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ACCES
Africa Clean Cooking Energy Solutions Initiative

CLEAN AND IMPROVED COOKING IN SUB-SAHARAN AFRICA

November 2014
Second edition

A Landscape Report

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ABBREVIATIONS

ABPP	Africa Biogas Partnership Programme
ACCES	Africa Clean Cooking Energy Solutions
ACS	advanced [biomass] cookstoves
AEF	Africa Energy Forum
AFREA	Africa Renewable Energy Access Program
ALRI	acute lower respiratory infection
AREED	Africa Rural Energy Enterprise Development
BC	black carbon
BEIA	Biomass Energy Initiative for Africa
bn	billion
BoP	base of the pyramid
BTU	British thermal unit
CAGR	compounded annual growth rate
CBA	cost-benefit analysis
CBFM	community-based forest management
CDM	clean development mechanism
CERs	certified emission reductions
CH_4	methane
CO	carbon monoxide
CO_2e	carbon dioxide-equivalent
CO_2-eq	carbon dioxide-equivalent
COPD	chronic obstructive pulmonary disease
DALY	disability-adjusted life years
DEEP	Developing Energy Enterprises Program
DHS	demographic and health surveys
DRC	Democratic Republic of the Congo
EC	elemental carbon
ECOWAS	Economic Community of West African States
EnDev	Energizing Development Program
EPA	U.S. Environmental Protection Agency
ESMAP	Energy Sector Management Assistance Program
EU	European Union
EWSA	Energy, Water and Sanitation Authority
FAO	Food and Agriculture Organization of the United Nations
FIP	Forest Investment Program
fNRB	fraction of nonrenewable biomass
g	gram
GACC	Global Alliance for Clean Cookstoves
GBD	global burden of disease
GDP	gross domestic product
Gg	gigagram (1 billion grams)
GHG	greenhouse gas
GIZ	Gesellschaft für Internationale Zusammenarbeit
GLPGP	Global Liquid Petroleum Gas Partnership
GS	gold standard
GSM	Global System for Mobile Communications
GVEP	Global Village Energy Partnership
GWP	global warming potential
HAP	household air pollution
HH	household
ICEED	International Centre for Energy, Environment, and Development
ICS	improved [biomass] cookstove
ICT	information and communications technology
IEA	International Energy Agency
IFC	International Finance Corporation
ILF	International Lifeline Fund
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
IWA	International Workshop Agreement
k	thousand
KCJ	Kenya Ceramic *Jiko*
kg	kilogram
l	liter
LED	light-emitting diode
LNG	liquefied natural gas
LPG	liquefied petroleum gas
LSMS	Living Standards Measurement Study
MFI	microfinance institution
MICS	Multiple Indicator Cluster Survey
mil	million
min	minute
MJ	megajoules
mm	million
MMt	million metric ton
mn	million
MT	million ton
MVP	Millennium Villages Project
N_2O	nitrous oxide
NCP	National Cookstove Program
ND	natural draft
NGO	nongovernmental organization

NMHC	nonmethane hydrocarbon
OC	organic carbon
OECD	Organisation for Economic Co-operation and Development
PAH	polycyclic aromatic hydrocarbon
PATS	particle and temperature sensor
PAYG	pay as you go
PCIA	Partnership for Clean Indoor Air
PICs	products of incomplete combustion
$PM_{2.5}$	particulate matter with diameter of <2.5 μm
PoA	program of activities
ProBEC	Program for Basic Energy and Conservation
QA&TS	quality assurance and technical support
QA	quality assurance
QC	quality control
R&D	research and development
RBF	results-based financing
RCT	randomized controlled trial
REDD+	Reducing Emissions from Deforestation and Forest Degradation in Developing Countries
REMA	Rwanda Environment Management Authority
SE4All	United Nations Sustainable Energy for All
SME	small- and medium-sized enterprise
SSA	Sub-Saharan Africa
SUM	stove-use monitor
TB	tuberculosis
TChar	combination TLUD and charcoal stove
TEG	thermoelectric generator
TLUD	top-loading updraft stove
$\mu g/m^3$	microgram per cubic meter
μm	micrometer
UN	United Nations
UNACC	Uganda National Alliance for Clean Cookstoves
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNHCR	United Nations High Commissioner for Refugees
UPDEA	Union of African Electricity Producers
USAID	United States Agency for International Development
VAT	value-added tax
VCS	verified carbon standard
VCU	verified carbon unit
VER	verified emission reduction
WACCA	West African Clean Cooking Alliance
WB	World Bank
WHO	World Health Organization
WLPGA	World Liquefied Petroleum Gas Association
WRI	World Resources Institute
WTP	willingness to pay
y-on-y	year on year


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FOREWORD

Evidence from the most recent World Health Organization (WHO) survey on the global burden of disease shows that nearly 600,000 Africans die annually and millions more suffer from chronic illnesses caused by air pollution from inefficient and dangerous traditional cooking fuels and stoves. This tragic and avoidable first-order public health crisis disproportionately harms women and children. Moreover, cooking with wood, charcoal, crop waste, dung, coal, and potentially dangerous and polluting modern fuels, such as kerosene, also imposes tremendous direct costs on economies and households in Sub-Saharan Africa (SSA) and contributes to a wide range of negative environmental and climate change effects.

The authors of this report believe that—with the right blend of political will, carefully targeted technical and financial support, and a renewed focus on enabling frameworks—the next 5–10 years can serve as a turning point for the African cooking sector, leading to a much broader uptake of cleaner and more efficient fuels and stoves. Important new developments include the emergence of new, clean cooking solutions; growing demand for fuel-saving alternatives due to escalating pressure on biomass resources and prices; innovation in business models for base-of-the-pyramid (BoP) products; and rising support for the clean cooking agenda from the public health community, governments, and donors. The African cooking sector also increasingly represents an attractive niche market for the private sector—as reflected by increasing entry over the past few years of social enterprises, multinationals, impact investors, and carbon finance projects, including the launch of several large-scale, Africa-based manufacturing facilities for cleaner and more efficient biomass stoves and fuels.

However, despite these encouraging trends, there is also ample reason for continued skepticism. So far, three decades of efforts to promote both modern fuels and improved biomass stoves have seen only sporadic success at scale in the region and globally. Penetration of clean cooking solutions remains limited, and efforts to promote their adoption face substantial obstacles, including the limited ability of consumers to afford high-quality clean stoves and fuels, and lack of consumer awareness of, and willingness to pay premium prices for, cooking solutions that offer long-term health benefits. Moreover, large gaps in financial and technical capacity across stove and fuel supply chains, and gaps in the enabling environment for both fuel and stove markets, including the continued absence of coherent quality and performance standards, present additional challenges. Addressing these barriers will require substantially higher private and public investment, greater stakeholder coordination, and improved information to help decision makers learn from past experience, innovate, and measure progress in what continues to be a very opaque and fragmented sector.

This overview report, prepared in support of the World Bank's Africa Clean Cooking Energy Solutions (ACCES) initiative, builds on earlier reports from the World Bank and the Global Alliance for Clean Cookstoves (GACC).[1] The report establishes a baseline for the SSA cooking landscape and offers an overview of emerging opportunities to encourage increased investment in clean and improved cooking businesses across the region. This document is meant to serve as a companion to the recently issued report *The State of the Global Clean and Improved Cooking Sector* (2014), jointly published by Energy Sector Management Assistance Program/World Bank (ESMAP/WB) and the GACC.

In terms of its scope, this report covers the full range of "clean" and "improved" cooking solutions in SSA that can enhance the fuel efficiency and emissions performance of traditional technologies, each varying widely in terms of fuel feedstock, design, construction materials, methods of production, and harm mitigation potential (Figure 1).[2]

The typology in Figure 1 is an attempt to rationalize existing clean and improved cooking-sector definitions and is used throughout the report for consistency. These definitions should be seen only as indicative, given the wide range of cookstove models and performance within each stove category. Wherever possible, the report has linked these definitions to the provisional standards and performance tiers adopted via an International Workshop Agreement (IWA 11:2012) by the International Standards Organization (ISO), which establish a common quantitative vocabulary for clean and improved cookstoves (ICS) based on absolute, not relative or comparative, measures of efficiency, emissions, and safety performance (see Appendix 1).[3] The provisional agreement was ratified in June 2013 with the formation of the ISO Technical Committee 285, the key global body charged with developing, approving, and monitoring improved and clean cooking standards in the

Figure 1: Overview of improved and clean cooking solutions

	"Improved" solutions		"Clean" solutions		
	Legacy and basic ICS	Intermediate ICS	Advanced ICS	Modern fuel	Renewable fuel
					
Key features	Small functional improvements in fuel efficiency over baseline technologies; typically artisanally produced	Rocket-style designs with focus on highly improved fuel efficiency; includes both portable and built-in models	Fan or natural-draft gasifiers with high fuel and combustion efficiency; often designed for pellet/ briquette fuels	Stoves that rely on fossil fuels or electricity; have high fuel efficiency and low emissions	Derive energy from renewable non-woodfuel energy; often used as supplementary stoves
Technologies	• Legacy biomass and coal chimney stoves[1] • Basic efficient charcoal • Basic efficient wood	• Portable rocket stoves • Fixed rocket chimney • Highly improved (low CO_2) charcoal stoves	• Natural-draft gasifier (top-loading updraft (TLUD) or side-loading) • Fan gasifier/fan jet • Combination TLUD and charcoal stoves	• LPG • Electric (including induction) • Natural gas stoves • Kerosene stoves[2]	• Biogas • Ethanol • Solar • Retained heat cookers
Efficiency	Tier 0–2	Tier 2–3	Tier 3–4	Tier 4	Tier 3–4
Emissions[3]	Tier 0–1	Tier 1–2	Tier 2–3	Tier 3–4	Tier 3–4
Overall benefits	Moderate				High

[1] Legacy stoves categorized as improved within typology but actual performance of many legacy stoves likely falls below provisional ISO/IWA standards
[2] Controlled tests of good quality kerosene pressure stoves show low emissions, but field data suggests that many kerosene stoves are actually highly polluting
[3] Particulate matter ($PM_{2.5}$) emissions at point of consumption; research suggests that high rating (Tier 3+) needed for significant health positive impacts

coming years.[4] The approval of testing methodologies is currently under discussion at the ISO. For the time being, the categorization according to tiers should therefore be understood as provisional.

Under the term *improved cooking solutions*, the report includes all cookstoves that improved fuel efficiency without reducing particulate matter emissions to the low levels necessary for optimal health outcomes as defined by WHO household air pollution guidelines. The "improved stove" category includes (1) basic chimney biomass and coal cookstoves, including many "legacy" biomass cookstoves distributed in early national stove programs (ISO Tier 0–2 for fuel efficiency, Tier 0–1 for emissions);[5] (2) "basic" portable wood and charcoal ICS (Tier 1–2 for efficiency, Tier 1 for emissions); and (3) highly fuel-efficient "intermediate" rocket-style ICS (Tier 2–3 for efficiency, Tier 1–2 for emissions).

Clean cooking solutions include low-particulate-emission technologies (ISO Tier 3–4 for emissions), such as (1) high-performance advanced biomass cookstoves (ACS) which use fans or natural-draft (ND) gasification principles, particularly when such stoves are combined with biomass briquette/pellet fuels;[6] (2) modern-energy cooking solutions, including liquefied petroleum gas (LPG), kerosene, natural gas, and electric stoves; and (3) a variety of renewable, nonsolid-fuel solutions, such as biogas, methanol, ethanol, solar cookers, and retained-heat cooking devices. The categorization of kerosene stoves as a clean cooking technology in this report is subject to a major caveat. While well-designed kerosene stoves have minimal particulate emissions, emissions from the low-quality kerosene stoves typically deployed in the SSA region are often much higher than expected and, more generally, there is a growing body of evidence about the dangers of kerosene cooking.[7]

The report incorporates the review of more than 300 secondary sources; analysis of primary data in dozens of existing market and household surveys, including the recent GACC market assessment reports; publicly available product-testing databases; impact evaluation data from large regional and country programs; focus group discussions with sector stakeholders in eastern, western, and southern Africa regional consultations; and interviews with more than 80 sector participants, including product designers, manufacturers, distributors, financiers, program managers, and policy makers. Data collection efforts have included the development of several country-level databases on historical fuel mix, energy expenditures, fuel prices, and cookstove penetration. Market models and analyses built for the report include an Africa-wide cost-benefit analysis tool for evaluating sector opportunity costs, a fuel use and expenditure forecast model, a cooking consumer segmentation, a manufacturer sales database, and a cookstove market forecast model. Depending on the analysis, the report uses data from 2010–14, with every effort made to ensure comparability across different sources and data points.

The resulting figures, facts, and analyses provide the most comprehensive picture of the clean and improved cooking sector in Africa available to date, but also have several weaknesses due to underlying data challenges. Across different sources, sector technology definitions, impact indicators, and sales-tracking methodologies are often inconsistently defined and variably applied. Therefore, end-user data, including information on consumer usage patterns and preferences, are of variable quality and available for only a small proportion of SSA markets. Finally, private-sector ICS and fuel sales information and public-sector cookstove program indicators are self-reported and, therefore, not always credible. The information assembled in this report constitutes a best-effort attempt to harmonize definitions and data sources, with the caveat of occasional lack of precision due to definitional and data-quality challenges. The report interprets data conservatively and highlights potentially contentious and ambiguous areas where appropriate. Consequently, this document should be seen as a starting point for sector analysis, and the data should be updated in future editions as the African cooking sector evolves.

EXECUTIVE SUMMARY

Reliance on solid-fuel cooking in Sub-Saharan Africa (SSA) is a large and growing problem. More than 700 million Africans (82%) use solid fuels, such as wood, charcoal, dung, crop waste, and coal, for their primary cooking needs—a number that will reach 850–900 million by the end of the decade. This high level of solid-fuel use, combined with household reliance on inefficient and unsafe traditional cookstoves, constitutes a first-order public health crisis: household air pollution (HAP) from solid-fuel cooking emissions kills nearly 600,000 Africans annually and is now recognized as the second-largest health risk factor in terms of death and disability in the region. Solid-fuel cooking in SSA accounts for up to 1% of global greenhouse gas emissions and 6% of global black carbon, an important additional driver of climate change because it both absorbs solar radiation in the atmosphere and deposits soot on snow and ice surfaces. Solid-fuel cooking also imposes significant costs on African households and economies, with a mid-range estimated opportunity cost of 3% of regional annual gross domestic product (GDP)—including avoidable spending on solid fuels, time losses due to firewood collection, the economic costs of increased mortality and morbidity burdens, and the environmental and climate costs of deforestation and carbon dioxide emissions.

The clean and improved cooking sector in SSA has evolved significantly, but is still highly underdeveloped. Only 11% of Africans use "clean" cookstoves that run on modern fuels, such as liquefied petroleum gas (LPG) (5%) and electric stoves (6%), as their primary cooking appliances. Many of these households continue to use traditional biomass-burning stoves as their secondary cooking device due to the common phenomenon of fuel and stove "stacking" (simultaneous usage of multiple fuels and stove technologies). Kerosene, which is used by 7% of Africans, likely does not qualify as a clean cooking solution in many instances, given the increasing evidence of harm from typical kerosene stoves in Africa. Stoves that run on such renewable fuels as biogas, ethanol, and solar are uncommon (less than 1%), and the penetration of "advanced" biomass gasifier cookstoves (less than 0.1%) that can come near the International Organization for Standardization's (ISO's) Tier 4 emission performance is still at a pilot stage. A growing number of SSA households (about 3.5%) use intermediate improved cookstoves (ICS) (e.g., rocket stoves), which are substantially more fuel efficient but do not achieve the emission reductions needed to realize the full health and environmental benefits of clean cooking. Another 9–10% of SSA households have access to both basic ICS (less than 5%) and legacy cookstoves (less than 5%) that offer only moderate improvements in fuel efficiency and emissions over traditional cooking technologies. In aggregate, Africa has a significantly lower rate of access to clean and improved solutions (25%, excluding legacy stoves) than any other region globally.

The continuation of current trends over the next decade is likely to offer ample opportunities for transformative advances in the adoption of more efficient and cleaner cooking solutions. On the demand side, key factors include a large urban population (a result of the region's two decades of rapid urban population growth); the emergence of an aspirational lower/middle class with rising incomes (the African population with discretionary income is expected to grow 50% over the next decade, to 130 million households); and escalating prices for cooking fuel (charcoal prices rose 11%, and liquefied petroleum gas (LPG) prices rose 8%, annually in 2000–10), a consistent long-term trend despite recent fossil fuel price declines in 2014-2015. A large and growing share of SSA consumers (50%) already pay something for their cooking fuels and can benefit tangibly from adopting even basic energy-saving cookstove alternatives. There is growing evidence across multiple SSA markets of consumer willingness to pay for basic ICS. Evidence of consumer demand for more expensive intermediate and advanced ICS is more limited, but emerging consumer survey data suggest that—with extensive consumer awareness building and the right products—demand for higher-cost, quality-controlled cooking solutions could grow rapidly.

On the supply side, key trends include accelerating technological innovation across the full spectrum of cooking technologies, including most notably the development of fan-gasifier biomass cookstoves that combine high rates of fuel efficiency (up to 50%) and very low levels of particulate-matter emissions (90%+ reduction vis-à-vis traditional biomass stoves). Other notable developments are the increased use of scalable and centralized industrial production—international players, such as Philips [ACE], Envirofit, and BURN Manufacturing, have opened new Africa-based manufacturing facilities, and EcoZoom also plans to do so in the near future—along with improved capacity for regional semi-industrial players. All these factors hold the promise of improved performance and higher product quality at lower cost. Another important supply-side trend includes the increasing availability of financing for manufacturers and distributors through the Global Alliance for Clean Cookstoves (GACC), the World Bank, the United States Agency for International Development, the Global Villages Energy Partnership, and recently launched private funds, such as the Base of the Pyramid Impact eXchange Fund, or BIX.

Meanwhile, two important trends are affecting both supply and demand in the region. First is the emergence of new distribution and financing models for reaching the poor, including carbon finance, microlending, lay-away and leasing schemes, and utility models for distributing renewable biomass pellet or ethanol fuels. Second is the growing number of entrepreneurs across all segments of the clean fuel and ICS value chain: over the past five years, the number of Africa-based industrial and semi-industrial ICS manufacturers has grown from less than 10 firms to more than 40.

The enabling environment for clean cooking solutions uptake is also seeing positive developments. There is a growing consensus among regional policy makers on the case for clean cooking energy. National cookstove programs are being launched or aggressively scaled up in such countries as Ethiopia, Ghana, Malawi, Nigeria, Rwanda, Senegal, and Uganda. There is an increased focus on cookstove quality testing and standards, as manifested by the adoption of provisional International Organization for Standardization/International Workshop Agreement (ISO/IWA) standards for stoves (see Appendix 2) and the growing number of testing centers across the region with increasing capacity to carry out tests according to the established protocols. There is rising interest from donors, nongovernmental organizations (NGOs),, and industry in championing innovation in clean and renewable cooking technologies. The monitoring and evaluation of cooking projects is improving. And, last but not least, global coordinating platforms are emerging—such as the GACC and the United Nations' Sustainable Energy for All; regional market transformation efforts, such as the World Bank's Africa Clean Cooking Energy Solutions program; and fuel-specific initiatives focused on Africa, such as the Global LPG Partnership and the Africa Biogas Partnership Programme.

Major obstacles remain on the path to maximizing the reach of clean and improved cooking solutions in Africa. Consumers' limited willingness to fully adopt new cooking solutions and limited ability to pay for higher-cost, clean, and improved cookstoves and fuels are the greatest long-term obstacles to broader adoption of clean cooking in Africa.

From the standpoint of willingness to adopt, limited consumer exposure to new technologies and low awareness of their benefits limit demand. Even when consumers are educated about stove benefits, however, willingness to adopt is often still low, due to the new solutions' inability to fit with consumers' cooking preferences (due to the reality or perception of inappropriate design); lack of consumer trust in stove performance and durability; concerns about the accessibility of fuel supply and after-sales support; and the behavioral (e.g., risk aversion, present bias) and cultural obstacles to sustained adoption of new technologies. The willingness-to-adopt challenge is not just an obstacle to initial stove uptake, but also affects sustained adoption and use—as manifested in the near-universal phenomenon of stove and fuel "stacking," where end users retain traditional cooking solutions for use alongside clean or improved solutions to accommodate both diverse household cooking needs and the force of tradition.

Even where households are willing to adopt improved and clean cookstoves and fuels, they often lack the ability to pay for the stove and fuel due to insufficient disposable incomes and/or the lack of savings. This "affordability challenge" is particularly acute for clean cooking solutions. The high upfront costs of higher-end cooking appliances (US$75–100 for fan gasifiers and US$25–100 for LPG and electric modern-fuel stoves) and the high ongoing costs of modern-fuel use relative to traditional biomass alternatives serve as a major constraint to the size of the clean cooking market. Affordability is likewise consistently rated as the top demand constraint by the manufacturers and distributors of industrially manufactured, high-quality intermediate ICS (rocket wood and charcoal stoves) in the US$15–50 range. For low-cost improved stoves (i.e., basic ICS in the US$3–15 range), aside from the poorest segments of the African population, affordability is a smaller obstacle, but nonetheless still serves as a brake on faster market development.

