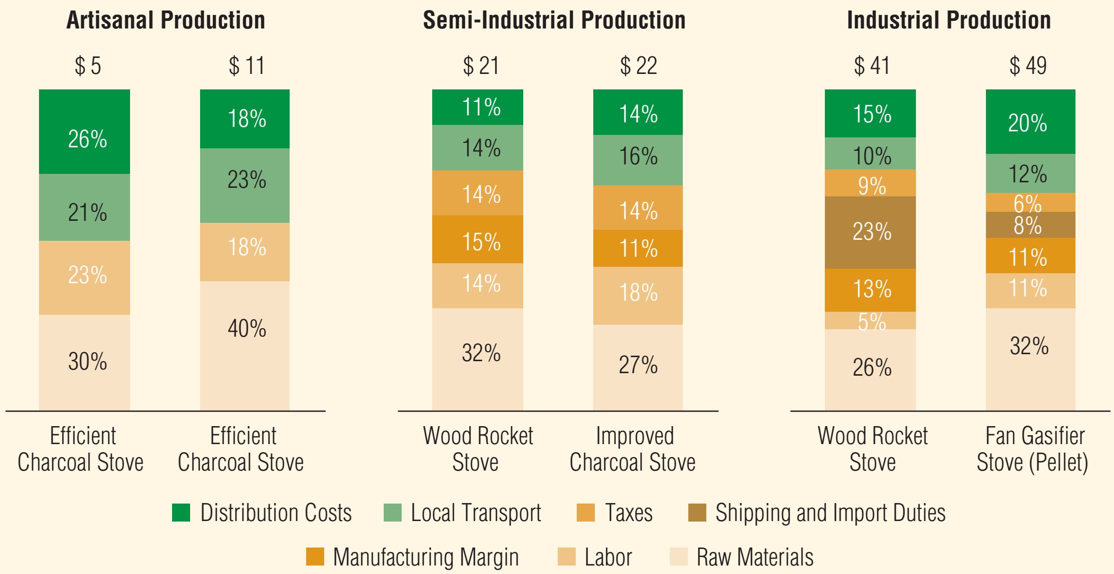
Note: Average annual cost is arrived at using amortized expenses and annual fuel usage cost; fuel usage is based on a 320 MJ monthly cooking diet. For less commonly used fuels such as electricity and LPG, average costs are calculated only from countries where usage of fuel is significant.

While one should not generalize too much, some patterns between models have emerged from research. As mentioned previously, cookstove costs vary both between and within the three principal production processes: artisanal, semi-industrial, and industrial. Artisanal processes are conducted locally in small workshops with a workforce or one or a few more employees. By contrast, semi-industrial processes, may not rely on well-integrated, machine-driven factories, but they do link purpose-built subcomponent supply chains, taking advantage of mass-production techniques. With such a wide variety of production techniques, it is not surprising that the distribution of raw material and manufacturing costs has significant variation both between and among production processes. Figure 5.6 demonstrates this variation by comparing the cost structure for two stoves in each process.

In all models, raw materials constitute the largest subcomponent, but are most significant in artisanal models that do not face many other costs. In these models, raw materials and labor often constitute over one-half of total costs—anywhere from $ 2–7, depending on the model. The remaining costs are made up of local transport and distribution. Although these costs make up a large percentage of the total, it is important to note that they are generally lower in absolute terms than industrial or semi-industrial models. The cost for local distribution and transport of artisanal models,

FIGURE 5.6:

Improved Cookstove Cost Structure for Artisanal, Semi-Industrial, and Industrial Models



Source: Stove price database with focus on Africa and South Asia based on value chain interviews; Task Team analysis.
Note: Labor costs include manufacturing margin for basic artisanal stoves.

which are often manufactured close to the end-customer, ranged from $ 2–5 among those surveyed, while the figure was $ 5–15 in the case of industrial stoves.

Semi-industrial and industrial models face a number of costs that artisanal stoves do not. This starts with government charges associated with these stoves being sold in the formal sector. Given the high price point of the stoves, taxes average $ 3 for a cookstove and import duties may add another $ 3, these numbers can rise dramatically in certain geographies where import duties and taxes on improved stoves can reach up to 50% of the stove's price.

Given the need for centralized, often international, production, advanced producers also incur other costs that accrue along longer and more complicated supply chains. These include manufacturer margins, extra distribution costs and, in the case of imported models, shipping. Of the surveyed producers that are importing stoves, none were spending less than $ 5 and some were spending considerably more. These additional costs can creep up. Figure 5.6 shows a wood rocket stove example where just less than 25% of the total price is consumed by shipping and import duties. As mentioned previously, stoves costing about $ 20 face a much larger potential market than those costing about $ 30; there is no doubt that these additional costs can seriously affect the marketability of advanced stoves.

In an increasingly competitive environment, there will be downward pressure on prices, but it will not be enough to defy the overall trend. As manufacturers grow in scale, the most competitive players will push down prices and margins will shrink. However, given the relatively simple designs of most stoves, particularly those destined for the African market, there is an upper limit on the level of margin-cutting that can be done. The more important drivers, especially for domestic stoves are inflation in subcomponents, such as labor and raw materials. These are set to grow quickly in African and Asian geographies where most production takes place. Other cost components tied to the cost of raw materials, such as taxes and duties, will rise in tow.

Suppliers are currently pursuing means of producing cheaper products and there is appetite in the market for cost-cutting innovations. Upward pressure on price poses a significant marketing risk to cookstove producers and especially those serving lower income markets. As such, suppliers are implementing or considering a number of approaches as a means to keep prices affordable for the cookstove consumers. Manufacturers have already begun shifting to local production and developing new low-cost designs. It may also be possible to upgrade the artisanal manufacture of some stoves to more efficient processes as a means of quality enhancement at competitive cost. In this case, the end price may not go down, but consumers can benefit by obtaining better value for money.

As highlighted previously, the market for improved stoves is growing and has space for many different players. As such, there are two important points to note when considering the dynamics of global production processes. First, the market is more than large enough to accommodate a rich diversity of types of players; and second, the market is significantly segmented, which lends itself to different types of producers manufacturing a variety of cookstove products at different price points. Ultimately, the market comprises a wide product mix, reflecting differences in both production processes and consumer impact. Given the varying needs of consumers, as well as questions of affordability, it is not surprising to see a wide range of products and variance in pricing. Different stoves will meet the needs of different customer segments.

ENDNOTES

[230] Global Alliance for Clean Cookstoves, 2011.

[231] ibid; plus site visits of semi-industrial production.

[232] Producer interviews.

[233] World Bank EAP CSI, 2013.

[234] ibid.

[235] A notional cooking diet of 320 MJ of effective energy per month is equivalent to 2.5 meals per day per individual, or roughly 1.6 Gg for a household of five. The concept of a notional cooking budget is widely used in the literature on clean and improved cooking (see, e.g., Daurella et al., 2009; Schlag et al., 2008).


R4B

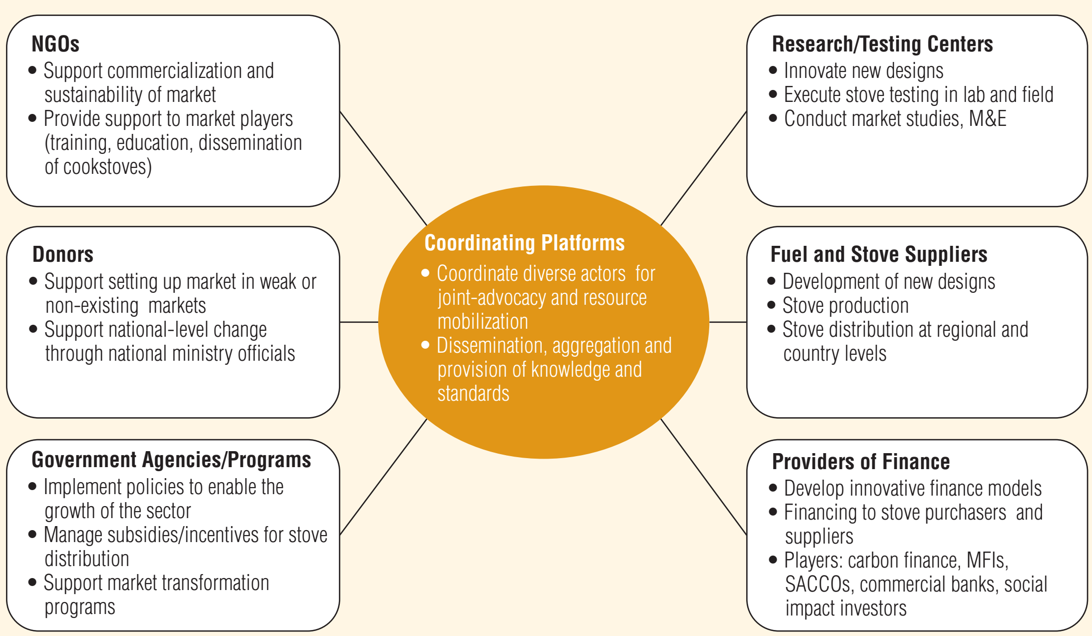
THE SECTOR ECOSYSTEM

A. OVERVIEW

The cooking appliance landscape is rapidly evolving as a diverse group of players grows in significance and takes fresh approaches to sector development. The major players that enable and support the clean energy ecosystem can be divided into seven categories: research institutions and testing centers; fuel and stove suppliers; providers of finance; government agencies/programs; donors; NGOs; and coordinating platforms and initiatives (see Figures 6.1 and 6.2).

Numerous players fall under one category. For example, providers of finance include carbon financiers, micro-finance institutions (MFIs), commercial banks, social impact investors, and savings and credit cooperatives (SACCOs). With respect to the NGO sector, these include international, national, and regional organizations. Additionally, fuel and stove suppliers—a sector dominated by private industries—consist of international and domestic manufacturers, importers, and distributors.

FIGURE 6.1:
Overview of Clean and Improved Cooking Ecosystem



Sources: Organization websites; Literature review; interviews; Task Team analysis.

FIGURE 6.2:
Examples of Key Players in Clean Cooking Sector

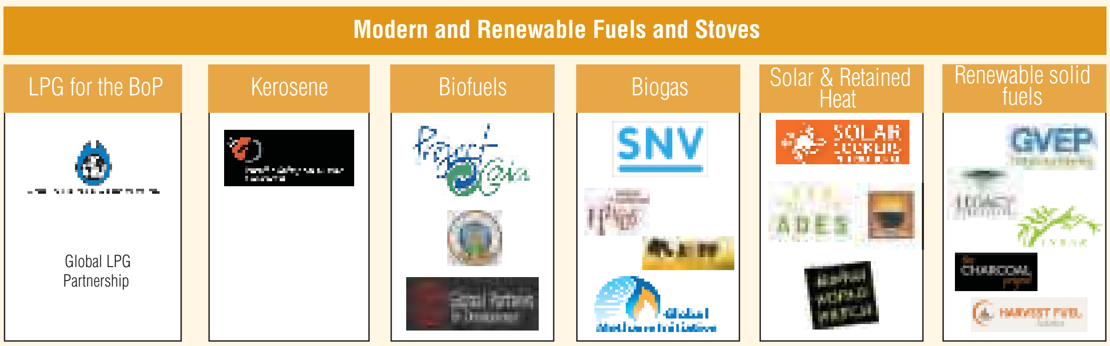
Source: Global Alliance for Clean Cookstoves member database; organization websites; literature review; Dalberg analysis.

At the nexus of this ecosystem are international coalitions that can be either technology specific (such as LPG Global Partnership) or sector specific (such as the Global Alliance for Clean Cookstoves).

While most actors cut across different clean technologies, a number of large international organizations and NGOs specialize in specific cookstove and fuel technology types. For example,

FIGURE 6.3:

Illustrative List of Non-Governmental Organizations and Investors, by Fuel Type



Sources: Literature reviews; organization websites; interviews; Task Team analysis.

biofuels are the focus of a select group of NGOs and producers (e.g., Project Gaia), as contrasted with the large assemblage of international NGOs and multilaterals in the biomass cookstove sector. Other players have specialized in stoves that use LPG and renewable solid fuels such as briquette and pellet fuel (Figure 6.3).

B. ROLES OF ACTORS WITHIN THE ECOSYSTEM

Actors in the ecosystem often decide to focus on the activities they engage in based on their relative strengths along the value chain. Donor agencies and NGOS remain a dominant force in this value chain**.** The private sector has a high potential to add value in capacity development and quality control as well as cookstove production, distribution, and dissemination. Likewise, coordinating platforms specialize in activities such as awareness raising, knowledge sharing, and project monitoring. In some activities, actors have proven high potential for success. In others, they have made significant contributions, but may not have been the best-suited or most effective player. There are also activities where actors have not had significant impact to date or are ignored completely. Donor agencies and NGOs play a role in most activities; this dominance, while necessary in some regards, is hotly debated with respect to its efficacy and potential for crowding out other players.

As different actors coalesce on the basis of the activities they engage in, certain partnerships form naturally at each stage of the value chain. This is an evolving landscape and, while some players may have historically filled a role, others may now be supplanting them. For example, while R&D used to be firmly rooted as a role of the private sector stove-makers, donors and governments are seeking involvement due to the public-good benefits of new designs. Design institutes and

government-funded research have sprung up as major activities by these actors. Another notable trend in this area is the involvement of the private sector in new activities along the value chain; this can be seen in the areas of production, consumer marketing and distribution, and after-sales service and monitoring.

C. PUBLIC AND DONOR SECTOR ENGAGEMENT MODELS

International actors and governments that support cookstove value chains have placed their focus on increasing the commercialization of improved appliances and building out sustainable markets. We have classified three major intervention types pursued by donors and NGOs:

1. Donor initiatives (e.g., the World Bank)
2. National programs (e.g., GIZ with host country government)
3. Coalitions and partnerships (e.g., Global Alliance for Clean Cookstoves)

An overview of each of these intervention types is provided below.

1. Donor Initiatives

Bilateral, multilateral, and UN development agencies have played significant roles in mobilizing global resources for clean cooking solutions and supporting the creation of enabling environments. Some initiatives, including the UN's Sustainable Energy for All (SE4ALL), are advocacy groups. SE4ALL's efforts to elevate the issue of clean cooking at global venues, such as UN Conference on Sustainable Development, have raised billions of dollars in commitments from governments, private companies, and development banks. Other donors lead by funding pilot programs to develop new cooking and fuel technologies. The World Bank's Biomass Energy Initiative for Africa (BEIA) has been co-financing multiple pilots to test early-stage innovations in ethanol, briquettes, and improved biomass stoves. The World Bank and ESMAP have likewise launched regional cooking market transformation programs in Africa (ACCES), Central America (CACCI), India, and East Asia and Pacific (EAP CSI) to advance the clean and improved cooking agenda in the coming years.

Finally, many organizations specialize in technical training and capacity building at the national and local levels, without which well-designed policies and products cannot be successful. The EnDev project—supported by the governments of Australia, Germany, the Netherlands, Norway, Switzerland, and the United Kingdom—provides technical and business skills training to execute clean energy projects. For example, in Peru, EnDev is providing technical assistance to suppliers and technicians along the cookstove value chain, improving cookstove quality and sharing information on use to rural consumers. USAID has numerous capacity-building programs focused on the stoves sector that are delivered through USAID missions worldwide and has launched a $ 100 million guarantee fund for stoves. DFID also has a range of programs in place for the cookstove sector, including research programs, innovation pilots, and results based financing facilities. Many of these donor efforts are

coordinated via the Global Alliance for Clean Cookstoves, which, as noted below, has an important resource mobilization, coordination, and implementation role across the global cooking sector.

Such donors are well-suited to funding advocacy, R&D, and capacity-building efforts because activities such as these take a long time to produce tangible results, though they are critically important to supporting ICS sector development. Donors can provide capital without expectation of monetary returns, and they accept that some types of impact are valuable even, if it must be measured by more qualitative methods.

2. National Programs

National cookstove programs have increased sharply, in number and quality, based on lessons learned. The first programs began in the 1970s and have quickly spread across the globe in recent decades. As of 2010, there are over 100 active national-level clean cookstove programs.[236]

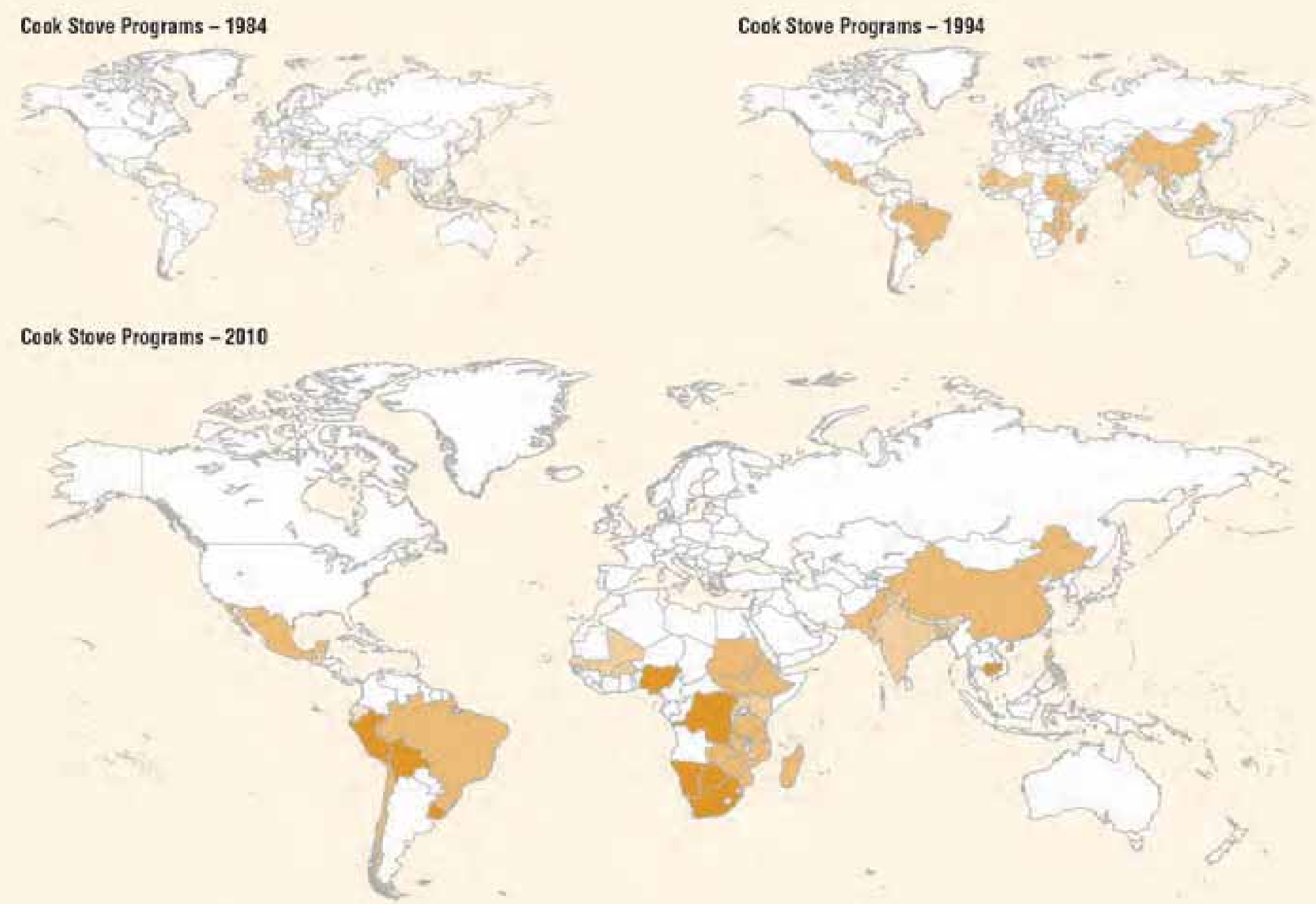
Over time, cookstove programs have evolved from use of large-scale subsidies to more demand-driven models that include indirect subsidies for market development alongside direct support for stove producers and customers (Figure 6.4). National improved cookstove programs in China, Nepal, Peru, and Sri Lanka, for instance, have each employed innovative, market-based methods to reach poor consumers. Another important trend has been a greater attention to biomass fuel value chains (e.g., in the upcoming China program), and clean modern fuels (e.g., LPG) being integrated into program design in countries ranging from Indonesia to Ghana and to Mexico. Despite substantive growth, however, only 14% of programs globally have actually achieved their distribution and adoption targets. Thus far, public programs have distributed fewer than 30 million stoves outside of China and India.

Furthermore, the quality of stoves under many past national programs has been variable. For instance, a majority of the stoves installed under the National Programme for Improve Chulha (NPIC) in India are no longer in use.[237] Similar results were seen in programs in Asia and Africa, particularly those that lacked a strong market component.[238] Nevertheless, the future of national clean cooking programs appears promising. China's national program will be launching in the near future with ambitious plans and a focus on both biomass fuel and stove markets. Other national programs in Asia have been launched in recent years in countries like Indonesia, India, and Bangladesh.