In making the decision to adopt or pay for improved and clean cooking solutions, Africans are primarily interested in fuel and time savings, convenience, smoke reduction, durability, and safety, with relatively little interest in the long-term health benefits and public-good aspects of cooking solutions. Reduction of fuel expenditures is the most powerful motivator among these factors, but does not apply for many end users. Only half of SSA households currently purchase cooking fuel, and many such fuel-buying households continue to rely on fuel collection in parallel, adjusting their mix of purchased and collected firewood as opportunities and economic situations dictate. Although the number of such fuel-purchasing households is growing, the pace of this change is unclear due to a lack of long-term data. The economic motivation for fuel-saving stoves is particularly weak for the poor (i.e., those earning less than $1.25 per day), collectors of wood and other biomass fuels (such as dung and crop waste), who constitute nearly 30% of the SSA population. Biomass-collecting households do face the physical harms and time burdens of firewood gathering, but tend to place a low value on time losses, given the low opportunity cost of rural labor; polychronic traditional cultures that generally undervalue time; and patriarchal family structures in which men play the dominant role in stove-purchasing decisions, leaving the time burdens of fuel collection to fall primarily on women and girls.

Many of these willingness-to-adopt and -pay issues can be addressed via consumer education and awareness building, as well as marketing solutions that enhance end-user trust (e.g., warranties, right to return). In addition—assuming that the underlying technologies are appropriately designed, distribution and financing approaches can build up end-user comfort through exposure (e.g., free trials), and innovative financing techniques (e.g., installment payment plans, pay-as-you-go/utility business models, and consumer financing) can address the liquidity constraints of those consumers whose income levels can sustain stove purchases but who lack the near-term savings needed for stove purchases.

For many cooking solutions, even when such approaches are applied, willingness to pay will remain a barrier to adoption. There is strong evidence that most African consumers are not willing to pay price premiums for stoves and fuels that generate incremental long-term health benefits—a factor that inherently limits the market-based potential of clean solutions that cannot compete with traditional or improved stoves on purely economic terms. Willingness to pay is also an issue for intermediate ICS technologies, where actual willingness to pay can be significantly below the stove's fair market price. Even after willingness to pay is improved through marketing, many ICS providers will still need to subsidize the upfront cost of their stoves—with carbon revenues, for example—to see adoption at scale, particularly in rural areas.

On the supply side, corresponding obstacles to wider adoption of improved and clean cooking solutions include the cost and complexity of last-mile distribution; the limited business management capacity and financial constraints of cooking-sector entrepreneurs; the still-limited adoption of uniform quality standards and product certification to minimize market spoilage; biomass supply market failures limiting fuel sustainability; and regulatory constraints, such as high taxes and duties on clean technologies or perverse subsidy incentives for the ongoing use of harmful fuels.

To address these various obstacles, sector funding is a cross-cutting challenge involving financing for fuel-supply chains, working capital for improved stove producers and distributors, public-sector funding for market transformation programs and enabling market infrastructure, and—where sensible—targeted subsidies and incentives tied to access, health, and climate change goals. The International Energy Agency (IEA) estimates the funding needed for universal access to clean cooking energy in SSA at more than US$1 billion annually through 2030—whereas the current fund flow is US$50–125 million. Public- and donor-sector funding, in particular, is far below levels that can realistically address the immensity of the health challenges caused by household air pollution: current SSA funding levels are an estimated US$100–250 per death for HAP versus US$2,000–4,000 per death for public health crises, such as HIV/AIDS and malaria.

The "business-as-usual" scenario for the clean and improved cooking sector's growth is encouraging but falls far short of potential and need. Existing market dynamics will ensure that tens of millions of new SSA households will gain access to at least minimally improved cooking solutions by the end of the decade without any further interventions. But by 2020, the business-as-usual scenario would still leave 80% of Africa's population without clean cooking solutions and more than 60% without access to even minimally improved cooking solutions. This would still represent a much lower level of access than what is currently seen in such regions as South Asia, where the lack of clean cooking solutions is being addressed as a major crisis. Furthermore, in the absence of significant public- and private-sector investment, the spread of clean cooking solutions across SSA will be highly uneven—with successes in countries, such as Ghana, Kenya, Senegal, and South Africa (where the combined penetration of ICS and clean fuels is already above 50%) serving as exceptions amidst the overwhelming majority of SSA countries still mired in traditional solid-fuel cooking. In places where ICS adoption is growing quickly, much of this growth is still in basic and intermediate ICS, rather than in clean cookstoves and fuels. Furthermore, the vast gap in clean cooking access between rural and urban areas is likely to widen further in the absence of new targeted investments. African governments, the development community, and the private sector can and must do better.

Disrupting the status quo will require stepped-up investment and a differentiated approach. While this is a moment of great promise, it is also one of great responsibility for sector stakeholders. To ensure that the current revival of interest in clean cooking does not become a passing fad or disappoint with meager results, new investments are needed to accelerate the uptake of clean, high-quality cooking appliances and fuels in such countries as Cameroon, Côte d'Ivoire, Ghana, Kenya, Nigeria, Senegal, and South Africa, where sizable markets for clean fuels already exist. Many of these countries—and others, such as Ethiopia and Uganda—already have significant markets for basic and intermediate ICS that could likewise benefit from further acceleration.

At the same time, it is also vital to establish the foundations for clean and improved stove ecosystems in the vast majority of other African countries, where the current penetration of ICS is negligible and the enabling environment antecedents for clean cooking are weak. While a major push is needed in both cases, the relative intervention priorities and appropriate technologies will vary by market stage. In less developed countries, public-sector support will be particularly critical, since the creation of artisanal ICS markets and early-stage "market-seeding" awareness campaigns are time- and resource-intensive efforts in which the private sector is typically less willing to invest.

Changing the status quo likewise requires a significant further tailoring of sector approaches based on target technologies, consumer-segment characteristics, and policy objectives. Market-led approaches hold significant promise for expanding access to clean cooking solutions for middle-income consumers, particularly for the urban and peri-urban segments that have growing disposable incomes. The optimal strategy for such consumers involves expanding uptake of modern fuels and, where biomass cooking persists, progressively displacing household biomass stoves with clean or highly improved biomass cooking solutions to transition the entire fuel "stack" to cleaner cooking energy.

Poor urban consumers, who already often face significant fuel costs, similarly offer growing opportunities for the private sector. Reaching them, however, will likely require different strategies and challenges, such as (1) capitalizing on carbon finance markets and growing demand via businesses that generate fuel savings (e.g., via highly efficient charcoal stoves), or (2) offering competitively priced alternatives to expensive biomass (LPG, biofuels, biomass briquettes) that can also create significant health co-benefits.

In contrast, for rural poor consumers and other marginalized segments (e.g., refugee camp populations), the path forward will very likely involve continuing to expand low-cost artisanal ICS markets that, while potentially generating significant fuel savings, will realistically have only minimal health benefits. High-quality intermediate ICS, advanced biomass cookstove (ACS) technologies, and clean fuels will likely remain inaccessible to most rural African consumers without public-sector leadership and significant subsidies for many years to come.

Recommendations

Aside from an across-the-board need for new investments, the report highlights the following specific recommendations for sector stakeholders.

Public Sector, Donors, and NGOs

- Increase investment in clean cooking solutions, while maintaining momentum for intermediate and basic ICS technologies where cleaner solutions are not feasible in the near term. The scale of the HAP public health crisis calls for a revision of donor priorities, with a need for expanded investment in clean cooking technologies. Achieving proportionality to investments in such public health challenges as HIV/AIDS and tuberculosis would require at least a tenfold increase in public-sector and donor funding for clean cooking technologies. At the same time, the slow pace of transition to clean solutions and the unaffordability of these solutions for the rural poor dictate sustained large investment in intermediate and basic biomass ICS.
- Design interventions to drive consumer behavior change; simply distributing cleaner cooking solutions and fuels will not lead to optimal health and environment outcomes. The challenge of achieving the benefits of universal clean cooking in SSA is not simply one of technology and economics. Like water

and sanitation programs and other public health initiatives, clean cooking promotion efforts can achieve health impact objectives only when accompanied by large-scale behavior change in the target end-user population.

- Prioritize market-based approaches, but also deploy direct subsidies linked to health and climate impacts. Market-led models should be emphasized wherever feasible to ensure sustainability. However, maximizing climate and health benefits might also require targeted subsidies delivered through carbon markets and focused "pull" mechanisms (e.g., results-based credits for health benefits).
- Support sustainable production of clean-biomass and renewable-fuel alternatives alongside stove efficiency and emissions. Given rapidly rising demand, more efficient cooking solutions alone will not be enough if the sustainability issues in African woodfuel value chains remain unaddressed.
- Focus on providing critical public goods to accelerate the development of the clean cooking sector. Emphasize consumer education, access to finance, funding for research and development (R&D), the expansion of standards and testing, and clean cooking focused policies (e.g., tax, tariff, and subsidy reform).

Private Sector

- Invest to capture the opportunity. Despite many challenges, the untapped SSA demand for clean and improved cookstoves is immense. The opportunity is further enhanced by a resilient and fast-growing voluntary carbon finance market and the potential for additional funding streams from social impact investors, governments, and donors for the health benefits of clean cookstoves and fuels.
- Focus on cooking-fuel opportunities, not just cookstoves. The SSA cooking-fuel market (US$20 billion) is orders of magnitude larger than the market for cooking appliances, though it is also more complex due to often perverse regulatory incentives, vested interests, significant investment requirements in the case of modern fuels, and fragmented and informal markets for biomass.
- Address the affordability challenge to grow market share. Recommended measures include reducing stove prices via low-cost design and economies of scale, transitioning to local production or assembly, and embracing innovative distribution and financing models that can lower upfront stove costs.
- Address willingness-to-pay (WTP) barriers head on. Even if you have the ideal product, focus on adapting marketing, distribution, and financing models to address WTP challenges, such as low consumer awareness, trust gaps, and liquidity constraints through proven approaches, including consumer education, field demonstrations, trial periods, warranties, and pay-as-you-go schemes.
- Use a variety of distribution channels, with an emphasis on getting closer to the consumer. Getting to scale requires exploiting a range of models (e.g., direct, third-party, institutional), with the greatest scale seen by those who take on the expense of building direct bridges to consumers, or partner with third parties with direct-sales or demand-aggregator capabilities (e.g., distributors of synergetic products and household appliances, carbon project coordinating/managing entities).
- Design products with an emphasis on the complete end-user experience and attention to quality at every provisional ISO/IWA performance tier. Most consumers, even the poor, are willing to pay for improved design, with an emphasis on "aspirational" stove designs that require minimal behavior change, while maximizing fuel savings, end-user convenience (e.g., cooking time), and durability.

KEY FACTS AND FIGURES

The Cooking Energy Challenge in Sub-Saharan Africa

- Cooking with traditional fuels and stoves represents a US$32 billion opportunity cost (3% of SSA GDP).
- Each year there are nearly 600,000 avoidable African deaths, and more than 26 million disability-adjusted life years are lost.
- More than 40 million worker years are wasted each year on fuelwood gathering and slow biomass cooking.
- Solid-fuel cooking in SSA accounts for 6% of global black carbon emissions and 1.2% of carbon dioxide emissions.

Cooking-Sector Demand

- An estimated 700 million Africans (82%) cook primarily with solid fuels (and 850–900 million will do so by 2020), 7% with kerosene, 5% with LPG, and 6% with electricity.
- SSA is already a large cooking market: US$20 billion was spent annually on cooking fuels in 2010, and US$300–400 million was spent on all types of stoves. By 2020, fuel spending is set to more than double to US$47 billion.
- Fuel prices are rising fast across the region, stimulating demand for fuel-saving solutions. Annual price growth is 8% for LPG and 11% for charcoal, and the average charcoal cooking cost is now higher than that for LPG, a trend that has accelerated with recent fossil fuel price declines.
- Half of all SSA consumers already regularly pay for cooking fuels. Although 70–80% can afford the upfront cost of basic ICS (US$5), less than 20% can easily afford high-end cookstoves (US$50–100).
- Willingness to pay/adopt is a major constraint: 10–30% of SSA consumers are not readily willing to adopt new solutions. The initial willingness to pay for quality ICS is often 20–50% of stove value, but can be increased with marketing and consumer education.

Cooking-Sector Supply

- In SSA, the growth in uptake of clean modern-fuel solutions is slow—the annual growth of primary users is 3.5% for electric stoves and less than 5% for LPG—though total volumes of fuel use are likely growing faster.
- The biomass ACS market is nascent: 50,000–100,000 gasifier stoves have been distributed across a handful of SSA pilots.
- The number of renewable fuel project pilots is growing, but penetration is likewise very low: about 40,000 biogas stoves, 50,000 solar cookers, 75,000 ethanol stoves, 0.5 million retained-heat cookers, and 25,000 biomass pellet stoves.
- Biomass ICS distribution is small but growing: fewer than 10 million SSA households use basic ICS, 5–7 million use intermediate "rocket" or highly improved charcoal ICS, and another 7–8 million have legacy stoves.
- The ICS supply is focused on urban areas: less than 20% of urban solid-fuel households have ICS, versus less than 5% of rural households.
- More than 90% of ICS in Africa are artisanally manufactured cookstoves—chiefly portable, ceramic, ***jiko***-style ICS; legacy chimney stoves; and, in select geographies, efficient rocket stoves.
- Adoption of industrially manufactured ICS is growing quickly: there are more than 40 SSA industrial/semi-industrial manufacturers (35 more than five years ago), and major players are seeing 35–100% annual growth in sales and 5–25% self-reported margins (10% on average), including carbon revenue streams.
- Sector financing is a major challenge: funding needs (US$1 billion annually) are 8–20 times the current level of investments by donors and the private sector in ICS (US$50–125 million annually).

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THE CASE FOR CLEAN COOKING

chapter 1

THE CASE FOR CLEAN COOKING

This chapter draws on cutting-edge academic research and a wealth of recent household survey data to build the case for donor, government, and private-sector investment in improved and clean cooking solutions in Africa. The analysis begins by examining the harmful effects of traditional cookstoves and fuels. This includes (1) an assessment of the economic opportunity cost of traditional cooking for the region and (2) an aggregation of never previously linked research on the economic, social, health, and environmental harms resulting from Africa's dependence on solid fuels. We then review the potential of existing clean and improved stove technologies to mitigate these harmful effects in SSA.

The Harmful Effects of Solid-Fuel Cooking and Traditional Cookstoves

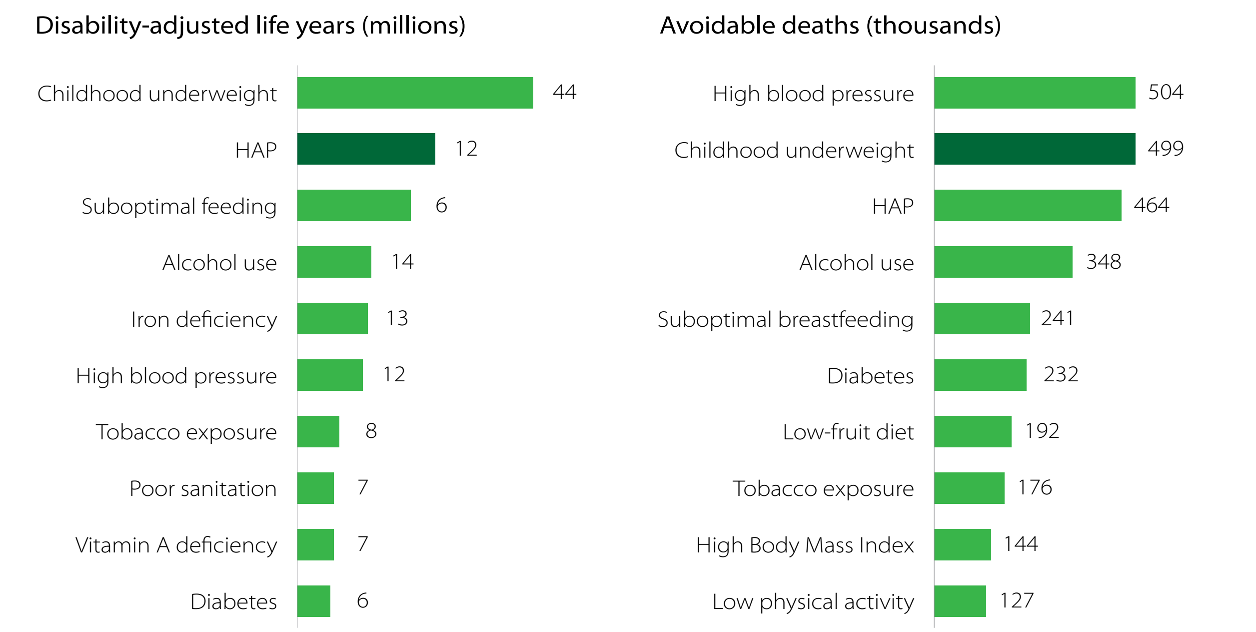
Reliance on solid fuels and inefficient cookstoves imposes significant costs on SSA. More than **700 million** Africans (82%) depend primarily on solid fuels for their cooking needs, and the penetration of clean cooking technologies in this population is negligible (<0.1%).[8] The mid-range economic value of the resulting health, economic, environmental, and gender-equity externalities is a staggering **US$40 billion annually** (US$5–58 billion) or 3% of the region's annual gross domestic product (GDP). [9] This chapter addresses each area in turn.

HEALTH

The release of particulate matter, carbon monoxide, and other harmful products of incomplete combustion (PIC) from solid-fuel cooking is strongly linked to acute lower respiratory infections (ALRI), chronic obstructive pulmonary disease (COPD), lung cancer, ischemic heart disease, cerebrovascular diseases, cataracts, and low birth weights.[10] Across these illnesses, household air pollution (HAP) contributes to at least **581,000 premature African deaths** per year and the loss of more than **26 million disability-adjusted life years (DALYs),** out of a global total of **4.3 million** deaths (2012) and **110 million** HAP DALYs (2010).[11] In SSA, HAP was the second-highest risk factor for DALYs and the third-highest driver of premature deaths in 2010—a ranking likely to increase in the next revision of the Global Burden of Disease database (Figure 2). In absolute terms, the level of HAP-related mortality in Africa already exceeds SSA public health crises, such as tuberculosis (TB); globally, HAP deaths exceed the mortality burden from HIV/AIDS, TB, and malaria combined.[12]

Other health effects of solid-fuel cooking not quantified in this total, with varying degrees of epidemiological evidence, include asthma, TB, adverse pregnancy outcomes, pediatric sleep disorders, depression, bacterial meningitis, a variety of moderate-to-severe physical injuries associated with firewood collection, burns, and widespread minor ailments from smoke inhalation, such as eye irritation and headaches.[13] The negative health effects of cooking with low-quality kerosene cookstoves in Africa are likewise not included in current disease estimates, but could be substantial.[14]

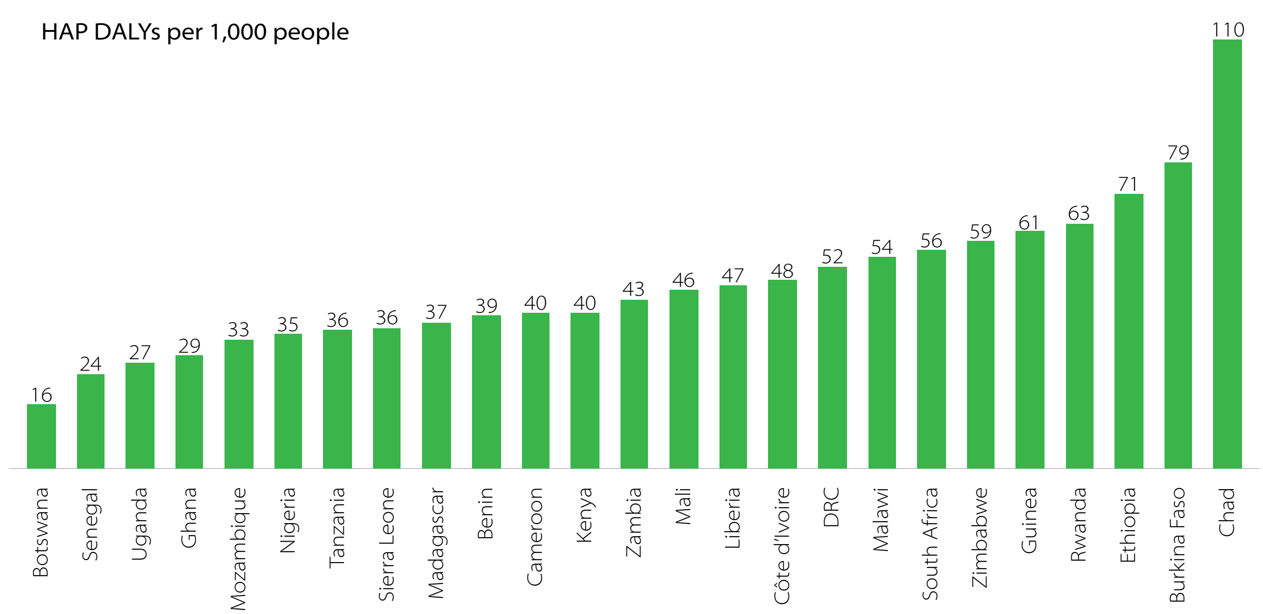
Figure 2: Sub-Saharan Africa mortality and morbidity, by risk factor (2010)



Note: As of the latest World Health Organization/Global Burden of Disease (WHO/GBD) analysis using 2012 data, the estimated number of HAP deaths in SSA stands at 581,000, suggesting that HAP may become the leading regional risk factor for mortality once the GBD data is fully revised for 2013-14.