In Africa, the Ethiopia program has reached significant scale (over one-third of rural households) across a range of improved biomass stove technologies using national coordination and subsidy mechanisms and market-based approaches. The Senegal national program (PROGEDE), with donor support, has seen success in urban areas for improved charcoal stove adoption. Recently launched programs in Nigeria (2014), Malawi (2013), and Uganda (2014), have ambitious targets and strong market-based components.

In Latin America, there is major progress in national cooking program innovation and design. Countries, like Mexico and Peru, have longstanding programs; and others, like Nicaragua, Guatemala, and Honduras, are in the midst of program design, with the president of Honduras, for instance, prominently featuring the national clean cooking program as part of his political platform.

FIGURE 6.4:
Global Cookstove Programs Over Time



Source: Review of global cookstoves programs in (Giffords, 2011).

3. Coalitions and Partnerships

There are several high-profile coalitions and partnerships that play a coordinating role among actors in the cookstove ecosystem. These groups are involved in the provision, aggregation, and dissemination of knowledge rather than the direct provision of support to the sector in particular countries. Led by the UN Foundation, the Global Alliance for Clean Cookstoves mobilizes support from public, private, and non-profit stakeholders to address the production, deployment, and use of clean cookstoves in the developing world. The Global LPG Partnership[239] is a partnership between public stakeholders and LPG industry leaders that is working to ensure a safe and dependable LPG supply chain in developing countries.

D. POLICY AND STANDARDS LANDSCAPE

Establishment and enforcement of standards are important government responsibilities when it comes to cookstoves, and market growth may suffer if they remain absent or poorly enforced. Having robust testing mechanisms and standardized benchmarks against which tests (both laboratory and field based) can be evaluated is critical to ensuring accurate assessment of cookstove performance and fair comparison of different cookstove products. Several different testing protocols exist, but no single standard for governing cookstove performance has yet been implemented. The five-tier ISO IWA standards process led by Global Alliance partners, and described at the outset of this report, is currently the closest to a rating and testing system for cookstove performance. It also allows for harmonization of different protocols together in the same framework, and flexibility for national and organizational adoption according to their local priorities. Adoption of these provisional standards is still at an early stage.

In the meantime, standards have largely been driven at the country level. For example, the Bureau of Indian Standards, Chinese Standards, GIZ Benchmark, Kenyan Standards, and the Shell Foundation Benchmarks all provide some guidance on comparative standards. Although varying standards can make it difficult to compare stoves across countries, national standards take into account the importance of various cookstove parameters within the local context. Increasingly, these legacy national standards are being harmonized with ISO IWA guidelines.

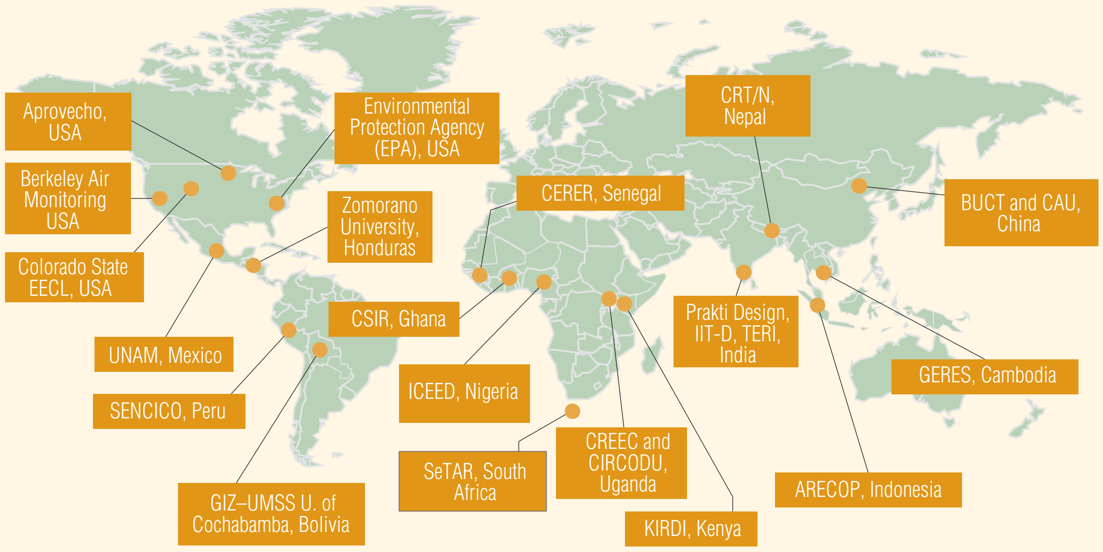
The presence of high-quality cookstove testing centers is another constraint. Under the leadership of the Global Alliance, donors are helping to equip and certify a number of new facilities across global regions to make sure existing and future standards are practically feasible to enforce. The Global Alliance is funding capacity-building activities at 13 Regional Testing and Knowledge Centers.[240] Other major centers are also active across the globe to advance the stove testing agenda (Figure 6.5). Technical capacity to manage the centers, though, is limited and stove-testing costs are frequently prohibitive for the small industrial manufacturers and artisans that currently produce the majority of improved stoves.

Fuel subsidies are a common policy tool that governments have employed to encourage use of modern fuels, but programs are often costly and difficult to phase out. Many countries have legislated subsidies for LPG and kerosene, ostensibly to reduce the level and variability of fuel costs to poor households. Indonesia has maintained subsidies for petroleum fuels, including LPG

FIGURE 6.5:

Examples of Cookstove Testing Facilities around the Globe

Select Testing Facilities (existing and emerging)



Sources: Global Alliance for Clean Cookstoves; press searches; interviews; Task Team analysis.

and kerosene, since the 1960s, but these policies place great pressure on the national budget. In 2005, 21% of spending by the Indonesia government was used to pay for fuel subsidies, more than education, defense, health, and social security spending combined.[241] Senegal faced similar difficulty supporting its national LPG subsidies, which, in 2006, cost the equivalent of 1.4% of GDP.[242] Once in place, these broad subsidies are notoriously difficult to reduce or eliminate. Brazil's recent attempts to remove fuel subsidies established 50 years ago have met strong resistance from industry and ethanol producers, so much so that 20 years after the "liberalization" of the energy sector, Brazil pays an estimated $ 1 billion annually in consumer fuel subsidies.[243]

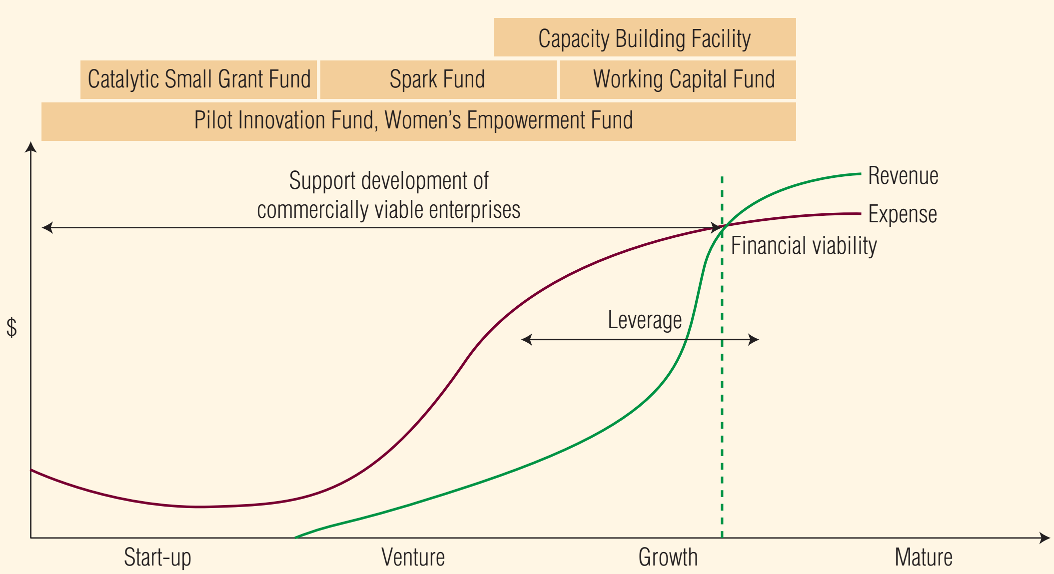
Broad-based subsidies also did little to reduce energy poverty, and governments are currently exploring methods of better targeting poor consumers. Numerous impact reviews of national fuel subsidies have determined they are highly regressive, with low-income households often receiving less than 20% of total subsidy spending.[244] Most savings accrue to wealthier households or commercial customers that purchase fuel in higher volumes. Subsidies also allow distributors to purchase cheap fuel and resell it on the black market for a profit. In India, studies estimate that up to 50% of subsidized kerosene in some states is resold illegally.[245] To reduce this leakage, Indonesia and Mexico have implemented cash transfer programs for fuel subsidies that allow benefits to be electronically delivered to beneficiaries' bank accounts. Cash transfers create some new problems in delivering

benefits—receiving compensation requires the beneficiary to have a personal bank account—but it is a step toward greater accountability within fuel subsidies.[246]

As for biomass policy, institution of favorable tax regimes for managed forests has been proven effective at promoting and sustaining responsible biomass fuel production. From 1998 to 2003, the World Bank worked with over 100 communities and local governments to strengthen land tenure rights and establish favorable tax conditions for 450,000 hectares of sustainably managed forest. Taxes were increased up to fourfold on wood harvesting from open-access lots and illegal logging, while proceeds from these penalties were channeled back to sustainably managed forests and the local government. As a result of this incentive program, the retail price of woodfuel increased by 20% in two years, which allowed communities to invest further in the health and quality of their forest stock. Use of improved stoves in the area also increased.[247] This demonstrated the sustainable forest sector's potential not only to protect valuable fuel resources, but also to create jobs and stimulate rural economies.

In contrast, bans on charcoal have been ineffective at shifting consumers to cleaner fuels and prevent government from monitoring the sustainability of the charcoal industry. In the past, countries such as Chad, Ethiopia, Kenya, and Tanzania have banned either the production or transport of charcoal in an attempt to shift consumers toward cleaner fuels. Tanzania's ban resulted in a sustained rise in charcoal prices and had almost no effect on charcoal trade, as producers bribed

FIGURE 6.6:
Financing Facilities from the Global Alliance for Clean Cookstoves



Sources: Global Alliance for Clean Cookstoves, 3rd Annual Report (2013).

government officials to continue operations. Meanwhile, the government lost all official revenue from taxing commercial charcoal activities. The ban remained in force for only two weeks.[248] Indonesia's Quezon province has recently introduced a ban on charcoal production, citing links to the destruction of mangrove forests in the region; based on other nations' experiences, it is unclear whether pushing the local charcoal industry underground will reduce mangrove deforestation.[249]

With regard to modern fuels, stronger regulatory frameworks and investment are needed across countries to ensure consumer safety. Specific protocols are required for transporting, storing, and using liquid fuels, such as LPG and kerosene, safely. Appropriate training must extend through the value chain to small-scale distributors to prevent accidents. Many countries lack the certification and licensing capability required to ensure such handling, in part, because the physical infrastructure for safely transporting liquid fuels is not in place. Pursuit of stronger standards and requirements for fuel distributors in conjunction with joint investments in infrastructure would increase the integrity of the value chain and effective distribution of liquid fuels. Consumer education is especially important for LPG and kerosene because they are responsible for proper storage and operation after sale. Malfunctioning LPG canisters can cause explosions, and improper fuel storage poses risks to the entire household. Sixty percent of child poisoning incidents in Kenya and South Africa are a result of accidental ingestion of kerosene.[250] As fuels such as LPG become increasingly affordable, governments will need to work with companies to disseminate safe-use knowledge and minimize public health risks.

E. THE FINANCING CHALLENGE

In future, the continuing high prices of many cooking appliances will prompt producers to invest in cost cutting and distributors to develop financing models for consumers. This will require sources and facilitators of finance throughout the value chain. The need for financing by players throughout the value chain is consistently brought up as a core challenge by stakeholders across technologies, regions, and production models.

Upstream Financing

The key finance needs on the supply side, as noted earlier, are finance for capital investment and working capital. Startup capital is especially necessary for some of the newer technologies that require long R&D processes, sophisticated machinery, or investment in distribution channels. By contrast, working capital constraints are generally more relevant to lower end products. Despite widespread need, access to finance for production and distribution is limited, especially for smaller manufacturers and networks of artisans (Table 6.1). Key constraints include the following:

- The often small size and informality of operations make the investment seem too risky for commercial banks.
- The low-profit nature of the business limits access to commercial capital.
- Limited financial/business literacy among small producers limits their capacity to navigate the loan application process and to develop business plans that appeal to financiers.

TABLE 6.1:
Financing Needs, by Player

	FINANCING REQUIRED ($)	USES FOR FINANCING	KEY ISSUES / CHALLENGES
MANUFACTURERS & FUEL SUPPLIERS	250,000–10M	• Initial capital for R&D and production assets • Working capital • Trade finance for inputs	• Substantial capital required for scaling up production for international players • Smaller scale local manufacturers (e.g., Africa semi-industrial manufacturers/assemblers) are largely new entrepreneurs and are underserved by financial institutions
ARTISANAL FINANCING	20,000–200,000	• Field testing/quality control • Securing of raw material supplies • Scale up funds	• Collateral requirements, land tenure issues, informality • Players range from tiny micro-entrepreneurs to mid-size SMEs in the stove production, renewable fuel manufacturing (e.g., briquetting), and traditional biomass solid fuel production (e.g., charcoal kilns)
DISTRIBUTORS	25,000–2M	• Trade finance for imports • Working capital for growing distribution network • Credit that can be passed down to last-mile dealers	• Typically offered little or no credit from manufacturers • SME lending poorly developed in many markets with no focus on renewable energy sector • Working capital/trade finance loans require substantial trading history and collateral, which firms often lack • High interest rates for available SME products
LAST MILE RETAILERS	300–10,000	• Working capital to purchase stove for sale or rental • Capital to extend credit to end users	• Often stuck between MFI and commercial bank value propositions with no natural provider of capital • Few financial institutions focus on renewable energy-related micro-enterprise loans
END-CONSUMERS	5–100 (up to $ 1.5k for biogas digester plants)	• Upfront cost of stove	• Upfront costs of existing lantern products too high (cannot pay more then 10–20% of monthly income upfront due to low income levels and limited savings) • No scaled examples of MFI lending for stove purchases globally

Sources: Sector interviews; literature review; Task Team analysis.

- The high cost of capital in emerging markets, even where business capacity exists to apply for loans, means most producers cannot afford the interest rates.
- The stringent collateral requirements upheld by banks (seeking to diminish their exposure to perceived risk) increases the difficulty of accessing finance. Some loan products, such as the partnership between GIZ and the Agricultural Finance Corporation, have been structured to use inventory as collateral, but these examples are rare and have not been sustained.

Of course, not all producers face these constraints to the same degree and several options exist for upstream players seeking finance. Table 6.2 reviews social-impact investment, commercial loans,

TABLE 6.2:

Financing Solutions for Suppliers

OPTION	DETAILS	PROMINENCE / REACH	EXAMPLE
Social Impact Investment	Funds seeking to pursue impact-driven goals alongside traditional investment targets provide both equity and working capital to players in the cookstove value chain	Some players have already made investments, but cook stoves still frontier market	acumen FUND; SEDF; BIX Fund; Persistent Energy Partners
Commercial Loans	Manufacturer already sufficiently "credit worthy" through other business lines or is able to provide enough collateral and to access commercial credit—interest rates often high, however	Commercial finance quite prevalent, but not tailored for stove sector and with limited reach due to access. USAID and others working to encourage commercial banks to engage	Stanbic Bank; Deutsche Bank; USAID From the American People
Subsidized Loans	Commercial credit is "subsidized" by donors, or loans provided by "impact investor" who's time horizons are longer and interest rates are lower. Also may involve innovative structuring of collateral requirement, and/or incorporate capacity building and training	Not many examples—not a prominent model. Reach is limited due to geographic focus and eligibility requirements	giz; OPIC; GE
Credit Guarantees	Funds established to guarantee loans and thereby partially underwrite the risk of lending to energy businesses e.g. SME loans can be guaranteed through an overdraft facility at a regional commercial bank	Not many examples to date, but growing attention from donors	USAID; GVEP International; Shell Foundation; IFC International Finance Corporation
MSME and MSE Loans	MFIs provide credit to stove distributors and retailers to finance business and inventory costs, and may partner to serve as warehouse facility and distribution channel also	Widely prevalent and accessible, although of less use to supply side actors who need large loans for scale	CAIXA; KWFT Microfinance; FINCA; microenergy credits
Grant-Based Seed Funding	Seed financing to move new solutions to commercialization or to help organizations scale	Growing array of organizations and facilities, most notably the new global facilities from the Global Alliance (e.g., Spark Fund)	SEED Initiative; Global Alliance for Clean Cookstoves; World Bank; Ashden; USAID

Sources: Press searches, interviews, Task Team analysis.

subsidized loans, credit guarantees, MSME/SME loans, and carbon finance. These are the financing sources that have been underwriting the already fast growth of the cookstove sector in recent years. In practice, subsidized loans and credit guarantees are rare and underdeveloped. As a result, carbon finance and commercial loans are the more prevalent sources of finance for those who can afford to take advantage of those (costly) mechanisms.

While the exact numbers are unknown, there is good evidence that the volume of financing has increased dramatically in the past two to three years. Some of the most important activities in this sector have been the ongoing boom of carbon finance projects for cookstoves, despite some cyclical softening in the carbon market in the past year; increased activity from social impact investment funds and more traditional finance players in equity investments in promising cookstove companies; the efforts of players like USAID to encourage commercial banks to scale up their SME financing for cookstove manufacturers and distributors; increased application of partial credit guarantees (e.g., $ 5 million partial credit guarantee in 2012 from IFC for SEWA in India); growing interest from MFIs, like Faulu and FINCA, in financing cookstove micro-entrepreneurs; and the increasing importance of guarantees, with USAID launching a $ 100 million Household Energy Guarantee program in September 2014 and the Global Alliance in the process of developing a comparable program for the clean cooking sector.

Another important recent trend in the market is the growth of startup and scale-up grant facilities. These facilities are aimed at helping subscale cookstove enterprises reach the size and phase of commercialization that would enable them to access private sector financing. Important examples include long-established, award-based programs like Ashden and SEED, alongside the suite of financial products established by the Global Alliance from the Pilot Innovation Fund to finance innovations across the value chain, the Spark Fund to finance the scale up of proven concepts, and the Working Capital Fund to provide affordable working capital loans for early-growth stage companies. The Global Alliance has also recently launched a Capacity Building Facility to provide Global Alliance-funded capacity building coupled with growth financing from impact investors. Figure 6.6 shows the suite of financial products the Global Alliance has designed to enable enterprises at different stages of development to grow and leverage further investment.

Downstream Financing

In consumer finance, in general, commercial banks are unwilling to lend to low-income consumers because of their lack of collateral, irregular incomes, and lack of formal identification. With cookstove purchases, in particular, banks are unwilling to finance this particular asset (as compared to solar home systems, for example) because the loan size is too small relative to the high transaction costs.

Similarly, MFIs, which would traditionally bear more of the burden of financing the BoP, are also wary of financing loans due to high risks. The first risk is linked to cookstove portability: for example, a person could move and take the stove with them, or give it to relatives. The second challenge is due to the fact that stoves do not generate cash revenue for the borrower. In financing stoves, institutions are

TABLE 6.3:

Financing Solutions for Consumers

OPTION	DETAILS	EXAMPLE
Carbon Finance (CDM)	• $ 10 carbon credit claimed by the manufacturer per ton of carbon abated, with varying shares of amount captured in manufacturer margin or passed through to consumer as savings • $ 61 million carbon offsets channeled to stoves projects last know year, but viability at scale unclear given state of carbon credit markets	The Paradigm Project; atmosfair; Global BDA; ENVIROFIT
Non-Carbon "Buy-Down" Performance Based Grants	• Performance-based subsidies provided directly by donors/ governments to lower upfront cost of the stove to the end user • Subsidy can go to the manufacture to lower price of stove, or to the user for purchase (e.g., voucher mechanism)	DFID Department for International Development; NPIC Program India; World Bank
Microfinance	• Small loans for stove purchase disbursed through MFIs/SACCOs and typically bundled with distribution arrangements • No demonstrated capacity for scale to date due to logistical challenges and low MFI appetite for financing <$ 60 products	Faulu; KUSCCO LTD.; FINCA; Impact Energies
Installment / PAYG Plans	• Consumers can pay for a stove in installments • Pay-as-you-go systems eliminate upfront costs for consumers but transaction costs of collection are high and difficult to scale	Toyola Energy Limited; Multilink; potential energy
Mobile-Enhanced Utility Model	• Potential for mobile financing and utility-based models with remote stove activation/deactivation (e.g., pay for 2 weeks of use) • Models currently being trialed for solar lighting and potential exists for extending model to cookstoves	 M-KOPA SOLAR
Fuel Amortization and Cross-Subsidy Models	• Stoves offered for free, at cost, or with partial subsidy but funds collected from fuel revenue stream • Stoves offered for free in return for fuel collection services	INYENYERI; oorja

Sources: Press searches, interviews, Task Team analysis.

financing savings, not income. Unlike lending to a small business, where loan repayment represents a clear future revenue stream, lending to a cookstove buyer finances a product that will generate savings and the repayment mechanism is less clear. There is high uncertainty that the savings generated will be used to pay down the loan rather than applied to other needs.