Sources: 2010 Global Burden of Disease (available at http://www.healthmetricsandevaluation.org); Dalberg analysis.

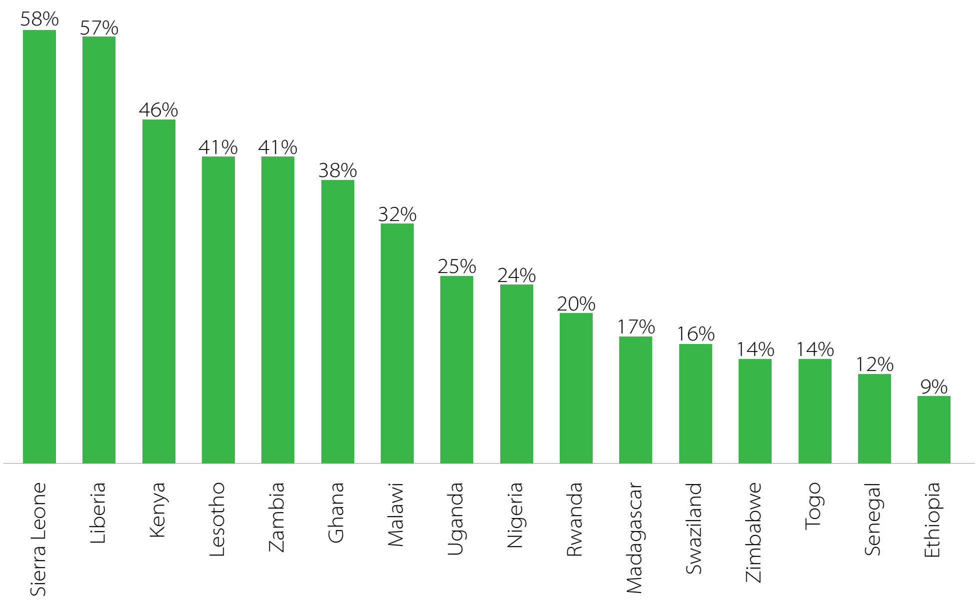
Figure 3: Relative incidence of HAP-related morbidity across Sub-Saharan Africa (2010)



Sources: 2010 Global Burden of Disease (available at http://www.healthmetricsandevaluation.org/); Dalberg analysis.

Aside from differences in fuel preferences, cooking technologies, and general health outcomes, the wide disparities in HAP-related morbidity also stem from differences in household cooking behavior. For instance, the proportion of households cooking outdoors—typically presuming that better stove ventilation results in lower exposure to particulate emissions—is highly culture-dependent, with major differences across SSA (Figure 4). These differences suggest that the importance of public efforts to improve access to clean and improved cooking solutions, relative to other drivers, such as economic and climate change impacts, will vary significantly by country.

Figure 4: Share of households cooking outdoors—select SSA countries



Sources: DHS/MICS surveys 2000–2013; Dalberg analysis.

ECONOMICS

African households dedicate a significant portion of their expenditures **(7% on average)** to lighting and cooking energy (Figure 5). The largest economic impact falls on the urban poor, who spend 15–20% of their monthly incomes on high-cost cooking fuels, such as charcoal, in some urban slum areas.[15] Because of the inefficiency of existing cookstoves and fuels, total fuel spending has risen to **US$10 billion annually**, or half of the total African household cooking fuel bill of **US$20 billion**—an amount that will more than double in the coming decade if current price and fuel-consumption trends continue.[16]

Africans also waste billions of potentially productive hours on avoidable fuel-collection tasks and—due to the slow cooking time of traditional solid-fuel cookstoves—suffer an efficiency loss of roughly 40 million potentially productive person years annually.[17] For an individual African firewood-gathering household, the average time spent on fuel collection daily ranges from just under 1 hour to more than 5 hours, with a regional average of 2 hours spent on the task daily (Figure 6)—an immense loss of human productivity.

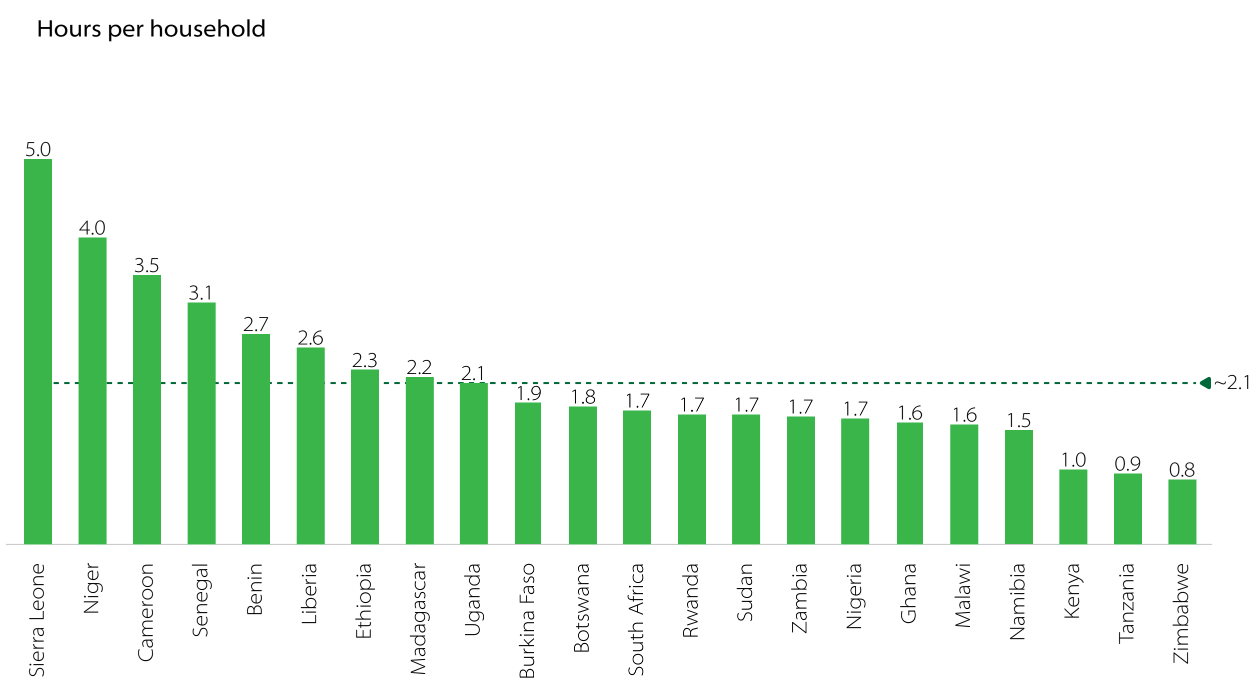
Figure 5: Cooking and lighting energy as a share of household expenditure

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

2. Modern-/solid-fuel split not available.

Sources: World Bank country surveys in Bacon et al. (2010); national consumption surveys; World Bank Survey-Based Harmonized Indicators Program (SHIP); Dalberg analysis.

Figure 6: Time spent on firewood collection in Africa

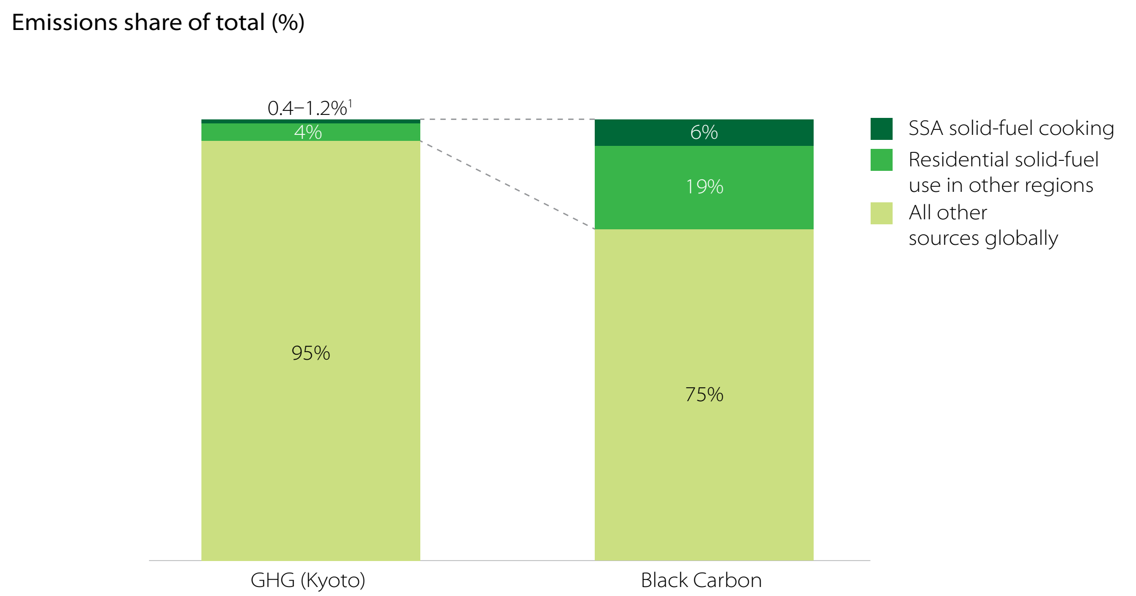


Sources: Database of 51 data points (1998–2012) for 21 SSA countries from census data; household (HH) surveys; Gesellschaft für Internationale Zusammenarbeit (GIZ); Energy Sector Management Assistance Program (ESMAP); Dalberg analysis.

ENVIRONMENT AND CLIMATE CHANGE

The production and use of solid fuels for cooking lead to the consumption of more than **300 million tons (MT)** of wood annually across SSA.[18] Of this amount, the wood harvested for charcoal production **(130–180 MT annually)** contributes to forest degradation, biodiversity loss, and, in a few instances, localized deforestation.[19] In terms of climate change, SSA solid-fuel use and charcoal-fuel production generate **120–380 MT of carbon dioxide (CO_2)-equivalent** of Kyoto protocol greenhouse gases (GHGs) (0.4–1.2% of global CO_2 emissions) and up to **600 MT CO_2-equivalent,** including non-Kyoto PIC (Figure 7).[20]

Figure 7: Contribution of solid-fuel cooking to GHG and black carbon emissions in SSA



1. Assumes a fraction of nonrenewable biomass (fNRB) range of 10–90% for firewood and 50–90% for charcoal, based on estimates from UN Framework Convention on Climate Change (UNFCCC) and Intergovernmental Panel on Climate Change (IPCC).

Sources: Bottom-up emissions inventory for CO_2 and BC based on known fuel-use volumes and typical SSA stove emissions profiles; total BC from residential solid-fuel use estimates from U.S. Environmental Protection Agency (EPA 2011) and Bond (2013); Dalberg analysis.

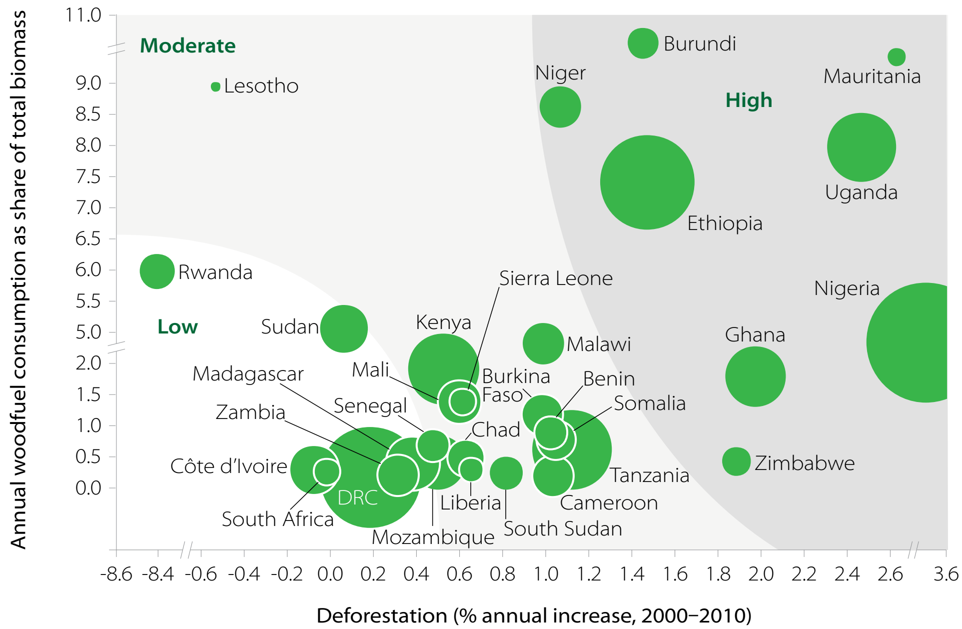
Solid-fuel cooking in SSA also accounts for **6% of global black carbon (BC) emissions**. The impact of BC emissions—the granular form of pure carbon that is the primary component of soot—is an important area of research because BC emissions contribute to local climate change and may be an important anthropogenic driver of global warming.[21]

Aside from issues associated with solid-fuel consumption, there are (1) inefficient biomass fuel production technologies, such as low-efficiency charcoal kilns, and (2) governance challenges across traditional biomass supply chains—including lack of sustainable forestry management, high rates of informality, poorly targeted taxes, and supply bans—that hinder the sustainability of traditional cooking approaches.[22] These challenges must be addressed as part of any holistic clean cooking interventions.

The scale and severity of the environmental impacts of traditional biomass cooking are likely to vary greatly across SSA. Likewise, climate-forcing emissions from traditional solid-fuel cooking are not spread evenly. Five large countries account for half of the solid-fuel-linked emissions in the region, and the top-10 SSA countries account for two-thirds of the emission-related impacts.[23]

Figure 8 shows one potential way of visualizing the relative environmental threat potential across SSA. The intensity of woodfuel harvesting is shown on the vertical axis, and existing deforestation pressures appear on the horizontal axis. 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 GHG and BC emission potential of each country, and also shows the relative scale of the deforestation and degradation challenge across geographies.

Figure 8: Biomass pressure map: solid-fuel cooking in Sub-Saharan Africa



Note: Bubble size reflects size of 2010 solid fuel population; biomass defined as above-ground biomass; woodfuel includes charcoal and firewood.

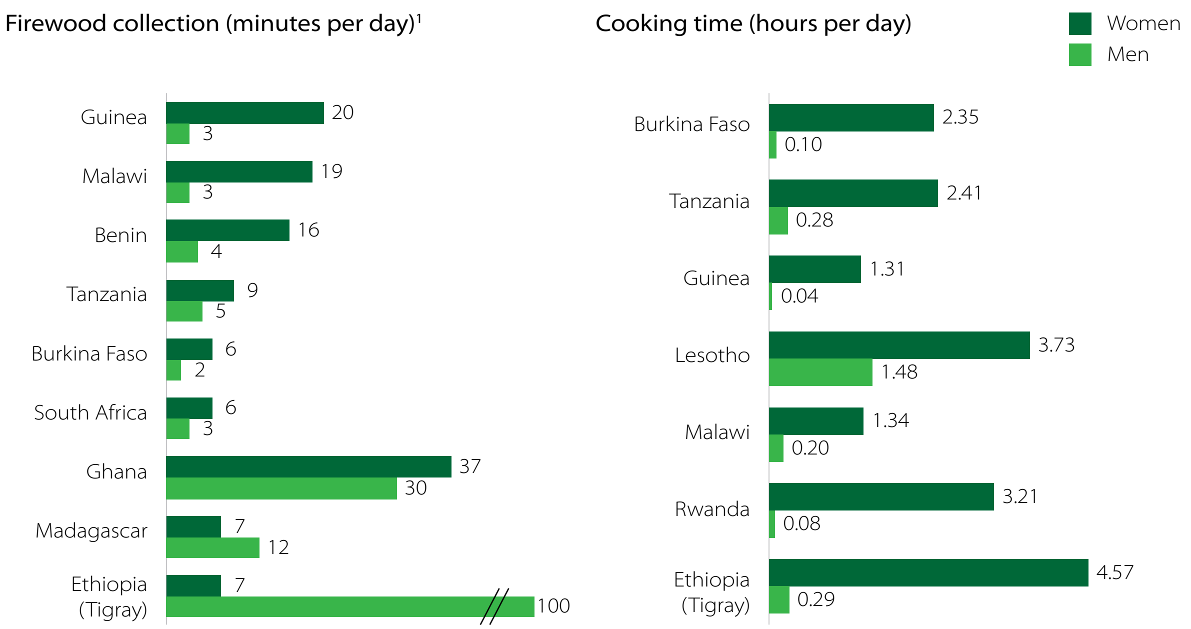
Sources: Food and Agriculture Organization of the United Nations (FAO) deforestation data; Dalberg global cooking fuel use database drawing on WHO, demographic and health surveys (DHS), Multiple Indicator Cluster Survey (MICS), and Living Standards Measurement Survey (LSMS) data; Dalberg analysis.

The figure shows clearly that a number of Africa's largest countries—such as Ethiopia, Ghana, Nigeria, and Uganda, as well as several smaller Sahelian nations—fall into the highest woodfuel biomass pressure zone. In this zone, high rates of deforestation are accompanied by significant use of woodfuel for cooking. While the two variables may not be directly related, it is reasonable to presume that the risks of woodfuel scarcity are higher in those geographies where the two trends coincide. There is also a wide intermediate zone of countries where the likelihood of forest degradation effects is significant, especially for those countries using a 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 the aggregate. Furthermore, recent research suggests that, in countries like Rwanda, the official Food and Agriculture Organization of the United Nations (FAO) forest cover data used in this analysis may significantly understate actual deforestation rates.[24]

GENDER EQUITY

The negative effects of traditional solid-fuel cooking on gender equity are clear (Figure 9). Women bear a disproportionate burden of the costs of solid-fuel cooking because of their primary responsibility for fuel collection (in most markets), cooking duties, and greater risks of physical injury and sexual violence during fuel-collection trips.[25]

Figure 9: Firewood collection and cooking time, by gender



1. Average across all households in the given country; collection times for rural firewood collectors only are much higher.

Sources: World Bank/Indepencent Evaluation Group (IEG) (2006); Blackden & Wodon (2006); Cecelski (2000); FAO (2011); Lawson (2007); Tanzania TUS (2006); Huba & Paul (2007); Kiros (2011); Dalberg analysis.

Notably, despite women's greater proximity to cooking fires, new epidemiological evidence suggests that in absolute terms, men and boys bear a slightly higher burden of HAP-related disease because of the generally higher background mortality and morbidity rates in the male population.[26] In addition, roughly half of the solid-fuel HAP disease burden falls on children under the age of five.[27] Other negative social outcomes include decreased educational opportunities for children, particularly girls; impaired nutrition resulting from the diversion of scarce resources to fuel purchases; and the aesthetic disutility of kitchens, dishes, and home environments damaged by smoke and soot.[28]

The Harm-Mitigation Potential of Clean and Improved Cooking Solutions

A range of cooking technologies can mitigate these harmful effects, but there is no ideal solution for all users. At the level of an individual cookstove, the potential to address the harms of traditional cooking varies greatly by impact objective, cooking technology, and the quality of the specific cookstove. Although a range of basic improved solutions can generate significant fuel and time savings for biomass consumers, climate benefits are harder to capture and are limited to only a subset of clean cooking technologies. In terms of health effects, only the very cleanest cooking solutions can address the severe harms of long-term exposure to HAP. Appendix 1 discusses the relative benefits of improved and clean cooking solutions compared with a traditional biomass stove (e.g., a three-stone fire) for the most common impact dimensions in the literature.

While different technologies have their own advantages, **there is no universally applicable answer to the challenges of solid-fuel cooking**. The ideal solution will vary based on market circumstances and on the social impact deemed most important. Even when the relative benefits of different solutions are clear, extrapolating from the features of an individual stove to market-level impact potential is difficult due to the complicating factors of stove and fuel affordability and consumers' willingness to adopt a specific technology. Many of the cleanest solutions from a health standpoint (e.g., biogas, LPG, electricity), which feature quick cooking times and other desirable features, such as safety and durability, are also the most expensive, limiting their uptake at scale. Cleaner solutions, on the whole, also require more behavior change on the part of the consumer relative to baseline cooking technologies. Therefore, any generalizations about the best solution must also take into account an assessment of the possibility of adoption at scale.

The following sections review in more detail what we currently know about the cooking solutions available in the African market in terms of economic benefits, environmental and climate change benefits, and health effects.