As noted in the "Product Economics" section (see Chapter 5), many appliances drive long-term savings for consumers and, if financing can be provided to overcome upfront costs, consumers will increase adoption in their own self-interest. Nonetheless, many challenges arise when considering financing options for consumers that are often not worthy for credit on paper. Many of the solutions shown in Table 6.3 are in early stages of development or have not scaled enough to meaningfully address the consumer finance gap.

Creative financing and pricing schemes to address this issue are currently being rolled out either in cookstoves or adjacent appliance markets. Some models rely on the use of new technologies, such as pay-as-you-go services. Others rely only on creative pricing schemes and the role played by local deal brokers:

- Technology enabled pay-as-you-go models have already been trialed in solar home systems. M-Kopa Kenya uses a pay-as-you-go model with mobile payments and an embedded mobile control technology enabling system shutdown if a customer does not pay. Likewise, Angaza's Pay-As-You-Go Management Solution likewise offers remote activation and disactivation functionality at very low cost ($ 2/unit). Azuri Indigo uses scratch cards sold through a vendor to activate its solar panel system via SMS. While these models have not been tried with cookstoves yet the model is possible, particularly for advanced gasifier fan models, and is currently being pursued by market participants.[251]
- DFID has recently launched an initiative for Results-Based Financing (RBF) to deliver targeted subsidies where projects deliver health and climate impacts that consumers may be unwilling to pay for, with a RBF pilot in progress to facilitate the extension of cookstoves to 200,000 rural households in Ethiopia.[252] The feasibility of applying RBF mechanisms for clean and improved cooking solutions in Africa is also currently being explored in World Bank-sponsored research focused on countries like Uganda and Indonesia.[253]
- While there is no commercial market for financing health impacts of clean cooking technologies, there are a number of important efforts under way to explore such approaches, with immediate potential application to Africa. The CQuestCapital team, for instance, drawing on its carbon finance market expertise, is exploring the potential to create a Clean Development Mechanism (CDM)-like market for cookstove health impacts; work on piloting a potential new RBF methodology is now in progress.[254] Similarly, the newly launched BIX fund, while most immediately focused on carbon finance revenues, is working on a methodology to package cookstove health impacts for social impact investors.
- Cross-subsidies between urban and rural consumers can also be employed to establish markets in hard-to-reach locations. Producers may charge full price to urban consumers and take lower margins on rural consumers in order to lower the rural distribution cost premium. One innovative

version of this model from Inyenyeri in Rwanda involves providing stoves free of charge to rural consumers in return for a contract for these consumers to supply Inyeyeri with fuel feedstock (twigs for the manufacture of pellet fuel). Rural consumers have indefinite access to a free high-end clean biomass cookstove as long as they supply fuel, whereas the fuel and cookstove are sold at full cost to urban consumers.[255]

- Credit schemes are not always based on high innovation, but on well-run rural financial institutions using traditional models. The traditional lay-away model is used by Toyola Energy in Ghana. Consumers make a down payment and are responsible for continuing monthly payments to the distributor.[256]
- PIMA gas in Kenya uses a traditional BoP model to address the issue of high one-time costs associated with fuel purchase: micro-packaging. It sells 1-kg cylinder gas stoves with refills starting at $ 0.60 for a partial refill, as opposed to the more expensive and much more common 13-kg models.[257] Similarly, Oando in Nigeria is piloting an O-Gas program to scale-up distribution of 3.5 kg cylinders to the urban mass market.[258]

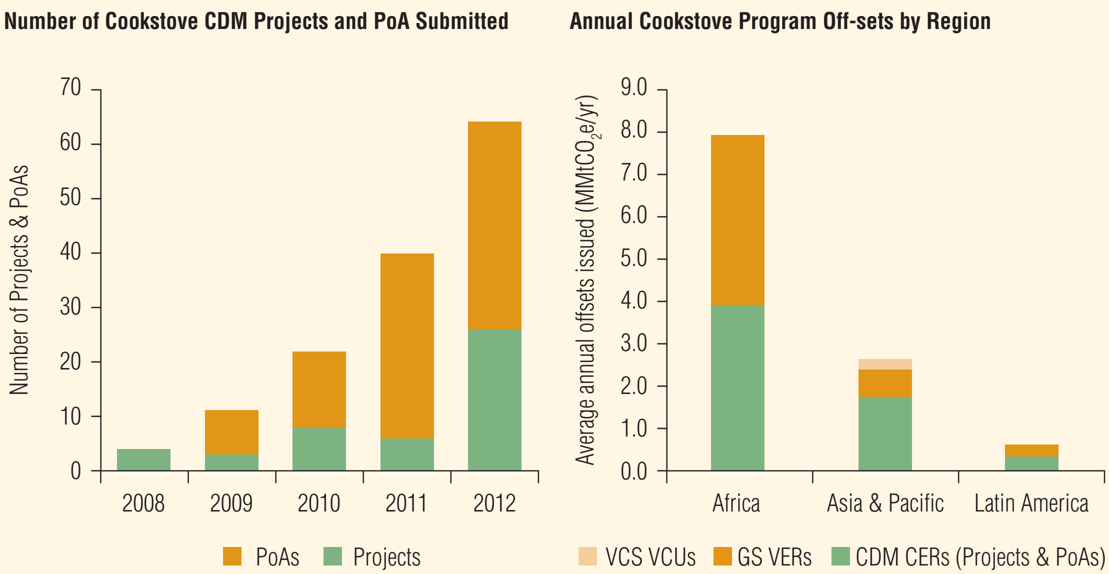
In the lower cost, "less advanced" cookstove market segment, the constraint to growth is usually on the supply side. In this case, demand exists for the locally produced stoves that provide significant fuel consumption savings, even if emissions are not reduced. The small enterprises or artisans that are manufacturing do not have sufficient working capital to purchase the raw materials and build a stock of inventory to keep up with the demand. In this case, financing efforts need to be focused on supporting the growth of such suppliers—providing investment capital for increased production capacity and working capital to enable larger scale production.

Carbon Financing

Interest from cookstove manufacturers and program designers in accessing the international carbon markets and the supply of such financing are increasing at a rapid pace. Despite challenges in the carbon market, carbon financing for improved and clean cookstoves is booming, with voluntary buyers funneling $ 61 million to Gold Standard-certified offsets from projects that distribute clean cookstoves in 2013, which is down from $ 80 million in 2012, but up from $ 42 million in 2011, and <$ 30 million in 2010.[259] CDM registrations of improved and clean cookstove projects, despite lower volumes, are still strong—10 Programme of Activities (PoAs) registered in 2014, 10 registered in 2013, 17 registered in 2012, and 3 in 2011.[260] The continued and growing importance of the carbon market is well illustrated by the fact that—despite depressed carbon prices—of the 8.2 million stoves distributed and sold in 2012 that were tracked by the Global Alliance, half received some support from carbon finance projects. This is up from 15% of cookstoves tracked by the Global Alliance receiving carbon finance support in 2010–11.[261] The carbon finance market was weaker in 2013–14, but the overall story is still one of secular growth relative to earlier periods of the clean cooking market.[262]

While this growth has been rapid, it is uneven. Relative to the global population without access to clean cooking facilities, the carbon finance project footprint is heavily biased toward Africa (Figure 6.7) and concentrated in a handful of countries. In Africa, the primary geographies are Kenya, Ethiopia,

FIGURE 6.7:
State of the Global Cookstoves Carbon Finance Market



Source: SEI (2013), drawing on data from UNEP Risoe Centre (2012), The Gold Standard (2012), Verified Carbon Standard (2012).
Note: Annual cookstove offset data include both registered and validation-stage projects. Gold Stanard (GS) projects include registered and listed projects. Verified Carbon Units (VCUs) are credits issued under the Verified Carbon Standard (VCS).

South Africa, Rwanda, Malawi, Ghana, Nigeria, and Senegal. In Asia, stoves carbon projects are concentrated in India, China, Myanmar, and Bangladesh. In Latin America, the major focal points are Mexico, Guatemala, Bolivia, Brazil, and El Salvador. In total, by early 2015, CDM and voluntary projects have been registered or listed for over 40 countries globally, three times the number of projects in place than just 2 years earlier.

Although the potential for carbon finance to support the increased production and adoption of improved stoves is significant, carbon finance is also inherently risky and challenging. In particular, carbon program developers and potential registrants cite the following as key risks:

- The enormous volatility and uncertainty around carbon prices makes the development of carbon funded programs risky.[263]
- The high cost and complexity of carbon program development and registration, as indicated earlier, pose significant challenges to scaling up the use of this financing tool. This includes the significant time required as well as the need for well-trained specialists.
- Retaining accreditation requires elaborate and long-term monitoring—including maintenance of complete sales, customer and project databases, routine kitchen surveys, and in-situ stove tests.

All these elements become increasingly difficult with increased distance from urban centers and can be hugely costly for the program.

The two available options for accessing carbon credit, the CDM and the Voluntary Offsets Market, are still complicated mechanisms to access, and access often comes with a high price tag.[264] If we consider the costs to obtain financing relative to the programmatic revenue from stove sales, the number of stoves that would have to be sold in order to pay back just the fixed costs ranges from $5,000 to over $30,000, depending on the scale of the program. Many cookstove programs take years to reach such high levels of market penetration and some never do. Furthermore, even where the economics are positive, clean cookstove projects often find it challenging to fund certification processes due to the one to two year time lag between registration and first revenues from carbon credits. As such, carbon finance is immediately available only to scaled programs. This issue is now being addressed by the new Clean Cooking Loan Fund recently launched by the Global Alliance in partnership with Nexus Carbon for Development and the Gold Standard Foundation. The Clean Cooking Loan Fund will take on the financial risk associated with the carbon certification process by offering loans to project developers to cover certification costs.

Despite these limitations, the continued growth in the carbon voluntary market and rising number of registered cookstove projects suggests that carbon finance will be a major driver of financing for the clean and improved stove sector for the years to come.

ENDNOTES

[236] Gifford, 2011.

[237] Venkataraman et al., 2010.

[238] Urmee & Gyamfi, 2014.

[239] http://www.sustainableenergyforall.org/actions-commitments/commitments/single/global-lpg-partnership

[240] Global Alliance, 2013.

[241] International Institute for Sustainable Development, 2011.

[242] Bruvall, et al., 2011.

[243] Includes spending on petroleum products other than LPG (Koplow, 2012).

[244] Based on analysis of fuel subsidies in Indonesia and Mexico (Ibid).

[245] Shenoy, 2010.

[246] Knowledge@Wharton, 2013.

[247] ESMAP, 2012.

[248] NL Agency, 2010.

[249] Mallari, 2012.

[250] Schwebel et al., 2009.

[251] Bloomberg, 2012.

[252] For example, see https://www.gov.uk/result-based-financing-for-low-carbon-energy-access-rbf.

[253] ibid.

[254] For the Uganda RBF context, see IMC (2014); for Indonesia, see APEX (2013).

[255] The issue has, for instance, been explored by CQuestCapital (http://www.cquestcapital.com/wp-content/uploads/2013/05/Health_reductions_paper_4_19_2013.pdf), which is now in the process of exploring and piloting such a mechanism.

[256] New York Times, 2011; http://kristof.blogs.nytimes.com/2011/06/13/a-low-impact-stove-for-rwanda/

[257] PCIA, 2012; http://www.pciaonline.org/toyola-energy-limited

[258] IFC, 2012; http://www1.ifc.org/wps/wcm/connect/region__ext_content/regions/sub-saharan+africa/news/cooking_up_an_energy_solution

[259] The Nation, 2012; http://www.thenationonlineng.net/2011/index.php/feed/business/energy/38019-associationmoves-to-deepen-lpg-consumption.txt

[260] Bloomberg Renewable Energy Finance and EcoSystem Marketplace, 2014.

[261] See http://cdm.unfccc.int/ProgrammeOfActivities/registered.html (accessed February 25, 2014).

[262] http://www.ecosystemmarketplace.com/pages/dynamic/article.page.php?page_id=10629&section=carbon_market&eod=1P

[263] Global Alliance for Clean Cookstoves, 2013.

[264] The recent State of the Voluntary Carbon Market report indicates average prices per ton of CO_2 as ranging from $ 0.1/tCO_2e (from the now defunct Chicago Climate Exchange) to more than $ 120/tCO_2e for J-VERs in Japan.

7 LOOKING FORWARD AND RECOMMENDATIONS

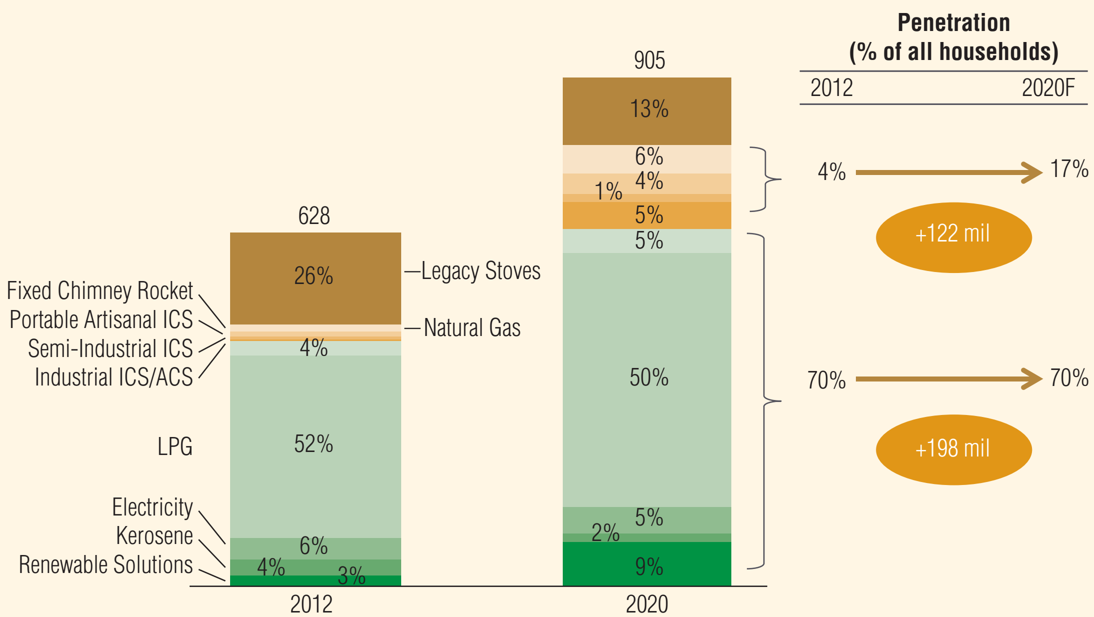
This chapter provides a market forecast for the sector, an overview of barriers to more rapid market growth and cross-cutting recommendations for the sector.

A. THE BASE CASE FOR SECTOR DEVELOPMENT

The business-as-usual scenario for 2012–20 shows promising growth, but is not yet on track with the sector's potential. Even without major new interventions, existing market dynamics will ensure that tens of millions of households will gain access to (at least) minimally improved cooking solutions by the end of the decade. This is encouraging, but not sufficient. While millions will gain access to some form of improved cooking appliance by 2020, 35–45% of the global population will remain vulnerable to the adverse impacts that stem from traditional cooking methods (Figure 7.1).

FIGURE 7.1:
Base Case Market Growth Forecast (2010–20)

Improved Stove and Clean Fuel Penetration of Global Households (millions of households, %)



Source: Clean and improved cookstove penetration forecast model; Task Team analysis.

The forecast is supported by a number of indirect indicators. First, many cookstove suppliers have only recently entered the market. This is especially true of advanced biomass stoves. Second, industry association data suggest that overall sales and market participation have sharply increased over the past decade. PCIA, an industry association integrated into the Global Alliance after its launch, experienced 400% growth in its membership in 2005–10, including many private sector members. PCIA's historical sales data from these members show cumulative sales growing at compound annual growth rate of 69% during this period.

BOX 7.1:

Methodology: Forecasting Stove Penetration

Dalberg used its estimation of stove penetration as its baseline for 2012 and calculated 2020 projections using forecast growth rates for each stove type. Forecast growth rates were calculated on the basis of historical growth rates and projections from stove manufacturers or other organizations. Multiple projections were considered and triangulated against other data, such as surveys. Where growth rates ranged widely, conservative estimates were applied. Sources included the ICS and modern fuel penetration database, WHO, World Bank, and expert interviews.

Furthermore, a limited sample of respondents to a Global Alliance manufacturers' survey, including many of the largest private sector manufactures and donor programs, predicted solid annual sales from 2010 through 2015 (34% CAGR across all players), but then expect an enormous growth in average annual sales (60% CAGR) to over 134 million stoves through 2020. Although, the long-term forecast appears to be overly aggressive compared to other market analogues (e.g., 50% growth over the first 10 years of the cell phone market in Africa, likely the most successful technology adoption curve example in history), the short-term 2010–15 forecast comes close to our base case scenario for long-term growth.

Given these concerns, it is important to carefully consider the barriers that stand in the way of greater growth. These are addressed in the following section.

B. BARRIERS TO MORE RAPID GROWTH

In order to expedite the growth of the clean and improved cookstoves market—especially in higher value products such as LPG, ethanol, biomass gasifier, and biogas stoves—some of the major barriers that keep demand in check need to be addressed. As described in greater detail throughout this report, the primary cross-cutting barriers include the following:

- **Affordability of clean cooking solutions.** Reducing end-consumer prices will require major investments in clean-fuel supply chains and scale up of quality-controlled production and assembly. On the demand side, innovation in distribution business models (e.g., stove utility/pellet-fuel model) and consumer finance (e.g., pay-as-you-go solutions) are needed to lower upfront purchasing barriers as traditional (e.g., MFI) end-user financing models will not drive scale. Aside

from such indirect methods of promoting affordability, wider adoption of clean cookstoves and fuels likely also requires targeted performance-linked subsidy approaches, including the scale up of CDM programs and the introduction of new market incentives linked to incremental health and environmental benefits of clean cooking technologies (e.g., producer and distributor subsidies linked to the reach of clean stoves).

- **Consumer awareness.** Many consumers are not aware of the health risks associated with burning solid fuels, and their knowledge about the availability and benefits of improved alternatives is low. This market failure cannot be addressed by the private sector alone, and will require government and donor support to help educate consumers on benefits and proper use of clean and improved cookstoves.
- **Producer capacity.** Technical capacity of domestic clean fuel and cookstove producers is low, there are major financing gaps for producers seeking to enter the market or move up the efficiency ladder, and working capital is also a challenge across the distribution value chain. For international manufacturers, market and consumer intelligence is often the biggest technical constraint, with limited data-driven insights into culture-specific consumer needs and product requirements.
- **Cookstove quality and performance.** The number of improved cookstove models and fuel production solutions customized for local environments is still low and systemic support for new innovation and R&D on new breakthrough solutions (e.g., gasifier technologies) is limited. For clean cooking solutions that do reach the market, access to standardized testing is limited or unaffordable for a range of players, though Global Alliance support for 12 new testing centers around the world is likely to mitigate this problem.
- **Policy gaps.** Ineffective or perverse incentives are common in regulations governing solid fuel production and improved biomass stoves; incentives for clean fuel scale-up are often absent or, in the case of large direct fuel subsidies, unsustainable; and high, poorly targeted import duties currently hold back the development of more effective domestic clean cooking sectors.

For many technologies, the most significant barriers lie on the demand side of the ecosystem. Of these, affordability and consumer awareness are identified as key barriers (Figure 7.2). As a result, incremental improvements to the effectiveness of the supply chain have limited impact without first addressing these challenges. On the supply side, fostering innovation to meet local consumer needs and navigating the difficulties of distribution/retail in new, often rural, markets remain as major challenges. One issue of particular relevance to both suppliers and consumers is the question of financing, though the challenges differ significantly for each group.

The most relevant barriers often differ by stove type. Both basic stoves and more advanced models that use biomass benefit from consumers that are familiar with the fuel type. Because consumers have a long history of obtaining charcoal and wood in local markets, they are willing to adopt even more-advanced models if the cost-savings and energy benefits are obvious to them. Basic stoves enjoy the greatest market penetration today, and more advanced biomass models are growing their customer base at fast rates.