ECONOMIC BENEFITS

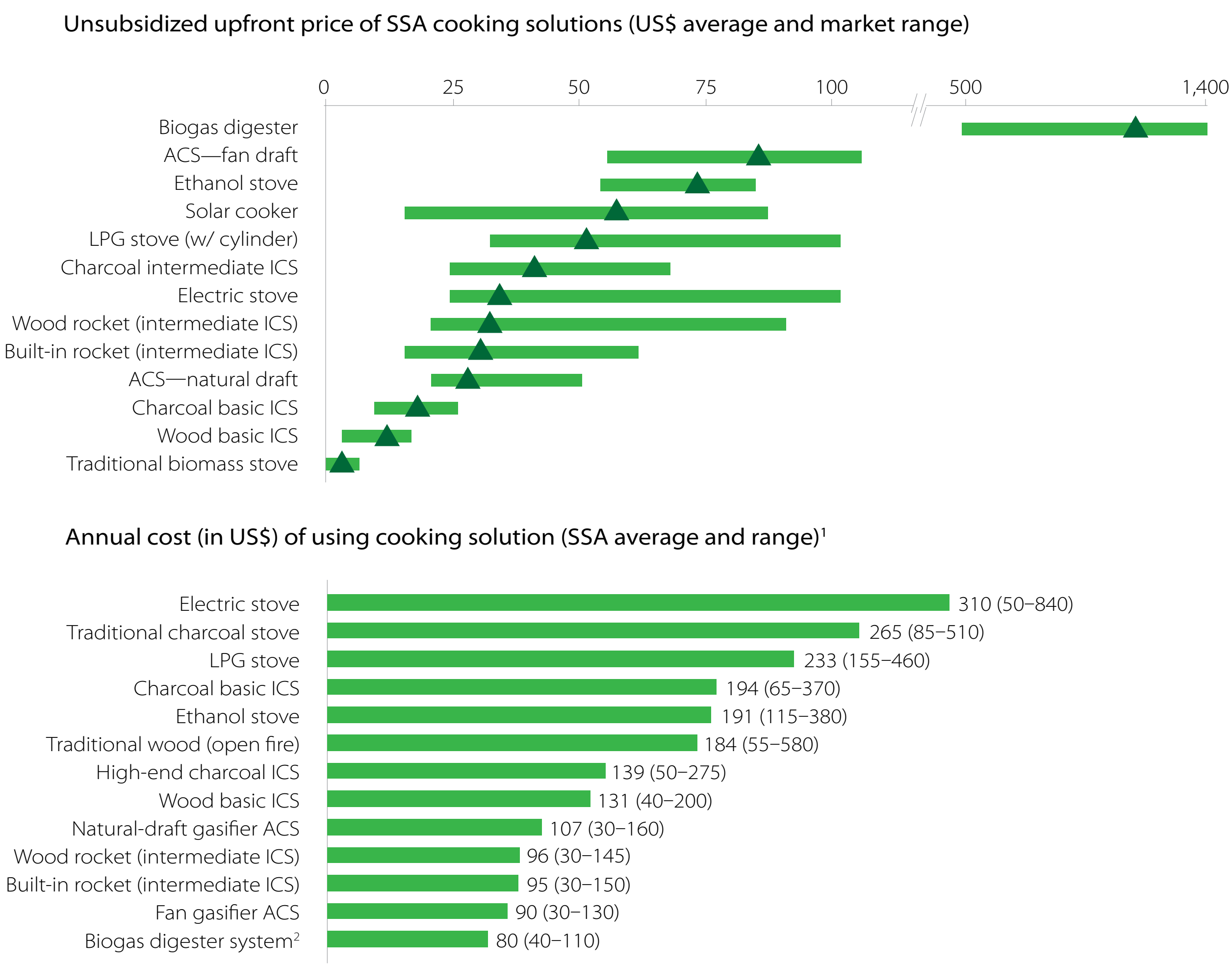
Fuel savings are both the most achievable and the most tangible benefit of clean and improved cooking solutions. Program evaluations and randomized controlled trials (RCTs) in Africa show that, while "legacy" biomass chimney cookstoves typically generate limited fuel savings under real-world conditions over long time periods,[29] well-designed, basic ICS can lead to meaningful savings in fuel and collection time. These savings are in the range of 20–35%,[30] and 35–65% for the portable wood and charcoal intermediate ICS that are the focus of large-scale Africa distribution efforts by such companies as Envirofit, Ezy Stove, EcoZoom, and BURN Manufacturing.[31] Results for intermediate built-in brick and mud rocket ICS of the type that have been distributed at scale in such countries as Kenya and Uganda are comparable.[32]

Self-reported field evidence from Africa suggests that advanced biomass ICS (i.e., fan-gasifier stoves) can match or exceed the fuel-saving levels of intermediate ICS technologies (40–80%), particularly when paired with well-calibrated renewable pellet fuels. Savings of 50–65% are reported for fan-gasifier stoves using standard (i.e., chunky biomass) fuel and more than 70% for a number of ND gasifier models.[33]

Actual savings at the household level over time tend to be lower than such figures suggest because, in most cases, households continue to cook with traditional stoves alongside the new solutions. For modern and (non-biomass) renewable cooking technologies—for instance, where full transition to the new stove and fuel should theoretically eliminate solid-fuel use entirely—actual results in SSA pilots are more modest due to baseline technology persistence (e.g., 30–70% biomass fuel savings for users transitioning to LPG, 66–80% for biogas, and 10–40% for solar).[34]

From the end user's perspective, the relative affordability and lifetime cooking costs of various solutions are in many ways an even more important dimension than relative fuel savings. Even if full adoption of LPG can help eliminate household spending on inefficient and harmful charcoal, for instance, this will mean little if the household is unable to afford the upfront costs of an LPG stove and cylinder or the ongoing costs of cooking with this fuel. Africa-wide averages and the range of costs for key stoves and fuels are demonstrated in Figure 10. Electricity is, on average, the most expensive fuel from a total cost perspective, followed by charcoal cooking with traditional stoves, and LPG. Renewable solutions, such as biogas and solar (not shown, as the stove does not entail any fuel costs), have the lowest life-cycle costs. The tradeoffs between upfront costs and lifetime cooking costs are explored in more depth later in the report in Figure 44.

Figure 10: Stove and fuel costs in Africa (2012)



1 Includes fuel consumption equivalent to 320 megajoules (MJ) and stove price amortized over average stove life. For less commonly used fuels, such as electricity and LPG, average costs are calculated only from countries where usage of fuel is significant.

2 Assumes life range from 10 to 20 years and includes US$10–20 annually for servicing/maintenance.

Sources: Dalberg cookstove database; manufacturer interviews; press searches.

ENVIRONMENTAL AND CLIMATE CHANGE BENEFITS

Environmental and climate change benefits are more challenging both to realize and to measure. Although there is some evidence that fuel-efficient biomass cookstoves have reduced net woodfuel consumption in such countries as Senegal, the scale of ultimate environmental impacts is unclear, given the limited empirical data on woodfuel consumption and forest degradation.

For climate change, the impact of basic and intermediate biomass ICS is likewise uncertain, since many types of improved cookstoves either fail to meaningfully decrease or, in the case of some rocket stoves, actually increase net climate-forcing GHG emissions once BC and other non-Kyoto PICs are included in the calculation.

Among biomass solutions, biomass gasifier cookstoves hold the greatest promise for climate change mitigation, given their large reductions in BC emissions (85–95%). However, more field data are needed to fully understand their net climatic impacts. For modern energy, the climate emission benefits of LPG and electric cookstoves are substantial at the point of fuel consumption, but are complicated by the climate costs of fossil-fuel and electricity production—which reduce and, in some cases, may cancel out the benefits of using low-emission modern energy sources. When adoption issues can be surmounted, renewable biogas and solar have the best overall environmental and climate change outcomes, but the two technologies have thus far seen little success in Africa.

HEALTH EFFECTS

Health impacts for such serious conditions as ALRI, COPD, and cardiovascular disease are the most difficult benefit to achieve. This is because meaningful reductions in HAP-linked morbidity and mortality require disproportionately large reductions in emissions due to the steep slope of the exposure response curve for particulate emissions (Figure 11).

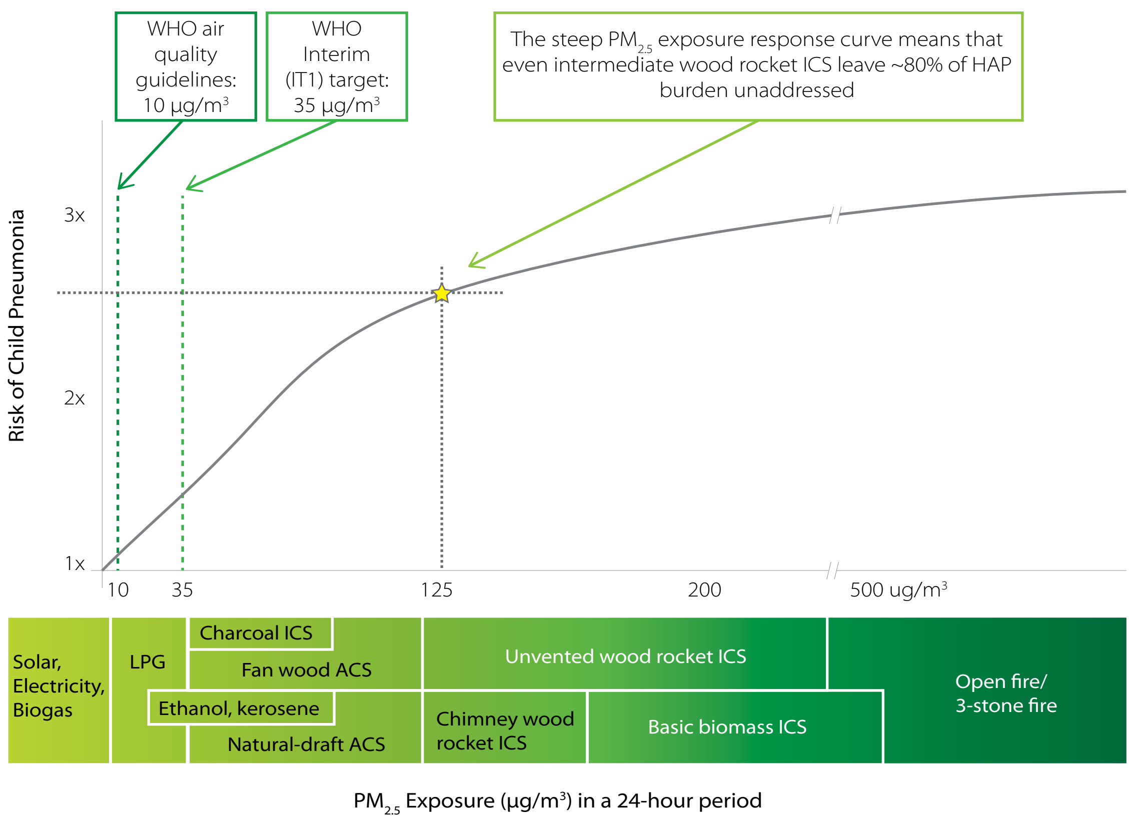
The bottom of Figure 11, based on the best evidence available, explores the likely mapping of common improved and clean cooking technologies in Africa against this dose-response curve.

LPG, electricity, biogas, and solar generate the highest particulate matter (PM) emission reductions vis-à-vis open wood fires (90–99%).[35] Ethanol cookstoves likewise enable significant emission reductions (85–95%) based on field trials in Madagascar, but have not yet been conclusively linked to improved health outcomes.[36]

For biomass cooking, **only well-performing fan gasifiers and, to a lesser extent, natural-draft gasifier stoves approach the emission levels of LPG** and hold the potential to significantly reduce the incidence and severity of HAP-linked illnesses.[37] Even the best of these gasifier technologies cannot yet fully match the performance of gas stoves, however,[38] and a number of questions about the emission abatement potential of gasifier stoves for small PM remain unanswered.

The search is currently on for a biomass gasifier stove that can achieve an IWA Tier 4 rating for emissions. A number of research and development (R&D) initiatives are in place, and there is optimism from some sector stakeholders that such a technology can be developed and piloted within the next two to five years.[39]

Figure 11: Exposure response curve for particulate matter emissions ($PM_{2.5}$)



Note: A comprehensive set of $PM_{2.5}$ µg/m³ data for all Africa stove technologies is not available, so the relative positioning is meant to be directional.
Sources: Adapted from Burnett et al. (2014); Jetter et al. (2012); Grieshop et al. (2011); Dalberg analysis.

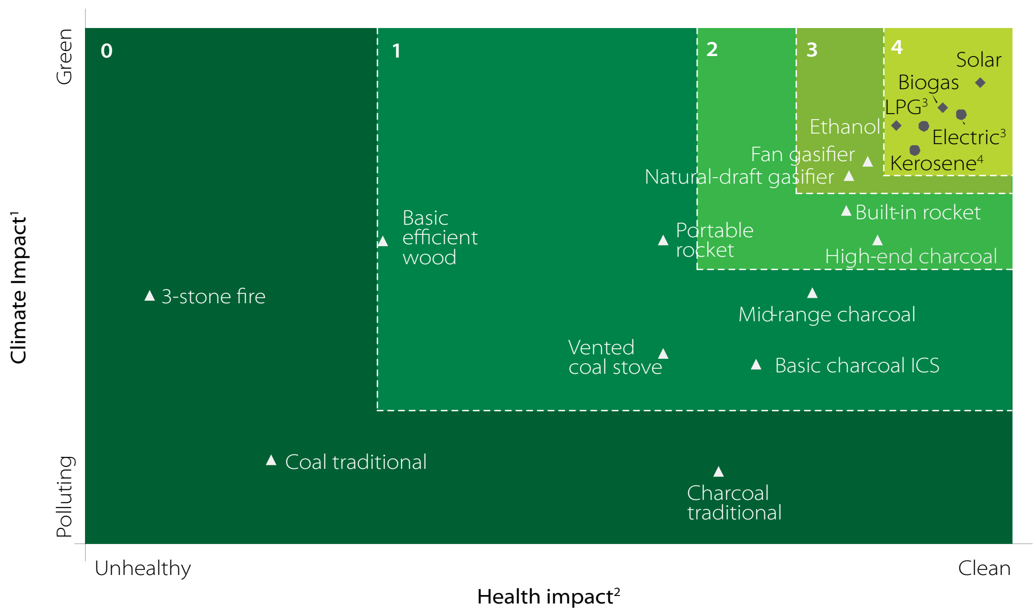
What is already clear is that **non-gasifier biomass cooking solutions are likely to have limited positive health effects**. Vented (i.e., chimney) rocket stoves under ideal circumstances and with full adoption can likely have small but material health benefits (e.g., a 60% PM reduction leading to reductions of 20–35% in respiratory illness, based on evaluation results in Guatemala).[40] Unvented basic ICS and rocket ICS—this includes nearly all stoves promoted in current African cookstove programs and carbon finance projects—likely have no or minimal impact on serious health conditions. These technologies are not, however, entirely without health merit, because improvements in minor maladies, such as eye irritation, headaches, and respiratory discomfort, are widely reported by basic ICS users and supported by mini-RCT data.[41] Broader claims about the health benefits of ICS solutions in Africa must be interpreted with caution.

COMBINING THE HEALTH AND CLIMATE DIMENSIONS

Combining potential health and climate impacts of stove emissions, Figure 12 illustrates the *directional* impacts of the most common SSA cooking solutions, with the white dotted zone lines indicating approximate provisional ISO/IWA emission tiers. The horizontal axis shows the relative health performance of different stove technologies, while the vertical axis focuses on the global warming potential of each technology.

The resulting positioning of different solutions requires several qualifications. First, the high health rating of kerosene is deceptive, as the analysis does not account for many harmful particles of kerosene combustion, such as polycyclic hydrocarbons. The climate impacts shown for fossil fuels reflect emissions only at the point of fuel consumption (i.e., emissions from the cookstove during the cooking process), whereas actual climate-warming impacts can be much more negative, particularly in cases where the fuel is produced via inefficient methods (e.g., electricity generated via traditional charcoal-powered plants). It is also important to note that the averages shown in Figure 12 may obscure the wide range of emission performance for these technologies, as can be seen in Appendix 11.

Figure 12: Comparative performance of "average" stoves on health and climate impact dimensions



1. 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 global warming potential (GWP)100; assumes fNRB of 0.5.

2. Index on scale of 1–10 of daily $PM_{2.5}$ intake per person and carbon monoxide (CO) concentration, weighted 80/20 to reflect the more deleterious effects of particulate emissions relative to CO .

3. 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.

4. Kerosene stove results reflect measured PM and CO emissions and do not incorporate potential kerosene carcinogen effects.
Note: The ISO tiers indicated in red correspond roughly to the ISO/IWA tiers for emissions.

Sources: Berkeley Air Monitoring Stove Performance Inventory Report (October 2012); Grieshop et al. (2011); Dalberg stove database; Dalberg analysis.

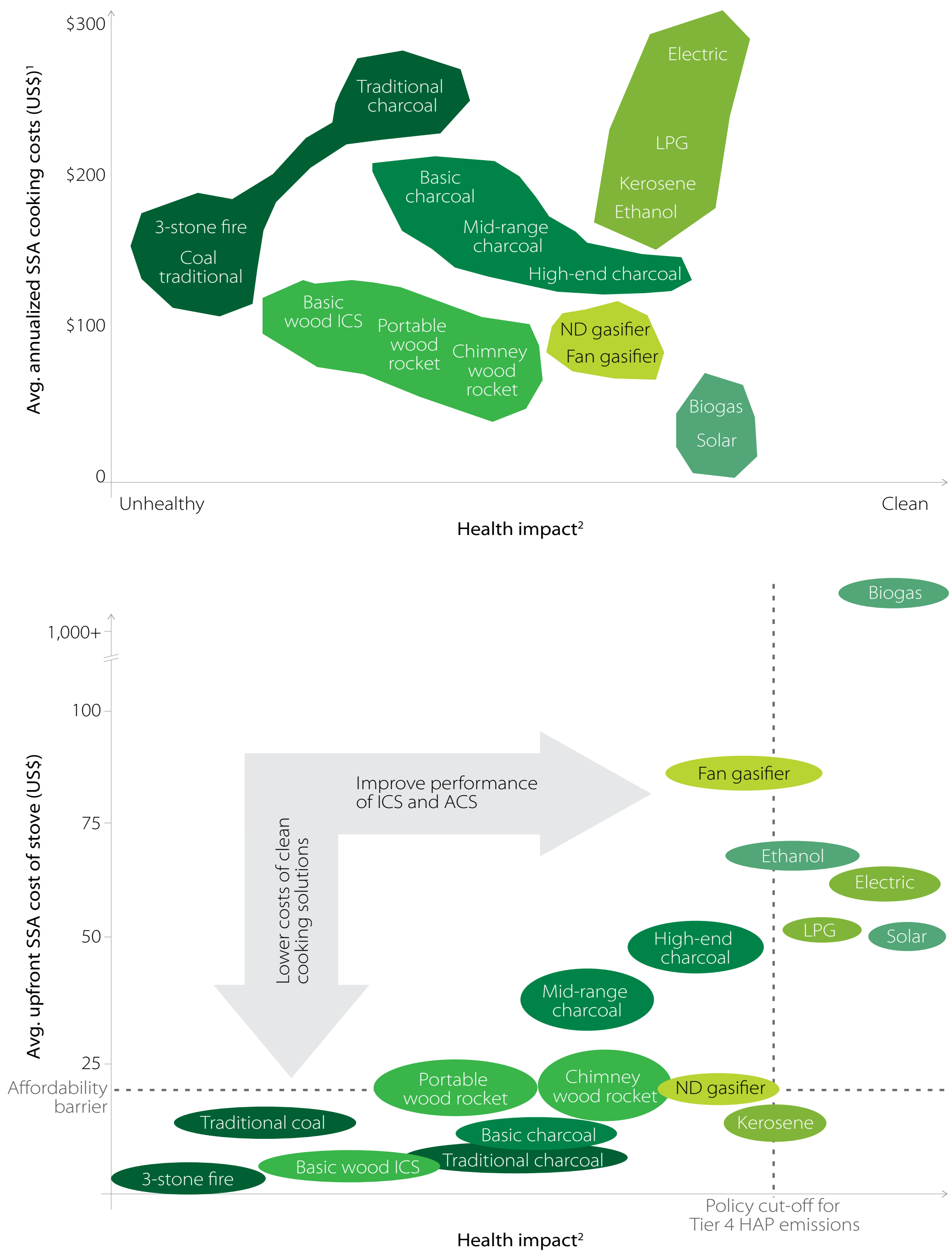
Even with such qualifications in mind, Figure 12 makes it clear that—in the case of full displacement of baseline technologies by the new cooking solution—such technologies as solar, biogas, LPG, electric stoves, and to a lesser extent fan- and ND gasifier stoves (ACS) produce the best health and climate outcomes.

Regrettably, as Figure 13 shows, in most instances the cleanest and greenest cooking solutions are also the ones that have either higher upfront costs or higher lifetime usage costs, or both. Achieving significantly greater penetration of clean cooking technologies will therefore require either (1) improving the affordability of *existing* clean cooking solutions (e.g., via financing to reduce upfront costs and, potentially, subsidies to improve ongoing affordability), or (2) creating lower-cost variants of stove and fuel technologies.

Currently, from an annualized cost perspective, using modern-fuel and renewable biofuel solutions, such as LPG, electricity, kerosene, and ethanol, results in very high costs that are unaffordable for the vast majority of Africans. Basic and intermediate biomass ICS (shown in light and dark blue) have low-to-moderate annualized usage costs, but also—with the exception of the highest-performing charcoal stoves—limited health benefits. Clean solutions, such as solar and biogas, and near-clean solutions, such as fan- and ND gasifiers (ACS), have relative low annualized costs. However, as is clear from the second chart in Figure 13, many of these solutions are still unaffordable for the majority of African consumers in the absence of financing or subsidies, given their high upfront costs.

The way forward must therefore involve either increased clean stove affordability or the continued migration of lower-cost biomass solutions to higher levels of emission performance.

Figure 13: Relationship between cooking solution performance (HAP emissions) and cost



1. Annualized cooking solution costs are based on average fuel costs across Africa, average cooking solution lifespan, and average efficiency.

2. Health rating blends $PM_{2.5}$ and CO emission performance are based on externally validated controlled cooking test and field data for dozens of African stoves, triangulated with performance catalog from Berkeley Air Monitoring Group (2012).

Sources: Africa stove price database; cooking solution performance database drawing on Berkeley Air Monitoring (2012), Jetter et al. (2012), and Grieshop et al. (2011) data; the conceptual layout draws on an analysis from Dr. Kirk Smith et al. (2014); Dalberg team analysis.

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DEMAND FOR CLEAN AND IMPROVED COOKING SOLUTIONS

chapter 2

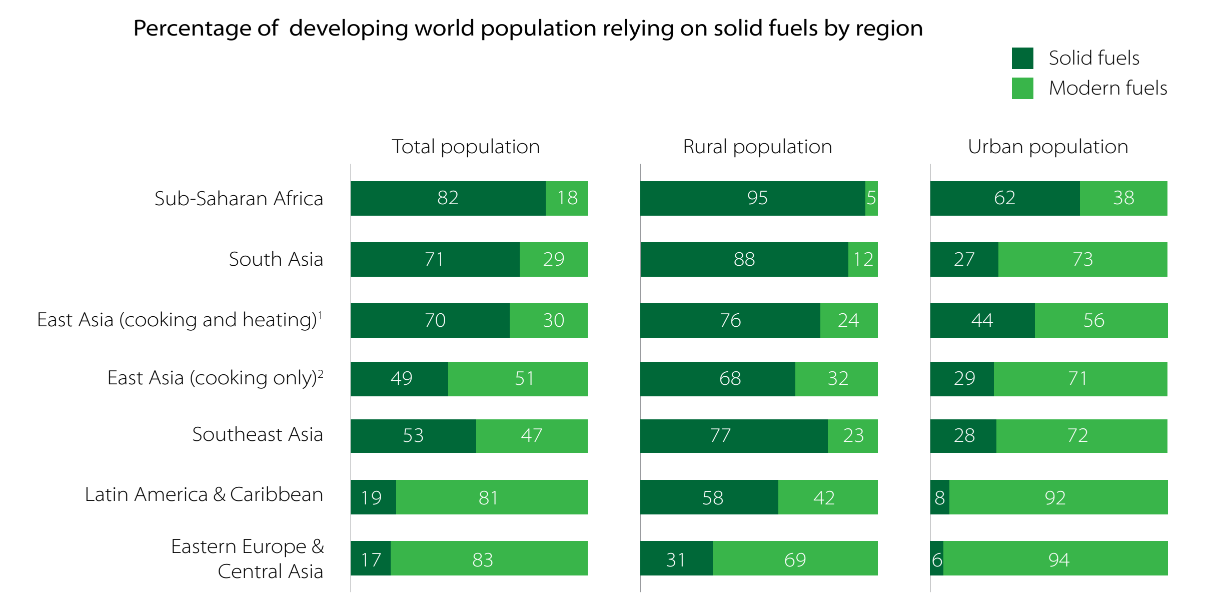
DEMAND FOR CLEAN AND IMPROVED COOKING SOLUTIONS

Although the case for deploying clean and improved cooking solutions in SSA grows stronger by the day, there is still little comparable, up-to-date information on the African cooking fuel and stove demand landscape. This chapter reviews trends in the region's cooking fuel mix and fuel demand, provides a forecast for fuel demand, progresses to an in-depth segmentation of the African cooking consumer, and then concludes with an overview of key cooking demand drivers and barriers specific to the region.

Demand Landscape for Household Cooking Fuels

The share of SSA households dependent on solid fuels stands at 82%, the highest level among developing regions (Figure 14).[42] Globally, the use of solid fuels for cooking has declined from 50% to 40% of households since 2000; in Africa, by contrast, it has stagnated at more than 80% since at least the mid-1990s.[43] In such countries as Ethiopia, Kenya, Madagascar, Nigeria, Senegal, Tanzania, and Zimbabwe, longitudinal survey data show that demand for modern fuels has declined in relative and even absolute terms in recent years because of rapid population growth, escalating fuel costs, and fuel supply interruptions.[44] This has resulted in the rapid growth of biomass-dependent households.

Figure 14: Solid- and modern-fuel usage, by global region (2012)



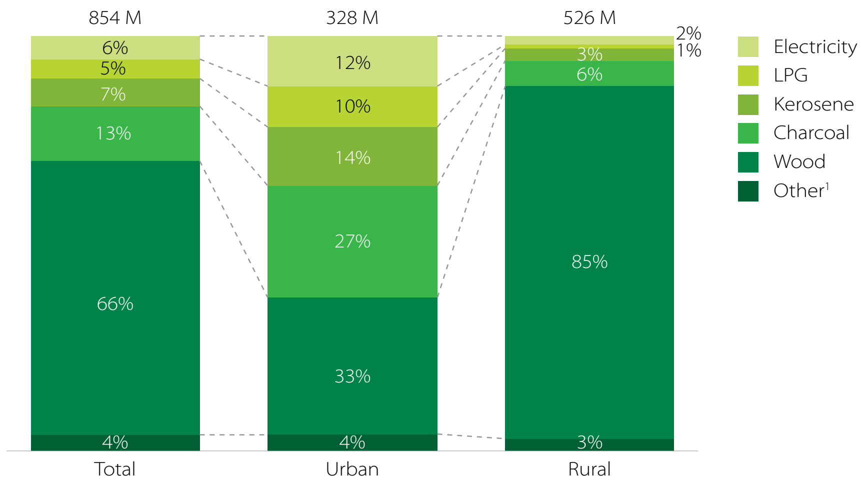
Sources: WHO Global Health Data Respository, DHS, MICS, LSMS, National Census data; Dalberg analysis

Note: Figures are latest available, roughly equivalent to 2012-2013 average, based on 2005-2014 data for individual countries.

The level of solid-fuel dependence varies across SSA countries and between rural and urban areas. As Figure 15 shows, across SSA, wood (66%) and charcoal (13%) are the primary cooking fuels, followed by kerosene (7%), electricity (6%), and LPG (5%). The "other" category in the figure includes a number of other notable fuels. Although animal dung plays a minor role in the region overall (less than 1.2%), it is locally important in such countries as Ethiopia, Lesotho, and Senegal. Coal use is likewise low in the region (1.2%) in absolute terms , but is locally important in such countries as South Africa and Sudan.

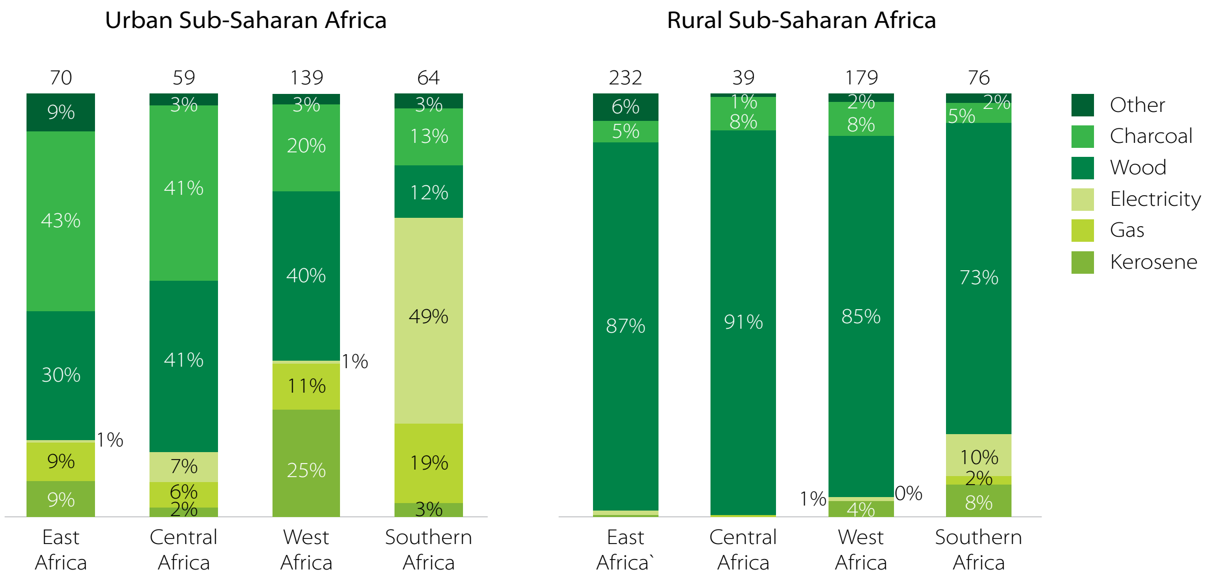
Figure 15: SSA primary cooking-fuel mix, by subregion and rural/urban area

SSA "primary" household fuel mix by type in 2010 (population in millions, % share)



1 Other primarily includes solid fuels like dung, crop waste, and coal, alongside small populations of natural gas and biogas users.
Sources: Dalberg fuel use database drawing on WHO fuels database, and DHS, MICS, LSMS, national census, and energy audit 2005–12 data.

Share of population using different types of fuels as primary cooking fuel, 2010



Note: Total countries profiled: 45; Central Africa=4; East Africa=12; West Africa=19; Southern Africa=10.
Sources: Dalberg fuels database drawing on WHO Global Health Data repository and additoinal surveys; Dalberg analysis.

The use of crop waste for cooking is widespread, particularly in West Africa, but is typically captured under wood biomass or "other" categories in survey statistics and, therefore, is difficult to quantify.

As a general trend, solid-fuel use predominates in rural areas; only 6% of rural households rely on modern fuels for their primary cooking needs, as opposed to 36% of households in urban areas.

By subregion, solid-fuel dependence is most acute in East and Central Africa. However, even in Southern Africa and West Africa, where urban modern-fuel penetration is moderate to high, the vast majority of rural households continue to depend on biomass cooking (Figure 15). The situation is particularly dire in a quarter of SSA countries, where more than 98% of all households cook exclusively with solid fuels.

Primary fuel data must be interpreted with caution—there are more modern-fuel users in Africa than is usually assumed, but the number of exclusive users of modern cooking fuels is very small. Even when SSA households own modern-fuel stoves, many continue to use traditional or minimally improved biomass stoves in parallel—a practice called "stove stacking."[45] Fuel and stove stacking are the rule across developing Africa. In Botswana, for instance, a reported 75% of modern-fuel households use wood alongside their modern-fuel stoves.[46] Half of the households in rural and urban southwestern Nigeria combine modern (kerosene and LPG) and traditional cooking solutions.[47] Similar ratios have been reported in surveys in Burkina Faso, Ghana, Kenya, and Senegal.[48]

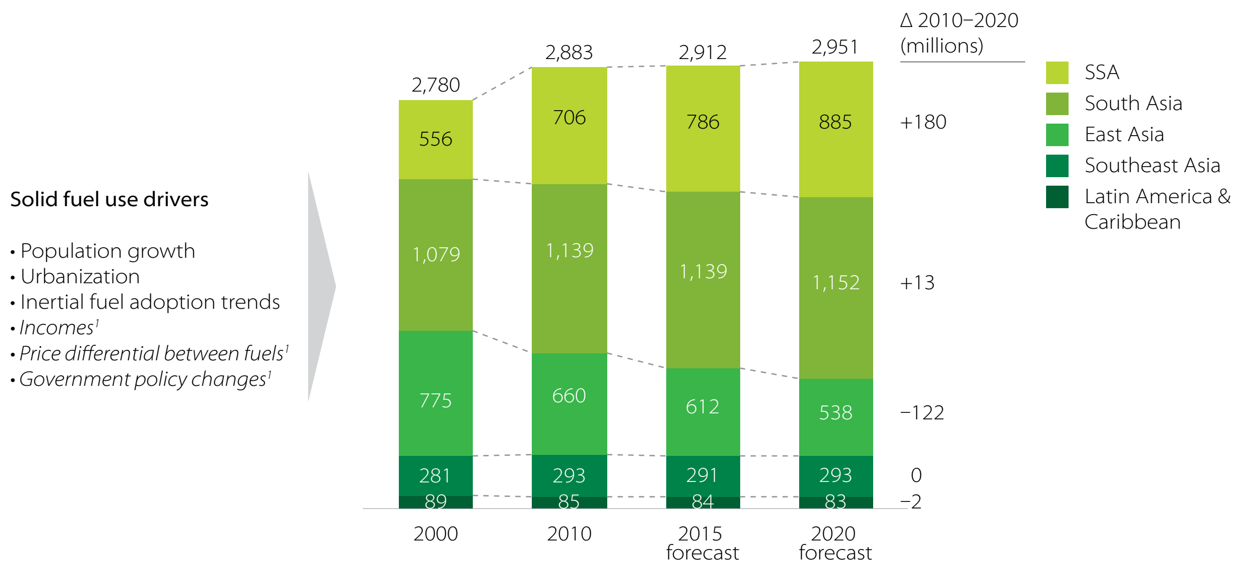
On one hand, this level of fuel and stove stacking suggests that the demand for clean modern fuels is much broader in Africa than indicated by primary fuel data—**such fuels as LPG, electricity, and kerosene likely reach 20–50% more households than primary modern-fuel cookstove numbers indicate**.[49] On the other hand, many of these households continue to use traditional or minimally improved biomass stoves, thus losing many of the benefits of clean cooking because even moderate exposure to particulate emissions leads to serious long-term health effects. The number of households that use clean modern fuels, such as LPG and electricity, exclusively is likely less than 5% of the SSA population.

The population relying on solid fuels in Africa is expected to further increase toward the end of this decade. Historical fuel mix trends and demographic drivers, such as population growth, suggest that the number of Africans relying on solid fuels as a primary fuel will grow to **850–900 million by 2020** (Figure 16).[50]

Even in scenarios of successful modern and renewable fuel scale-up, such as the achievement of the Global LPG Partnership's target of 70 million new African LPG users by 2018 and the Africa Biogas Partnership's target of biogas access for 10 million people by 2020, the SSA solid-fuel population would still be significantly higher than today **(>750 million)**.[51] Within this overall trend of persisting solid-fuel reliance, historical fuel-mix data suggest that charcoal will constitute a growing share of solid-fuel demand and, within the modern-fuel sector, LPG and electricity will continue to take shares from kerosene users—important news in light of increasing evidence about the harms of kerosene cooking (Figure 17).

Figure 16: Historical trends and forecast for the global solid-fuel population

Number of people living in households where the primary fuel is a solid fuel (in millions)[2]



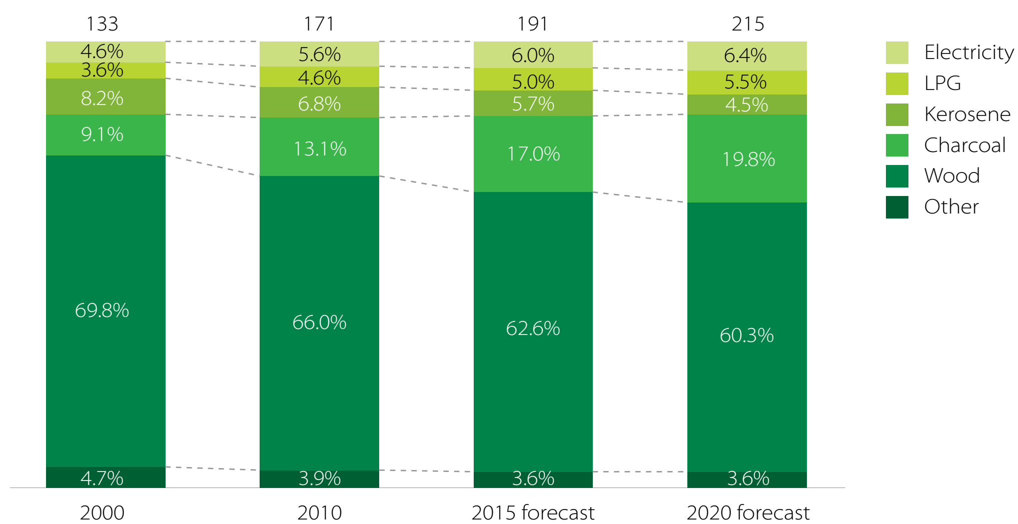
1. Factors considered qualitatively, but not modeled directly for the forecast.

2. Data set covers 82 countries accounting for 98% of solid-fuel users globally—i.e., actual number of solid-fuel users likely close to ~3.1 billion in 2010 if both solid fuel cooking and heating households are included.

Sources: 2000–15 data based on WHO, DHS, MICS, LSMS, and national survey data; projection based on inertial penetration trends adjusted for changes in urban/rural mix.

Figure 17: Historical and projected SSA fuel mix

Historical and projected SSA cooking fuel mix (million households, percentage)



Source: Dalberg projection based on inertial penetration trends for underlying fuels from 2000 to 2013, adjusted for changes in population and urban/rural mix (see Appendix 5).

Against this background of persisting reliance on solid fuels, high and rising fuel prices will be a major demand driver for fuel-efficient biomass ICS and clean-fuel alternatives. Over 2000–2010 time period, in nominal terms, LPG prices have risen 8% annually for key Africa LPG markets (11% globally); **kerosene prices have grown 9% annually**; electricity costs have grown more slowly, but vastly exceed the cost of other cooking fuels in most markets; and the price of ethanol, a potential alternative cooking fuel, has remained above that of kerosene.[52] Because of increasing demand and growing biomass scarcity, however, charcoal prices have grown even faster—more than tripling in a decade **(>11% annual growth)**. This long-term trend in fuel pricing has held steady over the long term, with a recent spike in fossil fuel prices in 2013-2014 compensated with moderate (10-20%) price decline for LPG and kerosene in late 2014-early 2015. Though fuel prices vary at the country level, as of 2011 the average cost of cooking exclusively with charcoal across the SSA region exceeded the costs of cooking with LPG and kerosene (Figure 18). This is particularly the case for the urban poor, who pay **25–70%** premiums (45% on average) for their small-unit charcoal purchases.[53]

Although firewood continues to be the cheapest cooking option overall, anecdotal evidence suggests that in at least some geographies wood scarcity is increasing—with rising firewood prices, a greater share of firewood-using households purchasing their wood, and longer collection times for firewood gatherers. Aside from continuing to increase energy poverty, in the years to come these trends should improve the appeal of modern fuels, increase demand for cookstoves that can save on biomass fuel, and improve the business case for such sustainable alternatives as renewable biomass briquettes, biofuels, and biogas.

Figure 18: Historical fuel cost for the average household in SSA

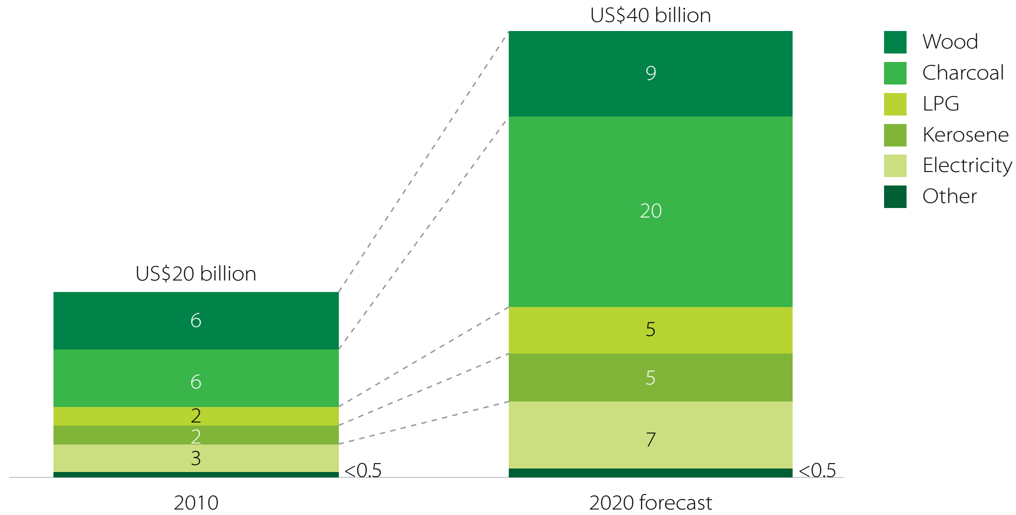
Average household cooking by fuel using constant fuel diet
(avg. real cost of 320-MJ cooking energy consumption in 2012 US$)

Note: This trend has continued through 2013-2015, with average retail LPG prices per kg declining ~15% from their 2012 peak while charcoal prices continue to stagnate or rise depending on geography.
Source: Dalberg SSA fuel price database (22 countries for charcoal, 11 for LPG, 45 for kerosene).