However, despite their relative success in consumer markets, these stoves still face more challenges on the supply side: the lack of distribution capability, access to finance, and technical skills tends to

FIGURE 7.2:

Major Barriers Affecting the Clean Cooking Appliance Ecosystem

Consumer Demand	Supply	Cross-Cutting Enablers
Affordability (product and fuel)	Cost-effective distribution	Policy and regulations
Consumer awareness	Producer and distributer access to finance	Quality standards and testing infrastructure
Access	Producer capacity	Lack of consumer/market intelligence
Culturally appropriate design and convenience	Lack of after-sales support	R&D and technical innovation barriers
Low product quality		Lack of sector coordination
		Program monitoring and impact assessment

Sources: WB regional consultations; Global Alliance for Clean Cookstoves market assessments; interviews; PCIA; Task Team analysis.

inhibit market growth. The same is often said for modern and renewable cookstove models. Major barriers are for each stove type are as follows:

- **Basic cookstoves.** Basic cookstoves, such as Kenya's Ceramic *Jiko* and the New Lao Stove in Cambodia, have thrived in a market that has largely been supplied by small artisanal operations. But as the market grows to even greater scale and policymakers seek to push the adoption of more efficient models, basic cookstove manufacturers will struggle to adjust. The often small size and informality of most basic cookstove production discourages investment from commercial banks. Access to finance suffers as subscale and small-profit businesses are ignored by commercial capital. Moreover, low levels of business literacy and technical capacity stand in the way of developing modern manufacturing processes. As markets expand and customers seek higher quality products with manufacturer guarantees, the former dominance of this stove type in terms of market share is going to be threatened. Familiarity will begin losing out to functionality and flexibility in the face of a dynamic market.
- **Higher end biomass stoves.** In higher end biomass stoves, consumers will be familiar with the fuel type, but must still be convinced to pay more than they would have for a basic cookstove. While a wood rocket cookstove may be a more cost-effective product, taking into account long-run savings, consumers will be unaware of this benefit unless it is well advertised. On the supply side, recent cost-cutting measures have brought the cost of energy efficient biomass stoves down significantly,

FIGURE 7.3:
Barriers, by Technology Type

	Significance of Barrier for Technology	Improved Cook Stoves-Biomas			Alternative-Fuels and Stoves			
		Artisanal ICS	Semi-industrial ICS	Industrial ICS and ACS	Briquettes /Pellets	LPG	Bio-fuels	Bio-digesters
Demand	Affordability (product or fuel)	◑	◑	◕	◑	●	●	●
Demand	Consumer awareness	◔	◑	◕	◑	◕	◕	●
Demand	Access	◔	◑	◑	◕	◕	◕	◕
Demand	Appropriate design	◔	◑	◕	◑	◑	◑	◕
Demand	Product quality/safety	●	◕	◑	◔	●	◕	◑
Supply	Cost effective distribution	◑	◕	●	◑	◕	◕	◕
Supply	Producer/distributor finance	◕	●	◕	◑	◔	◑	◑
Supply	Producer technical capacity	●	◕	◔	◕	○	◑	◕
Supply	After-sales support/warranties	◔	◔	◑	◔	◔	◔	◕
Enablers	Policy and regulations (i.e., duties)	◔	◔	◕	◔	◕	◕	◕
Enablers	Quality standards/testing	◕	◑	◑	◔	●	◕	◑
Enablers	Consumer/market intelligence	◔	◑	◕	◔	◑	◑	◑
Enablers	R&D and technical innovation	◑	◑	◕	◔	◔	◑	◑
Enablers	Sector coordination	◔	◔	◑	◔	◑	◑	◔
Enablers	Monitoring/impact assessment	◔	◔	◑	◑	◔	◑	◑

● Denotes major challenge for expanding the market for this technology.

Sources: World Bank regional consultations; Global Alliance market assessments; sector interviews; Task Team analysis.

but they are still too expensive for many consumers. As such, supply-side barriers (e.g., producer capacity and high-cost distribution) will continue to hold back the market from its full potential.

- **Alternative fuels and stoves.** Many modern stoves also face the awareness and affordability challenges associated with higher end biomass stoves. Added to this are the challenges of fuel switching, as household are hesitant to take the risk of relying on a fuel market that may be quite volatile and where they have no experience. Basic accessibility can also be an issue for fuels such as LPG whose distribution networks in rural areas are not well developed.

Figure 7.3 breaks down these barriers by type of stove technology.

C. POTENTIAL FOR FASTER SECTOR DEVELOPMENT

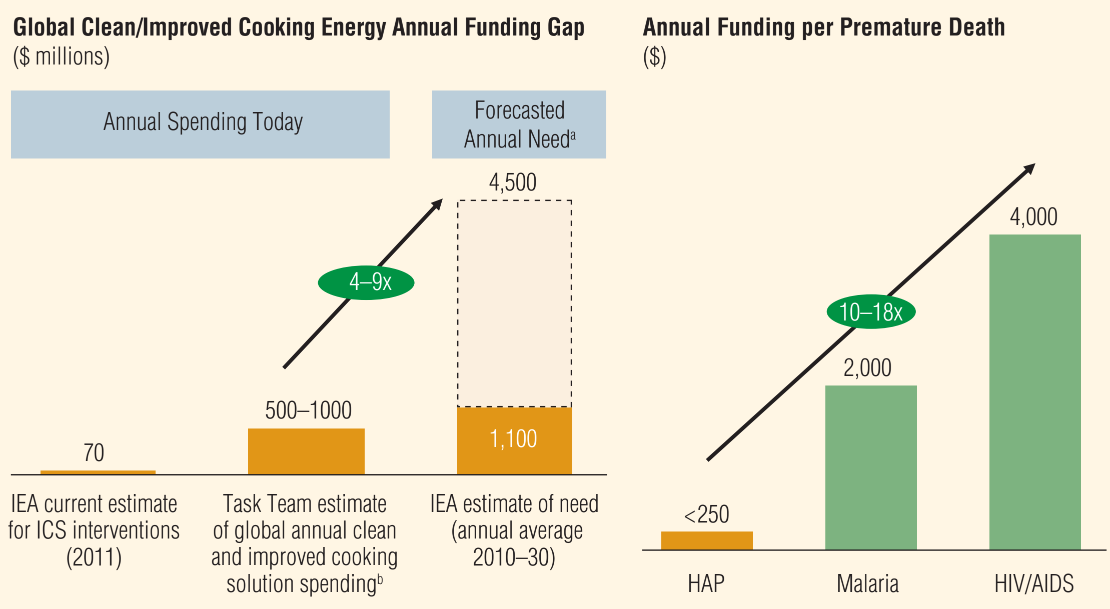
A more aggressive scenario is possible for the market's growth. The scale of ambition and aggressiveness of long-term forecasts from some manufacturers and project managers leave room for skepticism. Nonetheless, overall we believe that the optimism is well warranted on the basis of

historical sales data across multiple stove types, including pure private sector and donor-intermediated approaches.

A significant uptick in funding could unlock high growth. There exists a significant funding shortfall across the value chain (Figure 7.4). This extends from financing for improved biomass and renewable fuel supply chains to working capital for clean cookstove producers, importers, and distributors. Financial support is also lacking in supporting large-scale market changes, providing infrastructural investments, and delivering targeted subsides to achieve goals in public health and the environment.

The IEA projects that a total investment of $ 95 billion will be needed to achieve universal access to clean cooking by 2030, amounting to annual global investments of $ 4.5 billion. To achieve universal access to clean cooking by 2030, the IEA estimates the need for $ 95 billion over two decades.[265] The recent Global Energy Assessment (GEA) report[266] places the funding need at $ 36–41 billion annually over the same time period to achieve universal electricity and clean cooking energy access, with over 20% of the total being attributed to cooking. Current investment levels in clean cooking pale in comparison to this anticipated need. There are few comprehensive assessments of funding for clean and improved cookstove technologies, but IEA has estimated that $ 70 million has been spent by

FIGURE 7.4:
Funding for Clean and Improved Cooking Solutions



Sources: IEA; various reports tracking global spending on malaria and HIV/AIDS; Task Team analysis.

a Estimated need is based on the "Universal Modern Energy Access Case" (UMEAC) that targets full access to clean cooking facilities by 2030 (includes greater access to LPG, biogas, and advanced biomass stoves).

b Task Team estimate based on known public sector and donor spending for clean and improved stove programs; includes appliance but not fuel subsidies.

donors on improved and clean biomass cookstoves efforts globally.[267] The Global Alliance has mobilized roughly $ 50 million in the 5 years since its inception. Adding in LPG and biogas appliance investments and subsidies, and excluding ongoing fuel subsidies, we estimate that the total global funding for clean and improved cooking is unlikely to exceed the range of $ 500 million to $ 1 billion, suggesting that the need exceeds available funding by four to nine times. Seen against the background of global health expenditures, underfunding for the clean cooking sector is even more obvious: less than $ 250 in funding per HAP death in contrast to more than $ 2,000 per malaria death and $ 4,000 per HIV death.

D. RECOMMENDATIONS

To accelerate the path to universal access to clean cooking, this report includes a number of recommendations for various stakeholders.

Governments, NGOs, and the Donor Community

1. Significantly increase focus on clean cooking solutions, but continue to invest in intermediate and basic ICSs given the segmented nature of the consumer and the slow pace of market transition. Growing evidence for the negative health impacts of traditional biomass and coal cooking suggests that full technology neutrality is not an option for donors and policymakers. Only the cleanest modern and renewable fuels, and—pending further evidence from the field—advanced biomass gasifier cookstoves can meaningfully mitigate the HAP-linked deaths of millions in coming years.

Sector interventions should prioritize the uptake of high-performing clean cooking solutions that—because of their cost, early stage of commercialization, or limited consumer willingness to pay for incremental health benefits—are unlikely to reach scale without major new investments in fuel infrastructure, stove design, impact research (e.g., investment into RCTs and field performance studies focused on emerging range of ACSs), distribution capacity, and end-user finance. At the global scale, support is particularly vital for the cleanest modern and renewable solutions such as LPG and biogas, which have seen exceptional uptake in several middle-income countries over the past decade (e.g., Indonesia, Vietnam, India for LPG; and China, Nepal, parts of Southeast Asia for biogas).

While a rebalancing of sector investments toward cleaner solutions is needed, the public sector should continue to support fuel-efficient solutions such as intermediate and basic ICS, particularly in poorer, less well-developed cooking markets and for excluded populations. Some basic and, in particular, intermediate ICSs can generate fuel-saving benefits of clean biomass stoves at much lower price points; create moderate health, environment, and climate benefits; and, in many cases, remain the only improved solution that is reasonably accessible and affordable for the poor. Basic ICSs can have significant positive job creation effects, particularly in markets across Africa, Southeast Asia (e.g., Cambodia), and South Asia (e.g., India) where basic ICS markets are already robust. Furthermore, short payback periods for fuel-efficient ICS and possible positive externalities of artisanal and semi-industrial markets (e.g., consumer exposure to industrially manufactured, quality-controlled stoves) suggest that establishing an intermediate technology baseline will not impede and may even accelerate consumer migration further up the energy ladder.