Fueled by these trends, the absolute size of the SSA cooking fuel and stove market will grow quickly. In 2010 alone, consumers spent **US$20 billion** across all cooking fuels in SSA—an amount that will grow to an annual expenditure of more than **US$47 billion** by 2020, with such traditional fuels as charcoal and wood accounting for more than half of this total (Figure 19).[54]

Figure 19: SSA annual household spending on cooking fuels (US$ billions)

Annual historical and projected SSA household spending on cooking fuels



1 Based on inertial scenario, which assumes no major shifts in fuel-use patterns toward modern or renewable fuels. Excludes use of fuel for noncooking purposes (e.g., space heating), and excludes nonresidential fuel use (e.g., charcoal use by small industry and commercial sector). Does include fuel spending for lighting .

2 Calculation based on number of households using fuel as "primary" cooking fuel multiplied by average SS fuel price and averave consumption required for 320-MJ diet (i.e., 2.5 meals per day)

Source: Dalberg SSA cooking fuel market-sizing and forecast model.

Although fuel markets are magnitudes larger than the market for cooking appliances, spending on stoves is significant and growing. Annual SSA consumer spending on cooking appliances (across all traditional, clean, and improved technologies) is likely in the **US$300–400 million range** today out of a global stove appliance market of less than US$8 billion in the developing world.[55] The SSA market is small compared with global stove sales, because of much lower SSA access to modern-fuel stoves, and the low Africa penetration of biogas digesters (US$300–1,500 globally), which drive much of the annual spending on cooking energy appliances (e.g., 5–7 million new biogas digesters were deployed in China alone in 2012).

The large scale of the African cooking fuel markets makes it clear that SSA consumers are already spending significant funds on cooking on an annual basis. Furthermore, the relative scale of cooking fuel and appliance markets highlights the size of the opportunity for those private-sector players that go beyond stove appliance sales and are able to develop effective cooking-fuel production and delivery models (e.g., green charcoal and crop-waste briquettes, ethanol, methanol, or LPG).

African Cooking Consumer Segmentation

End-user demand and product preferences vary significantly across SSA customer segments. African consumers are an extremely diverse group, with a range of preferences across fuel types and stove designs. Although generalizations at the scale of a continent necessarily obscure regional- and country-level variation, it is nonetheless illuminating to divide the African consumer into seven segments based on a combination of income levels, urban versus rural status, fuel use preferences, and fuel procurement approaches (Figure 20).[56] These segments fall into four broad groups: wood collectors (labeled in shades of red in the figure), wood purchasers (blue), charcoal users (yellow), and modern-fuel users (green).

Figure 20: Segmentation of the SSA improved and clean cooking consumer

	Poor wood collectors	Mid-income wood collectors	Poor wood purchasers	Mid-income wood purchasers	Poor charcoal users	Mid-high-income charcoal	Modern-fuel users
Segment size (HH)	53 mil (31%)	25 mil (15%)	17 mil (10%)	16 mil (10%)	6 mil (4%)	18 mil (11%)	29 mil (17%)
Current spending *Monthly fuel cost (stove cost)*	n/a	n/a	$1–10/month ($0–5)	$5–25/month ($0–5)	$5–20/month ($1–5)	$5–35/month ($1–12)	$5–30/month ($10–70)
Household income[1]	<BoP 500	BoP 500–1,500	<BoP 500	BoP 500–1,500	<BoP 500	60% BoP 500–1,500, 40% >1,500	>95% BoP 1,500
Location of consumer	90% rural, 10% urban	90% rural, rest urban	>60% urban, esp. W. Africa	38% urban, 62% rural	50% urban	75% urban, rest peri-urban	>80% urban
Awareness of solid fuel health harms/risks	○	◔	◔	◑	◑	◑	◑
Awareness of improved fuels/stoves	◔	◔	◔	◑	◑	◑	◕
(Physical) access to improved and clean solutions	○	◔	◔	◔	◑	◕	●
Ability to afford new solutions	◔	◔	◔	◑	◑	◕	●
Access to finance	○	◑	◔	◑	◑	◕	●
Openness to new technologies	○	◑	◔	◑	◑	◕	◕

Note: Full circles imply higher likelihood of ICS and clean fuel adoption; excludes 6.5 million of "other" households which are primarily constituted of biomass (dung, crop waste, straw) collectors and have characteristics that are comparable with the poor wood collector segment.

1. Utilizes World Resources Institute (WRI) per capita expenditure proxy for household (HH) incomes, e.g., BoP 500 means HHs with expenditures of US$500 per capita monthly.

Sources: National income tiered end-user surveys; Shell Foundation; Alliance for Clean Cookstoves market assessments; Dalberg analysis.

Familiarity with the key consumer segments and their needs is essential to developing a nuanced understanding of the African clean and improved cooking opportunity. We will here review the segmentation in detail by profiling each of the four broad customer segments. The detailed methodology behind this segmentation is covered in Appendix 6.

The subsequent sections then turn to consider cross-cutting Africa demand drivers and constraints, such as stove design, consumers' willingness to adopt (and pay for) new stoves and fuels, and their ability to afford clean and improved cooking solutions.

WOOD COLLECTORS

Rural wood collectors, including a small segment of nonwood biomass collectors (i.e., dung and crop waste users), represent roughly half (48%) of African households. Most of these households (about 30% of the SSA total) are extremely poor (BoP <500). Many are subsistence farmers and pastoralists living in remote areas with little or no integration into the modern cash economy. Unsurprisingly, such households are difficult to reach through existing distribution channels. Tradition is important for this segment, and achieving behavior change requires finely tailored solutions. The fuel-saving motivation for most wood collectors is relatively weak, given their lack of direct economic benefits from such savings.

Firewood collectors do appreciate the time savings from wood collection that can be achieved by ICS and clean-fuel solutions, but the value placed on time savings by male household heads may not be high when the costs are borne disproportionately by women and girls. Although the avoidance of the immediate consequences of indoor smoke, such as coughing and eye irritation, is important to women in this segment, the longer-term health effects are rarely understood and scarcely valued.

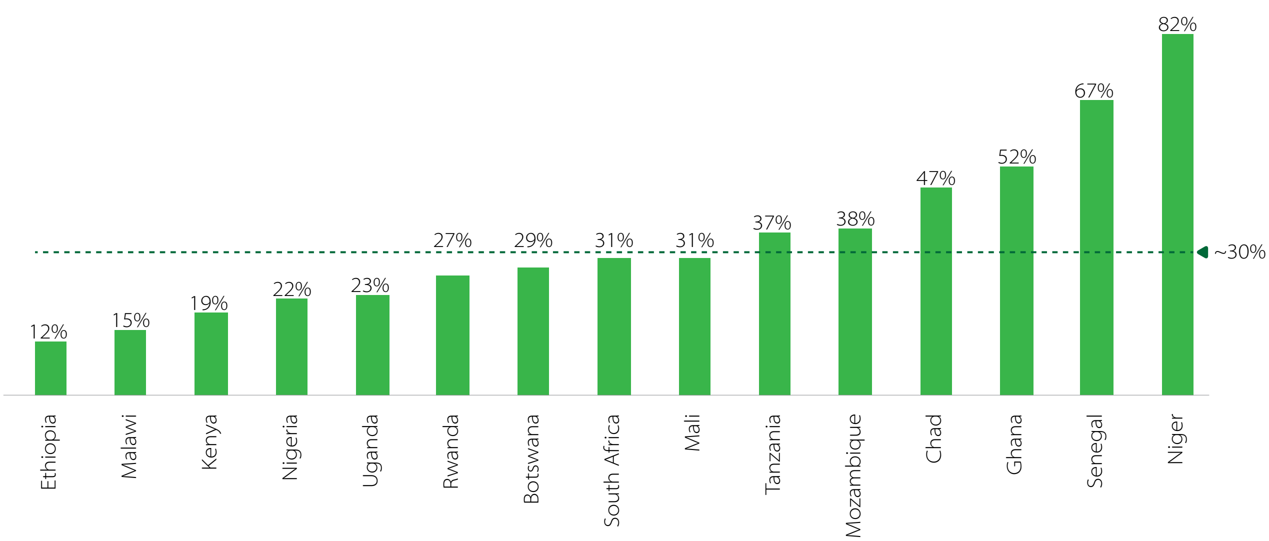
Middle-income (BoP 500–1,500) fuel-collector households (15% of the SSA market, or a third of this segment) can be persuaded to adopt and pay for improved stoves, given their greater means, educational levels, and greater exposure to markets. For the poorest wood collectors, however, ensuring adoption of improved solutions requires significant investment in behavior change and very low or, in some cases, fully subsidized ICS costs.

WOOD PURCHASERS

Wood purchasers, including middle-income and low-income wood buyers, constitute **20% of African households**. A third of SSA households use wood as a primary fuel (Figure 21). While the overall share of households cooking with wood will decrease by 2020 (Figure 17), the wood-purchasing segment will likely continue to grow as firewood collection becomes more difficult.[57]

Figure 21: Firewood-purchasing households as a share of all firewood users in Sub-Saharan Africa

Share of firewood-using households that purchase their woodfuel (percent)



Sources: Database of 26 surveys (2004–2014) for 12 African countries based on data reported in a range of sources, including fuel and stove program evaluations, firewood market surveys, and national energy census surveys; Dalberg analysis.

Middle-income wood purchasers: Middle-income wood purchasers **(10% of SSA)** are mostly rural (>60%) and are represented largely by middle-income farming households who can afford to avoid fuel-collection tasks by paying for their wood. There are also large urban populations of middle-income wood buyers who consist of salaried government employees (e.g., teachers), lower-income professionals, and small traders, particularly in West African countries with large commercial urban firewood markets. Although urban households in this segment often have access to modern fuels, such as LPG, kerosene, or electricity, adoption and use are constrained by high fuel costs. Across both rural and urban areas, wood buyers tend to be more socially conservative and risk averse in outlook than comparable charcoal and modern-fuel users, with the result that behavioral challenges to transitioning to new solutions can be substantial.

More important than the barriers of custom and tradition, the economics of cleaner cooking are the biggest challenge for this segment, as the leap in costs to modern fuels is large—an increase of 2–5 times relative to the annual costs of cooking with biomass fuels and stoves. The breadth of this gap suggests that, in the absence of large modern-fuel subsidies, fuel-efficient ICS are likely the optimal cooking solution for many households in this segment. For wealthier wood purchasers, clean fuels and wood gasifier stoves are also an option, as their disposable incomes and education make them more amenable to public health messaging.

Poor wood purchasers: Poor wood buyers **(10% of SSA households),** in contrast to the middle-income wood buyers, are primarily urban and are heavily concentrated in West Africa, where there is no tradition of charcoal cooking in most markets and firewood foraging is difficult or impossible near big cities. In urban areas, this segment largely consists of low-wage, informal-sector workers and slum dwellers. In rural areas, households in this segment are typically lower- to middle-income farmers.

Many poor wood purchasers (20–40%) resort to markets for only a part of their firewood needs, because purchased wood is often supplemented by wood collection, particularly in rural areas.[59] The size of this segment changes seasonally. There is ample anecdotal evidence that fuel purchasing by the African poor increases substantially during periods of heavy rain, when households are unable to collect sufficient firewood themselves.[60]

Given their income constraints, these households are highly opportunistic and primarily motivated by fuel savings in their choice of cooking solutions. Fuel-efficient ICS, when appropriately designed, can be an attractive solution for these consumers, but their ability to afford ICS is limited and, due to the low cost of firewood, payback periods are likely to be long for all but the most basic ICS.

CHARCOAL USERS

Africa is characterized by two distinct segments of largely urban households that use charcoal as their primary cooking fuel **(24 million households in SSA, 15% of the total)**[61]—the urban charcoal-dependent poor (4%) and middle- to high-income charcoal users (11%). Both of these subsegments will grow quickly.[62]

Middle-class charcoal users have some disposable income, but are often unable or unwilling to migrate to modern fuels due to cost and access constraints. These consumers constitute a large minority in many of the continent's urban centers, with many concentrated in African megacities, including Nairobi, Dar es Salaam, Antananarivo, Addis Ababa, Kampala, and Kinshasa in East and Central Africa; Maputo, Lusaka, and Lilongwe in Southern Africa; and Accra, Bamako, Dakar, Luanda, and Abidjan in West Africa.[63] While this segment is primarily motivated by value due to the already high and fast-rising costs of charcoal, the cost of stoves and fuels is not the sole driver of demand. Time savings, convenience, durability, and a modern appearance are important features. These consumers can be reached by mainstream urban distribution channels and, like modern-fuel users, already have experience with other consumer durable goods, including relatively high rates of adoption of mobile phones, radios, low-cost televisions, and refrigerators.

The middle-income charcoal user segment is likely the most studied and best understood by commercially minded ICS and clean-fuel promoters. It is currently the target market for most of the large urban-ICS and clean stove enterprises in the region, and is the anchor for the vast majority of successful SSA carbon finance projects. This segment also has the highest current penetration of improved and clean cooking technologies, ranging from (1) basic charcoal *jiko*-style ICS that are the baseline charcoal cooking solution in many big urban markets, to (2) high-performance rocket charcoal stoves in Kenya and Uganda, to (3) competing technologies like ethanol in Mozambique; LPG in markets like Kenya, Ghana, Mali, and Senegal; and electric stoves in South Africa and Ethiopia. The appeal of this segment is not surprising: it combines ease of access for distributors (given the density of urban populations), strong economic incentives for fuel-efficient technologies, and sufficient disposable incomes to purchase stoves upfront for cash, including at relatively high price points (US$25–50). Migrating such households to more efficient ICS or, when possible, to clean fuels remains a major commercial opportunity.

The poor charcoal user segment is also heavily concentrated in African cities (50% urban), but otherwise has very different needs and preferences. Although these households are part of the modern cash economy, they are some of the poorest (<BoP 500) and most disadvantaged on the continent. Poor charcoal users are often recent arrivals from rural areas or long-term residents of large slums and informal settlements; some live in provincial towns, peri-urban areas, or rural regions in proximity to major charcoal-producing centers.

Disposable incomes for this segment are nonexistent, penetration of other durable goods is negligible, and education levels are typically low. Fuel savings are the urgent and overriding motivation, since charcoal expenditures are among their biggest monthly budget items, with fuel purchases in some cases reaching more than 20% of monthly incomes. These households typically access charcoal via small daily (1–2-kilogram (kg) bag) purchases. From an ongoing cost standpoint, it is the only fuel these households can afford, since falling back on firewood collection is not an option in many urban settings. Demand for fuel-efficient solutions is therefore likely to be high, but ability to pay upfront for fuel savings is severely constrained.

MODERN-FUEL USERS

The modern-fuel segment **(30 million households, 17% of total)**[65] includes LPG (5%), electric (6%), and kerosene (less than 7%) stove users, and comprises largely urban, middle-income consumers with moderate disposable incomes. Though still small, this segment is projected to grow by 30–50% by the end of this decade, in line with Africa's increasing wealth.[66]

Relative to other user segments, African modern-fuel users are often better able to access clean and improved cooking solutions via their proximity to modern retail distribution channels in urban areas. Openness to new technologies for this segment is generally high, since such consumers have already adapted their cooking techniques significantly for modern-fuel use. This segment expects durable, aesthetically pleasing, "modern" appliances that adequately reflect their middle-class status. These users may have the education to appreciate the economic, health, and climate benefits of clean cooking; are typically reachable through mass media; and have at least limited access to modern financial services via banks, microfinance institutions, savings cooperatives, or mobile money channels.

This segment is not, however, without its clean cooking access challenges. Because unimproved or minimally improved appliances, typically charcoal and wood stoves, continue to serve as a secondary cooking solution in many middle-class SSA homes, many modern-fuel users continue to suffer the harmful effects of traditional solid-fuel dependence. A large number of SSA modern-fuel households (7% of the total) cook with kerosene stoves of variable quality that likely generate highly negative health outcomes.[67] Access to modern fuels can be difficult to arrange even for those who can afford such solutions, due to sporadic supply shortages for kerosene- and LPG-using households and frequent electricity outages for electric stove users. Many modern-fuel households continue to seek ways to reduce their energy bill via more efficient stoves or lower-cost fuels as high fossil fuel prices, compounded by reductions in modern-fuel subsidies, continue to be expensive for African middle-class budgets, even despite recent LPG and kerosene price declines across the region.

Although SSA modern-fuel users are typically not the focus of ICS promoters, the segment should not be ignored. As modern-fuel infrastructure on the continent is extended via enabling policies and investments, there is an immense opportunity to introduce millions of Africans to modern-fuel use and to improve the performance and quality of such modern-fuel technologies as kerosene stoves.

Equally important, there is an opportunity to convince modern-fuel households to eliminate their secondary biomass stoves—or, at the very least, to upgrade such stoves to intermediate or advanced ICS solutions, such as high-end charcoal ICS and fan-gasifier biomass ACS. Modern-fuel households, due to their disposable incomes, can be the ideal "early adopter" entry point for innovative cooking products and business models that can ultimately reach a much broader swath of the SSA population. Targeted marketing to such households could help social enterprises marketing cooking fuels and cookstoves establish themselves sustainably, creating the potential for cross-subsidy business models that can serve harder-to-reach consumers. Working with the modern-fuel segment can also broaden awareness and acceptance of new technologies among the urban poor and rural consumers who reach for aspirational technologies.

Demand for Clean and Improved Cookstoves in SSA: Drivers and Constraints

Although cooking preferences among African consumers vary widely, important cross-cutting demand drivers exist for stove adoption in the region. These include the appropriateness of **stove design**, consumer **awareness of the new solution** and its benefits, consumer **trust** in the vendor and confidence in the advertised benefits of the technology, consumer **ability to access** the stove and fuel, and the solution's **affordability** (Figure 22).[68]

Figure 22: Key demand drivers of, and challenges to, SSA clean and improved cooking solutions

	Major demand drivers	Current challenges
Willingness to adopt	Stove design: performance, quality, and appearance	• New solutions do not meet the consumer's design expectations for key stove features, such as time savings, or fit with cooking preferences (e.g., ease of refueling, size), or safety. • Stove appearance is not tailored to consumer concerns and aspirations (e.g., simple and rugged for rural older consumers, modern and aspirational for urban young).
	Awareness of new cooking solutions and their benefits	• Very limited SSA consumer awareness of new clean and high-end improved ICS and alternative fuel technologies; knowledge of basic ICS is also low for many rural poor. • Little knowledge and, where known, little appreciation of long-term health benefits of clean cooking due to present bias.
	Confidence in new stove technologies and trust in stove/fuel suppliers	• Inherent risk aversion of rural and poorer populations in any new technology. • Limited confidence in promised stove performance (e.g., advertised fuel savings) and durability, due to prior experiences with inferior products. • Low trust in existing sales channels and little faith in reliability of after-sales support.
	Access to stoves and fuels	• Reach of improved and clean cooking solution distribution into last mile is growing but is still highly limited across the continent, particularly for rural areas. • Constraints on clean fuel supply (i.e., lack of distribution infrastructure, intermittency of supply) reduce consumer interest in clean cooking solutions.
Ability to pay	Affordability of stove and fuel	• High costs in absolute terms—upfront costs of the higher-performing stoves and ongoing costs of clean fuels place solutions out of reach of bottom 30–50% SSA HH. • Significant consumer liquidity constraints (i.e., can only pay in small increments) even when, in absolute terms, annual household budget can cover stove purchase.

Sources: Systemic literature reviews for stove adoption factors; SSA manufacturer/distributor interviews; Dalberg analysis.

The relative importance of these five demand drivers differs based on the specific cooking solution, as well as the cultural context, socioeconomic status, and demographic characteristics of the end user. Nevertheless, a number of common points are clear.

The primary adoption driver across all consumer segments—**appropriate stove design**—encompasses the performance, quality, and appearance of the cooking solution. Among a multitude of other stove design features, fuel savings, time savings, fit with existing cooking preferences, and durability are critical adoption factors—with fuel savings by far the strongest motivator for stove purchase and sustained use for households who purchase cooking fuel.[70] Although well-designed stoves are built with such features in mind, sector interviews and literature reviews suggest multiple recurrent issues in current ICS and clean stove designs; these are reviewed later in this report.

Awareness of clean and improved solutions and their benefits is an important demand driver that has been demonstrated to boost adoption and sustained use of new cooking technologies.[71] However, levels of awareness vary significantly by country and stove technology. All else being equal, awareness is a particularly acute issue in markets that lack a history of large-scale ICS programs (e.g., Democratic Republic of the Congo (DRC), Nigeria), in remote rural areas, and for newer and higher-performing ICS and ACS technologies, such as rocket stoves and biomass fan gasifiers, which have had limited exposure in most African markets. The challenge is not just a lack of consumer knowledge about improved and clean stoves, but is also consumers' willingness to internalize such knowledge. The existence of "present bias" in poor consumers—impatience with long-term outcomes and, correspondingly, a very low value placed on future benefits when weighing them against near-term costs—is an underlying challenge[72] that is extremely difficult to address through consumer education and awareness raising alone. The present bias issue tends to undermine stove program-awareness efforts focused on long-term outcomes in health (e.g., "buy a stove now to lower the risk of death in a decade") and financial well-being (e.g., "pay now to save more in the future").

More important than general awareness of clean cooking solutions, there is much evidence to show that cookstoves are a quintessential "experience good." Consumer exposure to *specific* solutions is thus critical to building confidence in new cooking technologies and trust in stove and fuel vendors.[73] Poor African consumers are by nature risk averse when it comes to the adoption of new consumer durable technologies.[74] Anecdotal evidence from interviews with regional stove manufacturers and retailers suggests that risk aversion is especially acute for poorer, more rural, and older consumers. This risk aversion expresses itself in skepticism about the stated benefits of stove adoption (e.g., stove seller promises of quick break-even periods due to fuel savings), and in a lack of confidence about stove durability and after-sales support.[75] Given the quality issues affecting general consumer durables in many African markets, SSA consumers' low-risk appetite is not entirely unwarranted when it comes to purchasing relatively high-cost products, such as cookstoves.

Even when African consumers are aware of an appropriate cooking solution, it is often unavailable or difficult to access. Access to stoves and fuels is therefore another important factor in many settings. Although access to basic ICS is typically not a challenge in most urban SSA environments, even basic ICS solutions do not penetrate to remote rural areas—and access and availability issues are compounded for clean fuels and intermediate and advanced biomass stoves.[76]

Finally, the issue of stove and fuel affordability is a key constraint on demand, given the very limited means and liquidity constraints of most African consumers.[77]

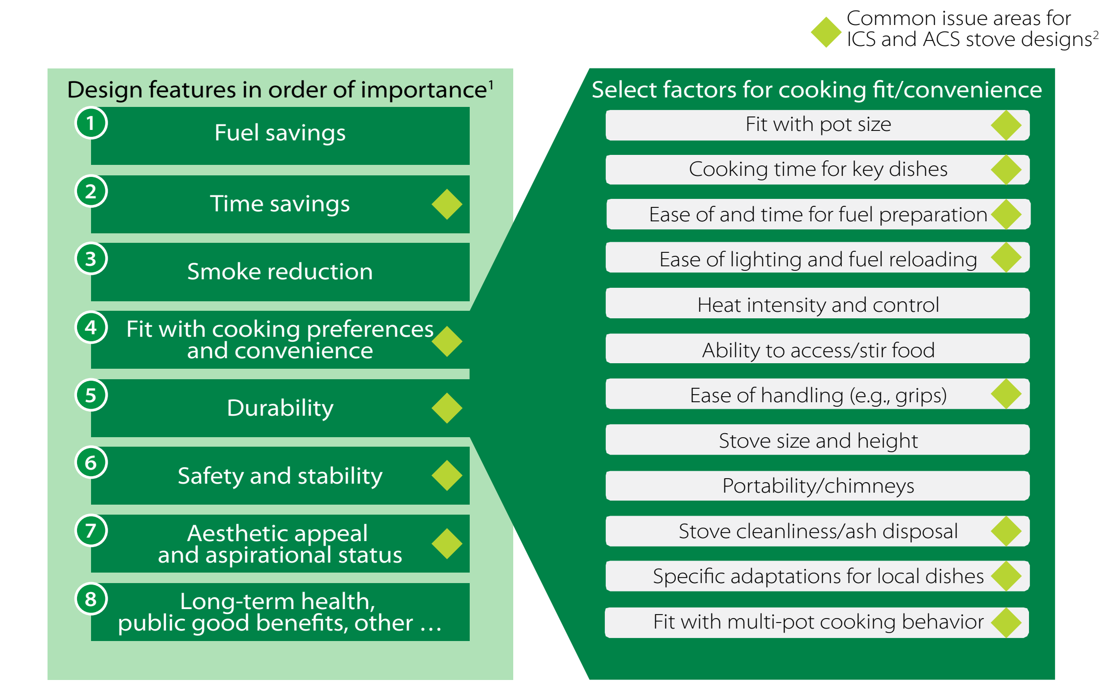
The preceding four demand drivers (stove design, awareness, trust, and access) translate into the consumer's willingness to adopt a new solution. The fifth driver, affordability, equates to the consumer's ability to pay, in terms of both providing upfront payments for a new stove and the ability to afford ongoing fuel purchases and stove maintenance costs relative to disposable income. In cases where the stove is marketed on a commercial or quasi-commercial basis, all of these drivers determine the consumer's willingness to pay (WTP), which is informed by both willingness to adopt and disposable incomes.[79]

Across all five of these demand drivers, assuming that the cookstove design meets end users' requirements, the *lack* of willingness to adopt and *lack* of ability to pay are the overarching constraints to the initial uptake of clean and improved cooking solutions. The relative importance of these two factors is largely an academic question; both matter greatly, and the balance between the two depends on the specific technology and consumer segment in question, with ability to pay and absolute affordability gaining in importance where higher-cost solutions and poorer consumers are concerned.

African End-user Preferences for Stove Design and Performance

Appropriate stove design is a central factor to consumer uptake of improved and clean cooking solutions. Stove design—and the resulting performance—directly affect consumers' willingness to adopt and pay for new stoves and are the critical determinants of sustained, long-term stove use.[80] The extensive literature on Africa cookstoves suggests that several ICS design features are particularly important (Figure 23).[81]

Figure 23: Stove design preferences of African consumers



1. Rating is based on a dozen rural and urban ICS end-user surveys across SSA (2006-2014) covering Kenya, Malawi, Uganda, Tanzania, Ethiopia, Rwanda, Ghana, and Mozambique; results were triangulated with global systemic reviews of cookstove adoption factors (e.g., Rehfuess et al. 2014) and market player interviews.

2. Common issue areas highlighted in SSA-focused stove manufacturer and distributor interviews and end-user feedback from SSA stove program evaluations.

Sources: Literature review; interviews; Dalberg analysis.

PRIMARY PREFERENCES

The first five design features shown in Figure 23 are the most significant. First, **fuel savings**—due to the increased thermal efficiency of improved and clean cooking solutions—is the most powerful stove-adoption factor across most SSA consumer segments, countries, and cooking technologies.[82] Savings are a particularly powerful driver for the roughly half of Africans who purchase their cooking fuel, a fast-growing group that faces increasing pressure from rapid fuel price growth across the continent. The use of more efficient cooking solutions for such households leads to direct and immediate reductions in household expenditures on fuel, which is a critical consideration for cash-constrained consumers. For firewood collectors, reduced fuel use is likewise important, as it reduces the economic opportunity costs of biomass collection, though this benefit is less direct.

Although **time savings** is typically rated as the second-most important adoption factor in African ICS household surveys, it often comes first for ICS households that do not purchase their fuels—and for the users of relatively expensive clean-fuel solutions, such as LPG, electricity, and ethanol.[83] Time savings includes the reduced time spent on fuel collection, as well as food preparation; the latter feature is common for improved and clean cooking solutions with the highest thermal-efficiency and heat-transfer levels (e.g., biomass ACS, LPG, biofuels).

Smoke reduction is a universally appreciated feature in end-user surveys for ICS and clean-fuel program evaluations and commercial pilots. It is a benefit that households can easily appreciate, due to reduced eye and throat irritation, even if they are unaware of, or uninterested in, the long-term health benefits of reduced PM emissions.[84]

The **fit of the stove with the user's cooking preferences** is likewise among the top demand drivers related to cookstove design.[85] This factor—often referred to as convenience, ease of use, or cooking comfort—covers a panoply of performance and design features that often link to deep-rooted cultural beliefs and practices and are therefore impossible to generalize across SSA. Some of the most common of these design features (see the right side of Figure 23) include the fit of the stove with preferred pot sizes; the ease of fuel feedstock preparation, stove kindling, and refueling; heat intensity and control to accommodate specific dishes (e.g., grilling of meat over open flame, rather than slow heating of long-simmering dishes); the ability to access food during cooking (e.g., for the stirring of stews);[86] specific adaptations for common national or regional dishes (e.g., the ability to accommodate the baking of *injera* flatbreads in Ethiopia and Eritrea); stove size and height to accommodate the design of end-user lodgings and typical cooking posture; stove portability and the presence of chimneys to accommodate indoor or outdoor cooking preferences; and stove impact on the cleanliness of cookware and lodgings.

A few of these features have the potential to affect the taste of food, and changes in the taste of common dishes arise in quantitative and qualitative end-user surveys (which is a barrier for transitioning from charcoal for cultures where meat grilling is common). However, taste appears to be a secondary consideration relative to other consumer behavior practices.

Overall, attention to consumer cooking preferences is essential. Experience of stove programs in Africa and elsewhere shows clearly that even significant fuel and time savings are unlikely to salvage a cookstove that does not fit consumers' needs or requires dramatic behavior change.[87]

Stove durability rounds out the top-five adoption factors. This variable includes the actual expected life of the stove; the need for maintenance (e.g., ceramic liner replacements for basic ICS, battery replacements for ACS, plant tune-up and repair for household biogas plants); and the perceived durability of cooking solutions (e.g., sturdy build and weight).[88] Durability is particularly important for households that are unable to afford frequent replacements or maintenance.

SECONDARY PREFERENCES

A secondary set of stove design features affects stove demand but is generally of lesser priority. It is important for stove designers and manufacturers to meet the basic level of performance on these dimensions, but they are unlikely to be the primary demand drivers for most consumers.

Stove safety, encompassing physical stove stability and the risk of burns, falls into this category and is especially important for households with small children and for technologies where the consumer is already cognizant of the risks of burns and explosions from such fuels as LPG and ethanol.[89]

Aesthetic considerations—traditionally undervalued by stove program developers, but now increasingly becoming the focus for stove designers—likewise belong to this category, at least for now. Although stove appearance does not rate highly relative to other adoption factors in historical evaluations of SSA region ICS programs,[90] the data are likely not representative of current stove-marketing efforts in Africa, especially those focused on urban and peri-urban consumers. New research suggests that status considerations can be extremely important for a subset of "aspirational" urban and rural consumers, typically those who are younger, exposed to mass media, and integrated into the cash economy, and who are therefore more attracted to cooking solutions that are designed and promoted as symbols of modernity and wealth. This factor is less important for older and more traditional consumers—who are, in any case, less likely to serve as early adopters for new cooking technologies.[91]

A related variable to cookstove appearance is the **cleanliness of the house and dishes** that results from the adoption of improved and clean stoves. This point is a nearly universal secondary factor in systemic reviews of stove adoption factors and regional ICS program evaluations.[92]

In contrast to the primary demand drivers reviewed earlier, there is strong consensus in the sector that some of the genuine advantages of improved and clean stove design have little impact on stove demand for most consumers. Specifically, there is little evidence that most current or potential end users appreciate the **health advantages** of clean cookstoves.[93] The long-term health benefits of particulate emission abatement are too remote a concern for most African households. This generally high "discount rate" for future health benefits means that health considerations often have limited impact on stove uptake—or, more specifically, on households' WTP premiums to gain the incremental health benefits of new cooking technologies. While this does not mean that health considerations are entirely unimportant in driving stove demand, experience suggests that expectations for health-motivated uptake of clean solutions should be modest.

Similarly, **environmental and climate benefits** and related public-good messages with respect to clean cooking technologies seem to be an insignificant demand driver for most Africans.[94]

The complexity of stove design factors and diversity of SSA consumers mean that human-centered design innovation must remain at the forefront of efforts to increase clean and improved stove demand. Africa-focused manufacturers of industrial ICS, ACS, and modern-fuel stoves increasingly place ethnographic research and end-user experience at the core of their stove designs.[95] Artisanal stove program developers likewise tend to be highly sensitive to end-user preferences and often seek opportunities to tailor products to local market niches.[96] The issue of design has also received increasing attention from policy makers and the Global Alliance for Clean Cookstoves.[97]

Despite increasing focus on design, several cross-cutting challenges to better stove design will likely persist in the coming years in the absence of significant interventions. One such issue is that there are very little quantitative data on the cooking preferences of African consumers and on the resulting importance of various design features from an end-user standpoint. Such data are very costly to collect for any given market player, and donor investment in open-source ethnographic research is only now beginning to take off. A second related issue is that African policy makers and stove program managers, as a whole, still focus much of their energy on "fundamental" performance parameters of fuel efficiency, emission reduction, durability, and safety—a trend reinforced by ISO/IWA cooking standards—rather than on harder-to-capture usability features requiring a greater understanding of local consumers and markets. Finally, the challenge lies in the heterogeneity of the African consumer. Consumers from different regions, cultures, and customs will continue to place varying values on different design factors. There are natural limits to the degree of customization that stove entrepreneurs can pursue, because customized design comes at the cost of higher stove prices and reduced scalability.

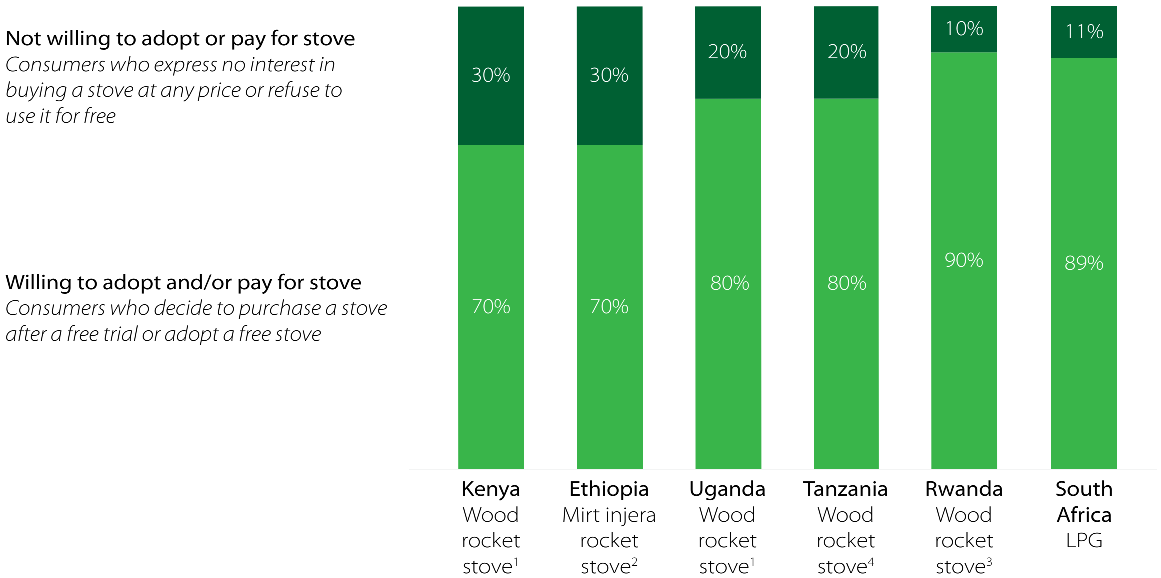
While end-user design focus has become more common in the African cooking sector, many new, improved, and clean cooking solutions continue to fall short of consumers' requirements. From an end-user perspective, the most common ICS and ACS design challenges highlighted in the literature and in stove entrepreneur interviews conducted for this report are noted in Figure 23 earlier in this section. Key issues include relatively long cooking times for many basic ICS and intermediate rocket-design ICS;[98] imperfect fit with local cooking practices, including failure to accommodate common pot sizes; inconvenience of stove refueling and fire tending; difficulty of fuel preparation; inability to use multiple pots for larger families;[99] durability concerns (e.g., poor quality and short life of some basic ICS);[100] and actual or perceived safety challenges (e.g., poor stability).[101]

Willingness to Adopt and Pay for Improved and Clean Solutions

A lack of willingness to adopt improved and clean cooking solutions is a major demand constraint across most African stove technologies and end-user segments. The design-related obstacles to cookstove uptake discussed in the previous section are an instance of a broader challenge to stove adoption. Consumers at all income levels have rejected improved and clean stoves, even when they have been made available to them at no cost or at a nominal cost. For instance, there are sizable nonadopter populations in SSA cookstove program pilots, with up to 30% of target ICS end users (Figure 24) rejecting stoves that were provided to them at no cost or expressing no willingness to purchase them at *any* price after an initial trial period. This proportion of nonadopters is similar to the experience of other global ICS distribution efforts in such countries as Bangladesh, India, and Mongolia.[102]

There is less quantitative evidence for nonbiomass improved and clean cooking technologies, but anecdotal reports from sector stakeholders suggest that similar nonadoption issues apply to clean modern fuels (LPG), biofuels (ethanol), and biogas.[103]

Figure 24: Willingness to adopt or pay: examples of nonadopter populations after ICS exposure



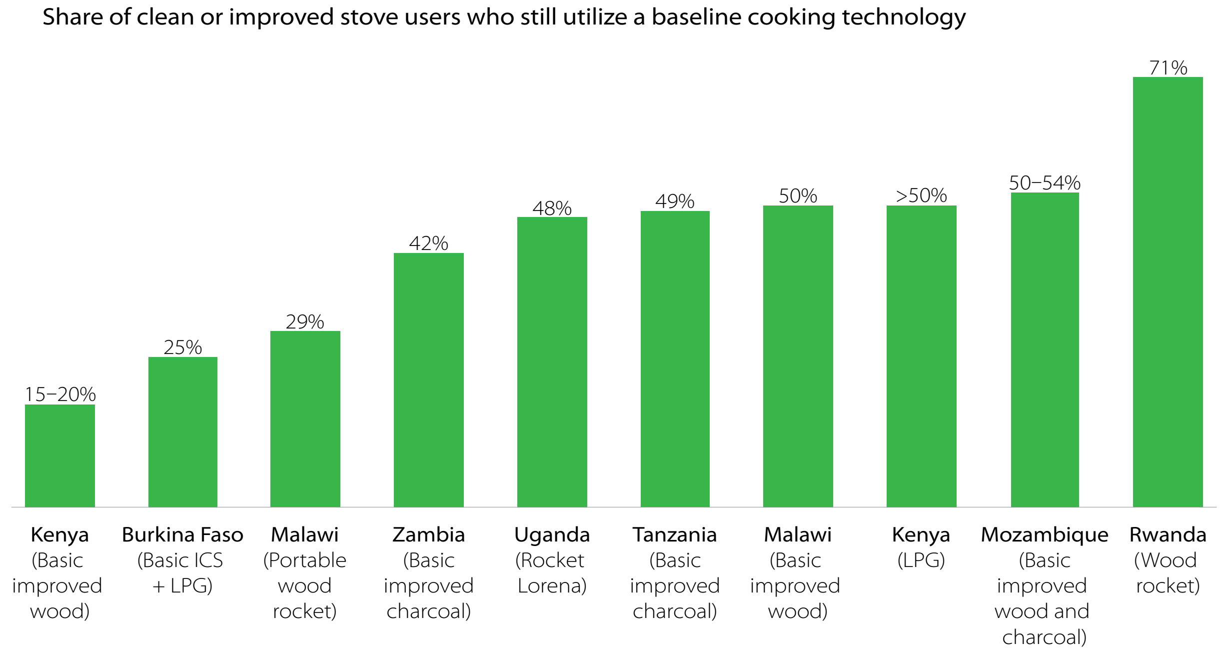
Sources: (1) Consumer survey data for Kenya and Uganda from Shell Foundation Breathing Space Survey (2007–8); (2) Ethiopia Mirt stove evaluation (MeGen 2011); (3) EcoZoom Rwanda rocket stove evaluation (Barstow et al. 2014); (4) Tanzania Millenum Village Program stove assessment (Adkins et al. 2010); (5) South Africa LPG (Mohlakoana and Annecke 2009).

Even more problematic is the frequently cited difficulty of convincing consumers to continue to use their new stoves. Long-term stove trials tend to show a drop-off in use over time. This challenge has been noted for technologies ranging from legacy stoves to basic biomass ICS, rocket stoves, natural- and fan-draft gasifier stoves, solar cookers, biogas, and LPG. The drop-off stems from a variety of factors, including changes in fuel prices, fatigue with required behavior change, durability issues, and inability to access or afford a replacement; but they all highlight the fact that willingness-to-adopt issues do not end once the stove is purchased or used for an initial period. [104]

Despite these challenges, there is incontrovertible evidence of the long-term adoption and use of many types of improved cooking solutions in SSA. For instance, evaluation data for basic efficient wood stoves and intermediate ICS solutions suggest that in most instances, ongoing use of improved stoves is high.[105] Ongoing use and sustainability are also strong for basic, efficient clay-lined metal stove technologies (e.g., the Kenya Ceramic *Jiko*), which—though they face a range of quality challenges—are on their way to being the baseline cooking solution for urban charcoal users in such countries as Ghana, Kenya, Madagascar, Malawi, Mali, Rwanda, Senegal, Tanzania, Togo, and Uganda. Global household-fuel surveys likewise demonstrate that modern-fuel solutions, once adopted, tend to see continued use over the years in the absence of major fuel price shocks.[106]

Like stove abandonment, the stubborn cross-technology persistence of stove- and fuel-stacking behavior (using multiple fuel and stoves in parallel, including traditional cooking solutions) indicates that low willingness to adopt—or, at least, low willingness to fully transition away from traditional solutions—is a widespread problem across all consumer segments (Figure 25).[107]

Figure 25: Baseline technology persistence in African clean and improved stove programs



Sources: Kenya, Malawi, Mozambique, Tanzania, Zambia (ProBEC monitoring and evaluation reports, see, e.g., Schutze 2010); Kenya LPG (Malla et al. 2009); Uganda Rocket Lorena (Malinski 2006); Burkina Faso basic ICS and LPG owners (Bensch et al. 2013); Rwanda EcoZoom wood rocket (Barstow et al. 2014); Dalberg analysis.