2. Support more sustainable production of clean biomass and renewable fuel alternatives alongside the current focus on stove efficiency and emissions; demand-side solutions alone are not enough. Historical trends make it clear that the rapid growth of woodfuel consumption will not be resolved via the adoption of more efficient ICSs. Even universal adoption of basic ICSs in a region like Africa, for instance, will only maintain the status quo of overall charcoal consumption by 2020 (i.e., it would simply cancel out the projected 30% increase in charcoal use by volume). Mitigating the environmental and climate change harms of biomass cooking requires supply-side interventions, including more rational biomass supply markets (e.g., linkages to sustainable forestry), more efficient biomass fuel production technologies (e.g., higher efficiency charcoal kilns in Africa), renewable solid fuels from new sources (e.g., agricultural waste and bamboo briquetting), the wider adoption of alternative fuels such as biogas and ethanol, and—where culturally appropriate—the promotion of supplementary cooking solutions such as solar ovens (e.g., in East and Central Asia) and retained-heat cookers (e.g., in Africa).

Fuel-side interventions, when properly executed, have high potential for sustainable market-based approaches given the significantly larger scale of consumer spending on fuels than stoves. Furthermore, fuel interventions have the advantage of the large labor force involved in cooking-fuel production and distribution—which can, in theory, be co-opted into new value chains for improved and clean cooking fuel.

3. Prioritize market-based approaches wherever feasible to maximize cooking market sustainability, but also deploy more direct subsidies when they can be tightly linked to health and environmental impacts. Indirect subsidies for cooking market support and facilitation—consumer awareness, testing centers, and industry associations, for example—have been an essential feature of all successful clean fuel and cookstove programs both in Africa and globally to date. Direct subsidies for producers have seen more mixed results, and subsidies for consumers have been the most problematic in both modern fuel and ICS markets. There has been some evidence of slower cookstove uptake than via purely commercial approaches, higher risks of promoting technologies that are not desired by consumers, and serious sustainability challenges when ongoing fuel subsidies are withdrawn.

Despite these dangers, direct incentives via CDM markets and new incentives tied to health outcomes are needed to scale up truly clean cooking technologies given their relatively high costs and the immensity of the affordability challenge. The logic of fuel savings, combined with investments into consumer awareness, will continue to convince consumers to adopt highly efficient, fuel-saving appliances such as rocket stoves. Holding fuel efficiency constant, there is little evidence that consumers are willing to pay the incremental $ 25–70 that separate high-quality industrial rocket stoves ($ 25–50) from truly clean advanced biomass gasifier solutions ($ 50–100). If CDM markets recover, they can bridge a part of this gap (e.g., lowering the end-consumer price by $ 5–20), but additional measures will be needed for compensating markets for introducing incremental health benefits that are not appreciated by consumers. Potential mechanisms for structuring such producer and distributor incentives include performance-based grants tied to proven health impacts or, perhaps, innovative social impact bonds that can be linked to projected public health system savings. Direct consumer subsidies can likewise be linked to impact and carefully targeted via vouchers or comparable mechanisms drawing on lessons from malaria bed nets, biogas digesters, and existing ICS programs.

4. Focus on providing critical public goods to accelerate clean cooking sector development. While the process has already launched via the coordinating efforts of the Global Alliance, there is still a great deal of debate about the ideal role of donors and governments vis-à-vis the private sector in the improved and clean cooking space. Report findings strongly suggest that, even with very strong private sector leadership, there are multiple public goods that will require continued public sector investment. Emphasis should be placed on consumer education, access to finance for producers and distributors, quality standards, policy reform, and market intelligence.

5. Consumer education campaigns to promote awareness of the harmful effects of solid fuels, on one hand, and the advantages of new clean cooking solutions, on the other hand, can and will be an important complement for private sector marketing efforts. This has been seen in other market transformation interventions focused on behavior change (e.g., solar lanterns, malaria bednets, water filters, handwashing campaigns).

6. Access to finance is a constraint across stove and fuel value chains, but donors and governments are uniquely well positioned to support critical upstream and mid-stream finance bottlenecks (e.g., in-country producers, importers, and distributors) via their engagement with financial institutions and SME promotion activities. The catalytic provision of first loss capital by donors to crowd in private investors is an important model to think through as carbon finance markets weaken.

7. Market intelligence is a vital public good at this early stage of sector development. Major knowledge gaps include the lack of systematized field data on the performance of new solutions like gasifiers under real world conditions; weak base of knowledge on the systemic health, climate change, and livelihood impacts of clean biomass and modern fuel stoves; and poor understanding of the potential African clean energy consumer.

8. On the quality and standards front, much more still needs to be done to **invest in global testing centers** since the capacity of local testing laboratories is constrained, and access to regional and global testing facilities is cost prohibitive or impractical for many. Investment is also needed to finalize the ongoing international standardization process, including the formalization of an ISO standard and the formation of ISO Technical Committee and, crucially, the harmonization of global ICS standards with local country standards bureaus and policymaker-rating approaches.

9. Policy is also a gap for many fuel and stove markets. For industrially produced cooking appliances, taxes and duties not only exclude the best cookstove technologies from domestic markets, but often adversely affect the potential for domestic cookstove assembly in markets such as Africa and Latin America due to the high cost of imported components. Policy issues play an even more important role in fuel markets. In Africa and Southeast Asia, in particular, with their large reliance on charcoal, more rational regulation of traditional biomass supply chains is needed to bring woodfuels into the formal sector. Across the board, in middle-income markets in particular, government support and public-private partnerships are vital for the development of modern (e.g., LPG) and renewable (e.g., ethanol) fuel markets infrastructure (e.g., transport routes and storage infrastructure), standards (e.g., LPG cylinder revalidation and certification standards), and the elimination of perverse market incentives (e.g., removal of kerosene subsidies).

Private Sector Stakeholders

1. Capture the first mover advantage: despite many challenges, there is an immense underserved cooking market with growing opportunities and a rapidly rising number of new entrants. The market has immense potential with hundreds of millions of fuel-purchasing households (90 million in Africa alone), including a growing middle class (>15% of consumers with per capita incomes over $ 1,500), and spending more than $ 20 billion on cooking fuel annually. Despite high prices and affordability constraints, modern fuel use is growing at a quick pace in several markets, clean solid biomass production and liquid biofuel enterprises are showing encouraging early results. Industrial and semi-industrial ICS manufacturers are experiencing rapid year-on-year sales growth (30–300%), attractive margins, particularly where carbon credits can be secured (5–20%), and, thus far, low levels of competition. The range of products and suppliers is very small relative to the potential consumer demand and in comparison to other analogous markets (e.g., ~10 sizeable international manufacturers focused on improved cookstoves with >50k of sales vs. dozens of international manufacturers focused on solar lanterns). This does not mean that the market lacks challenges, but the opportunity for early entrants, including both multi-national corporations and social entrepreneurs, is large.

2. Reduce prices via low-cost design, local production or assembly (where feasible), and innovative distribution and financing models that lower upfront stove costs. Affordability, while not the only barrier to cooking market development, is a major obstacle to the faster adoption of higher cost improved and clean stoves and fuels in lower income geographies. The challenge may require demand-side solutions such as consumer finance, but, in the near term, can likely best be addressed by producers via tailored product development and distribution strategies. Anecdotal evidence from interviews with cooking sector stakeholders suggests that even small reductions in cost can have major uptake implications with many suggesting that a $ 15–25 price point for highly efficient and clean stoves ($ 15–75 lower than prices in the market today) is required to ensure much broader market volumes. The importance of price reduction strategies is also clearly evidenced by other BoP product markets such as those for solar lanterns and mobile phones.

Drawing on lessons from other sectors, from a product design standpoint, manufacturers can lower costs by embracing "frugal design" solutions that include the use of indigenous or recycled materials, modular designs (e.g., ability to add on separate accessories, pot holders, plug-in TEG and fan units), and flat-pack solutions that allow for local assembly with manageable trade-offs for product quality. The development of low-cost intermediate ICS technologies in the $ 5–20 range (e.g., semi-industrial metal rocket ICS in markets such as Ghana, Uganda, Kenya, and Malawi, and lower cost, fixed rocket stove variations in Central America) and an emerging tier of $ 15–25 natural draft gasifier stoves in multiple pilots across the globe (e.g., Awamu/Mwoto in Uganda, GreenTech stove in Gambia, and rice gasifiers in Vietnam and Indonesia) is an important illustration of the opportunity.

Given the scale of Asia-based manufacturing, domestic production outside of large Asian manufacturing centers, such as India and China, is not necessarily a path to lower costs, but should be explored by manufacturers to tap into regional hubs (e.g., Kenya for East Africa). Transport,

insurance costs, import duties, and related expenses (warehousing, importer margins) are a large share of the final cost of international ICS products (20–35%), so domestic production or assembly may be the answer in those geographies that have sufficiently large markets, low labor costs, and sufficient labor quality.

3. Focus on performance and quality: most consumers, even the poor, are willing to pay for better design, and the public sector is increasingly willing to support solutions that can ensure health results. While market spoilage due to consumer disappointment with low-quality products is not yet a major concern for the cookstove sector in most countries, experience in other household energy markets (e.g., solar home systems, solar lanterns) shows that the BoP consumer is mindful of product quality (i.e., durability, shelf-life, safety). There is some anecdotal evidence that, in any given technology class, better-performing cookstoves see faster sales growth than products with inferior fuel efficiency and emissions performance. Consumer surveys also suggest that product design matters to end users: cookstoves that are better adapted to consumer usage patterns (e.g., pot size, stove height, cooking time) receive higher ratings from end users and are associated with higher willingness to pay. Self-reported sales and stove project data suggest that the highest market growth today (at least for high-end ICS solutions) is correlated with products that are perceived by the sector to have better design features.

4. Focus on opportunities in cooking fuels, not just cookstoves, because the global fuel market is orders-of-magnitude larger than that for cooking appliances. There is a significant opportunity for formal sector entrepreneurs with access to capital to adopt improved production technologies (e.g., efficient charcoal kilns) and capture attractive margins and rapid sales growth from burgeoning charcoal markets. Renewable solid fuel briquette and pellet manufacturing is a growing opportunity for private enterprises, ranging in size from artisanal producers to mid-sized industrial enterprises manufacturing thousands of tons of fuel annually. The biofuels sector also has promising and potentially profitable models on the horizon, including decentralized feedstock outgrower schemes and micro-distillery production units that can ensure a stable, low-cost biofuel supply. For maximum uptake, end-user impact, and (potential) profitability, clean solid biomass and renewable fuels can be integrated into clean-cookstove business models (e.g., free or low-cost cookstove distribution subsidized by high margins on fuel refill sales). The integrated fuel/stove model is being piloted in several projects in Africa and India with some encouraging early results.

ENDNOTES

[265] IEA, 2011.

[266] GEA, 2012.

[267] Advanced biomass stoves are defined by the IEA in this report as "biomass gasifier-operated cooking stoves, which run on solid biomass, such as wood chips and briquettes."

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