Affordability and Ability to Pay

Although many Africans 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. For low-cost, basic ICS, affordability and ability to pay are not major issues, except for the very poor. The vast majority of SSA consumers **(70–90%)**—including many of those who fall below the BoP 500 income tier (less than US$1.25 per day)—are able to afford paying US$3–7 for basic ICS, once they have access to improved stoves and are convinced of the quality and utility of the product.[108]

At the same time, for many long-established ICS and clean cooking technologies, cookstove and fuel affordability are likely the bigger near-term demand constraints relative to willingness to adopt. **The affordability challenge is especially problematic for higher-end cooking appliances and modern fuels,**[109] where high upfront costs (US$75–100 for biomass fan gasifier stoves, US$50–100 for LPG and electric stove kits, US$500–1,500 for biogas) severely limit the clean cooking market's potential for the bottom half of the SSA market.[110] The challenge is not limited to upfront costs; for such modern fuels as LPG and electricity, the ongoing costs of the fuel can be 4 to 10 times more expensive on an annual basis than purchased firewood. However, when compared with more expensive biomass fuels, such as charcoal, in some cases, modern fuels can be competitive, particularly where they are unsubsidized.

The acuteness of the affordability challenge for cookstoves is sometimes dismissed by referencing the high and growing penetration of mobile phones in Africa: more than **70% of SSA adults**[111] own a US$15–100 mobile phone handset. Matching this level of mobile handset penetration would mean more than tripling the number of SSA households (20%) that currently own intermediate ICS (US$15–30) or clean cooking solutions (US$50–100).

The analogy to mobile phone markets must be viewed with extreme caution, however, since the budgets of resource-constrained consumers differ widely for such categories as household energy, housing, food, communications, and entertainment. While a household may be able to afford spending more than the SSA average of 7% of its income on household energy in absolute terms, in relative terms incremental spending may be unaffordable, as it would mean reducing already constrained household consumption of vital goods and services, such as food and shelter. Furthermore, while investments in improved and advanced cooking solutions result in qualitative improvements over the traditional stove, the adoption of cell phones allows households access to an entirely new service that had not been previously accessible. Therefore, the value of the improvement is not comparable.

Historical purchasing behavior shows the importance of affordability as a factor. Less than 20% of SSA consumers today have spent more than US$15–20 on their primary cookstoves.[112] Shell Foundation surveys in Kenya, Tanzania, and Uganda, though somewhat dated, more broadly show that only **10–20%** of households in these countries purchased *any* consumer durable item costing more than US$30 over the course of a year.[113] Therefore, the adoption of an intermediate ICS solution in the US$15–30 range implies a significant reallocation of household budget priorities for an average SSA household. The challenge is even greater for clean cookstoves, since the average prices of such clean stove appliances as LPG and biomass fan gasifiers (US$50–100) are higher than the cost of an average SSA mobile phone handset (US$30–50). Furthermore, beyond stove costs, such clean cooking solutions as LPG, electricity, and ethanol have the additional hurdle of high ongoing cooking energy costs.[115]

In light of the data, it is likely that only the **wealthiest 15–20%** of SSA consumers can in the near term afford cash purchases of the highest-cost clean cooking solutions (US$50–100) without major saving mobilization or major shifts in consumer preferences.[116] Households' ability to afford intermediate ICS (e.g., industrial rocket stoves) and lower-cost ACS (e.g., ND gasifiers) costing US$15–40 is much higher, but likely is still **restricted to less than half of the SSA population** under normal circumstances.

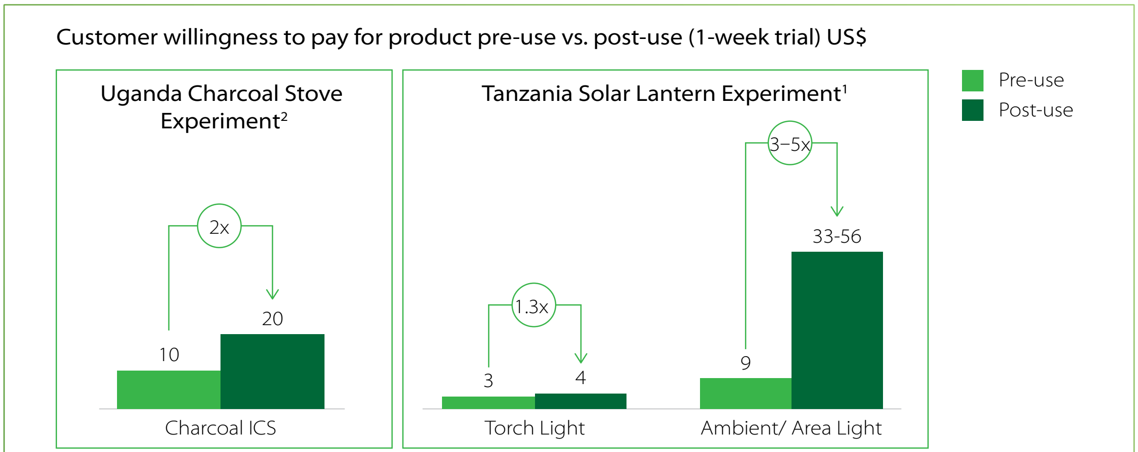
Addressing Consumers' Willingness to Pay

Willingness to adopt and pay for improved and clean stoves is a function of (1) consumers' exposure to these technologies and (2) their ability to afford them—or, in other words, the extent to which their "liquidity constraints" can be reduced. This section discusses each of these factors in turn.

INCREASING CONSUMER EXPOSURE

Willingness to adopt and pay for improved and clean stoves is a function of consumer exposure to these technologies—and can thus be influenced by stove designers and marketers. As noted earlier in Figure 24, a sizable portion of consumers will remain disinclined to convert to cleaner and more efficient cooking technologies in the near term at any stove price. However, the experience of the SSA cookstove sector (and of comparable BoP consumer durable technologies, such as solar lanterns) shows that stove program designers and entrepreneurs have several tools at their disposal to influence consumer WTP.

Figure 26: Increasing consumer willingness to pay through exposure



1. Rural Tanzania research (Lighting Africa 2012)
2. Extrapolated from results for urban Uganda randomized controlled trial with Ugastove charcoal stove (Levine et al.. 2012)

One important tool is exposure to the new technology. Clean and improved cookstoves are an "experience good," a product whose benefits are difficult to appreciate prior to consumption.[118] Assuming adequate design and performance, WTP for such experience goods as cookstoves, solar lanterns, and malaria bed nets is directly correlated with consumer exposure to the product. Evidence from the field suggests that the exposure effect for cookstoves could be substantial. A large-scale RCT on intermediate charcoal ICS in rural and urban Uganda, for instance, has demonstrated that consumers' WTP **doubles after one week of experience** with the stove (Figure 26).[119] This is comparable with IFC Lighting Africa research on solar lanterns, where WTP for different types of solar lanterns **increased 1.3–5 times** after a week of exposure.

It is important to note that uptake does not have a linear relationship to exposure. The relative benefits of increased exposure after some initial period will taper off and, in many cases, it is entirely possible for usage levels to fall with increased exposure as consumers learn more about the downsides of the improved technology.[120] The "experience good" status of improved and clean cookstoves does mean, however, that as long as the stove is well designed, relative to having no experience with the product, exposure will tend to improve adoption and WTP.

REDUCING LIQUIDITY CONSTRAINTS

Aside from exposure, there is also significant evidence showing that WTP can be increased by reducing households' liquidity constraints. In the Uganda study, moving to an installment payment option (four payments over four weeks) led to a **twofold increase in WTP**. In another large-scale experiment in rural Uganda, which focused on a rocket wood stove, a 42% increase in WTP resulted from moving to weekly installment payments.[121] A WTP study for a highly improved charcoal ICS in Mozambique likewise found a 51% increase in WTP by moving to installment payment plans.[122]

When combined with a free trial, the installment plan option in the Uganda trial shown in Figure 26 led to a **twelvefold increase** in uptake for both rural and urban consumers, the equivalent of a **250% increase in the price consumers are willing to pay**—a phenomenal result.[123] A similar **twelvefold increase** in uptake has been demonstrated for a US$16 wood rocket stove in another large-scale Uganda pilot with a free trial and installment payment approach.[124]

Aside from installment payments, liquidity constraints to WTP can be minimized by designing and marketing solutions that result in a quick payback period (i.e., the time needed for the savings generated by a new stove to exceed upfront stove costs). Evidence in the literature on both fuel-saving cookstoves and analogous devices, such as solar lanterns, suggests that **a target of a two-month or shorter payback period** is a strong rule of thumb for minimizing liquidity constraints for the very poor, though **the range of acceptable payback for most consumers will likely be between one and six months**.[125]

Such stove economics are feasible only with relatively low-cost solutions and where consumers already pay substantial amounts for their baseline cooking fuels. Other tools for easing liquidity constraints to WTP include providing upfront loans for expensive stoves,[126] applying stove-leasing and fuel-utility models in which stoves are provided with little or no cost and the value is recouped through ongoing fuel payments,[127] and deploying technology-enabled pay-as-you-go solutions in which the stove can be activated remotely when users pay their cooking utility payment via a mobile payment or account top-up Scratch Card.[128]

Unfortunately, the transaction costs for many such approaches are high—often prohibitively so, given the capital constraints and relatively low margins of many stove entrepreneurs. Figure 27 reviews the broader set of tools that can be deployed by stove designers and marketers to maximize demand by overcoming WTP and affordability constraints. All of these tools have been noted in the literature anecdotally but, pending further research, their relative value is at this point unclear.

While affordability is a challenge, it is clear that the truly nonmarketable population that cannot be reached by lower-cost commercial cooking solutions is small. Identifying likely market sizes for improved and clean cooking solutions requires considering ability and WTP by customer segment.

African urban consumers already purchase relatively expensive fuels and can realize immediate economic gains from switching to more efficient cooking solutions. Therefore, they will often show considerable WTP for new stoves within their relative affordability constraints.

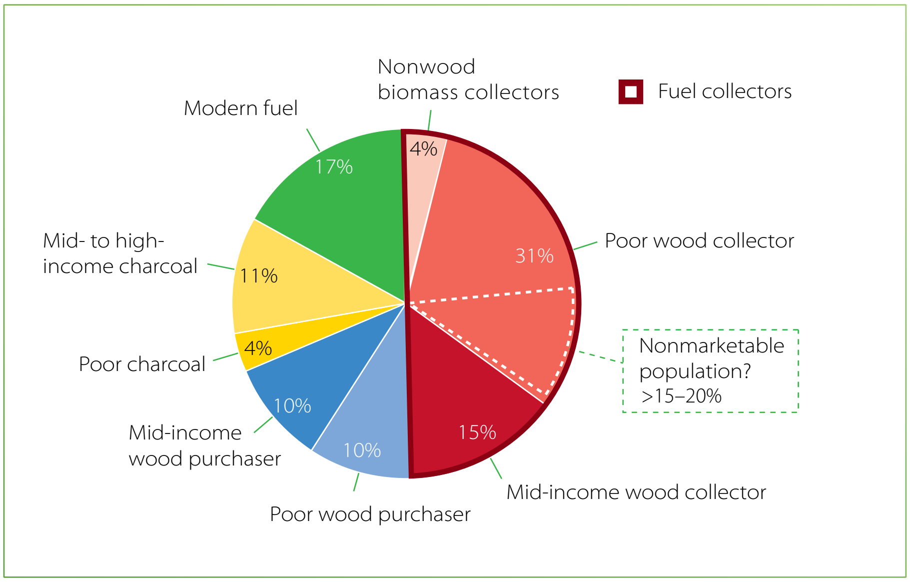
Figure 27: Approaches to improving consumers' ability and willingness to pay

Barriers	**Key issues**	**Ways to stimulate demand**
Appropriate stove design	• Poor fit with consumer needs, cooking behavior, lifestyle • Negative side effects that negate benefits (e.g., long cooking time)	• Adopt a human--centric design approach (ethnographic research, rapid prototyping) • Customize to accommodate needs of different segments • Focus on co-benefit features to boost stove value (e.g., appearance)
Trust in vendor and technology	• Low confidence in product's ability to deliver promised value • Low trust in sales channel/ manufacturer • Concerns about product durability • Low appetite for risk	• Offer free trial period, live demonstrations • Use peer pressure/social marketing • Co-brand/partner with known entity or trusted individual, (e.g., churches) • Offer easy returns/warranty period
Awareness of and appreciation for clean cooking benefits	• Low awareness of new cooking technologies • Present bias that minimizes appreciation for long-term clean cooking benefits • Decision makers not motivated by stove benefits (e.g., gender issues) • Limited decision making by women	• Conduct consumer education campaigns about stove benefits and potential savings (e.g., visualization of savings for consumers with low literacy) • Bundle product with products that the purchaser values in the near term • Tailor marketing to appeal to benefits for male purchaser, not just the cook • Market co-benefits (e.g., phone charging)
Stove and fuel access	• Few or no physical locations for stove purchasing/maintenance • Sporadic/unpredictable/low-quality fuel supply (e.g., LPG shortages, wet wood, unpredictable pellet prices)	• Provide local points of contact to reassure consumers about local presence (even if fixed locations not major sales driver) • Vertically integrate with stove supply to ensure availability; stockpile fuel supplies
Liquidity constraints	• Limited disposable income and few if any savings	• Provide installment payment model • Provide consumer finance

Sources: Levine et al. (2012); Beltramo et al. (2014a and 2014b; Mullainathan and Shafir (2011); Honkalaskar et al. (2013); O'Dell et al. (2013); Miller and Mobarak (2013); Dalberg interviews and analysis.

At the same time, most such urban consumers also have moderate, but growing, disposable incomes. When combined, these segments (i.e., most urban modern-fuel and charcoal users) represent nearly a third of SSA households, and should be a prime market for highly efficient and clean stoves and fuels (Figure 28). Evidence from the field supports this hypothesis: the vast majority of profitable, unsubsidized intermediate ICS business models in Africa focus on this segment, given its very high inherent willingness and ability to pay. For instance, surveys in Kenya, even in poor slum areas, show that a significant share of charcoal users are willing to pay more than US$30 for an improved stove—a substantial amount that allows users to purchase relatively high-cost charcoal cookstoves manufactured by such companies as Envirofit and BURN Manufacturing.[129] A caveat nonetheless remains: in most countries in Africa, from a mere fuel-savings perspective, the payback periods for such cookstoves can easily exceed an entire year of stove operation.[130]

Figure 28: SSA population by cooking market segment (primary fuel)



Source: Dahlberg analysis.

Another **20% of African households rely partly or exclusively on purchased firewood** and, theoretically, should also find the fuel-saving value proposition of ICS attractive.

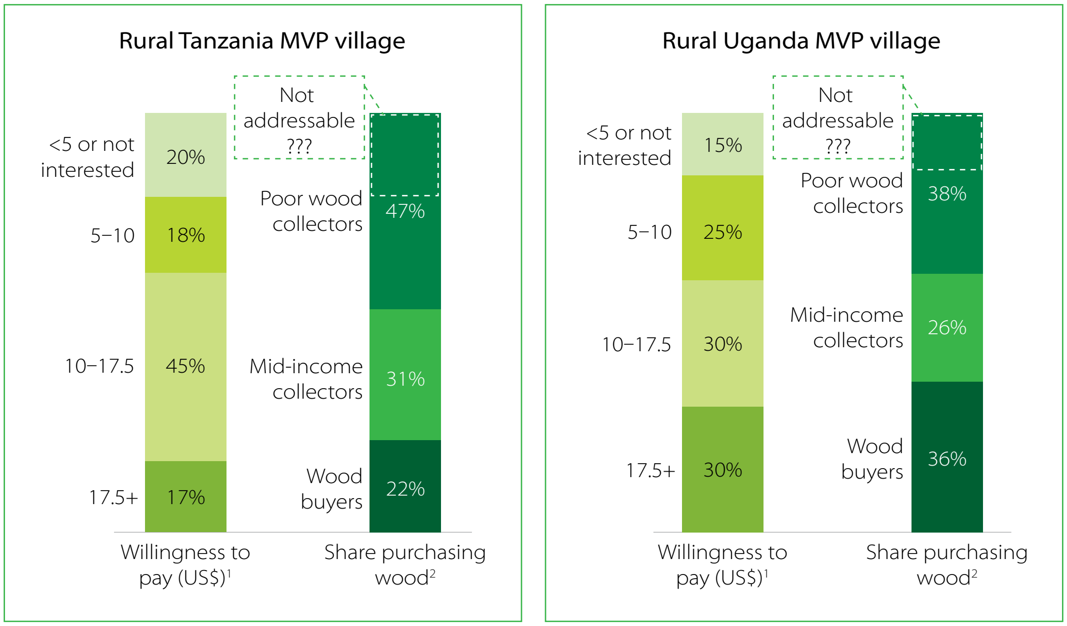
The **remaining half** of the SSA consumer market, however, consists of rural households who collect their biomass (circled with a thick red line in Figure 28). Interviews with program developers and social entrepreneurs who focus on these segments suggest that most of these consumers do not place a high value on the time lost to fuel collection. Therefore, they are less motivated by the fuel-saving potential of improved cookstoves.

Even among this rural segment, however, anecdotal data from cookstove entrepreneurs suggest that the uptake of improved stoves could be significant, though more difficult to achieve and requiring lower price points than urban markets. Survey evidence from the Millennium Villages Projects (MVP), for instance, shows that a significant share of consumers in rural Uganda and Tanzania (17–30%) were willing and able to pay US$17.50 or more for quality intermediate ICS (Figure 29).[131]

This suggests that the absolutely "unmarketable" segment may be much smaller than is usually assumed. It is likely that **less than 15–20% of all African consumers** will view improved solutions as being absolutely unaffordable or will have no interest in adopting a new stove under any circumstances (see dotted white line segment in Figure 28).

This does not mean that WTP challenges for low- and moderately priced ICS are immaterial. The gap between WTP and the fair-market value of such moderately priced technologies as intermediate ICS and ACS can be substantial in rural areas (rocket stove WTP can be 20–50% of a stove's retail value),[132] with many cooking-sector players interviewed for this report describing both psychological and affordability barriers for solutions that greatly exceed an upfront cost of US$10–15. Even if WTP can be improved significantly with exposure and financing for such consumers, this will usually still mean that the cookstove entrepreneur will need to subsidize upfront prices (e.g., by recouping costs from carbon-financing revenue streams) to see significant adoption at scale.

Figure 29: Willingness and ability to pay by segment—example of two SSA villages



1. Data extrapolated from Adkins et al. (2010) an reflects willingness to pay for improved rocket stoves.

2. Data for specific Millennium Villages Project (MVP) villages not availale. Uganda and Tanzania collector data based on GVEP International 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.

Sources: Adkins et al. 2010; GVEP International 2010; Dalberg fuel collection database; Dalberg analysis.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SUPPLY OF CLEAN AND IMPROVED COOKING SOLUTIONS

chapter 3

COOKING SOLUTION SUPPLY

Chapter 2 reviewed the main determinants of demand for cooking energy in SSA, including the fuel landscape and consumer preferences. This chapter focuses on how this demand is being served through supply—that is, the manufacturing and distribution of stoves and fuels. Therefore, while it also touches upon issues related to the cooking fuel mix, this chapter examines a different set of questions, including the number of clean and improved stoves currently manufactured and distributed in SSA, their segmentation by type and performance level, and the growth and geographic distribution of stove sales over time.[133] It then discusses stove manufacturing models, cooking-sector market structures, product and supplier economics, emerging technology and business model innovations, and distribution approaches.

Penetration of Clean and Improved Stoves in Africa

SNAPSHOT OF CURRENT STOVE AND FUEL DISTRIBUTION

The penetration of clean cooking energy in the SSA region today is very limited—only one in six Africans has transitioned to clean fuels and cookstoves for the majority of his or her cooking needs. Clean cookstoves—defined for the purposes of this report as stoves running on LPG, electricity, kerosene,[134] liquid and gel biofuels, biogas, and solar energy, as well as retained-heat cookers and biomass gasifiers (ACS)—were the primary cooking solutions for only **30 million** African households, constituting **17%** of the SSA population (Figure 30).

In 2010, the SSA penetration of modern-fuel stoves stood at **8 million for LPG/liquefied natural gas (LNG), 10 million for electricity, and less than 12 million for kerosene**.[135] While the number of Africans using modern-fuel stoves as a secondary cooking solution is not known, estimates from sector experts, triangulated with detailed survey data on multi-fuel use in such markets as Kenya and Senegal, suggest that the total number of African modern-fuel stoves is likely 20–50% higher than the number of primary cooking appliances, translating into **10–12 million LPG, 13–15 million electric**, and as many as **15–18 million kerosene** stoves.[136]

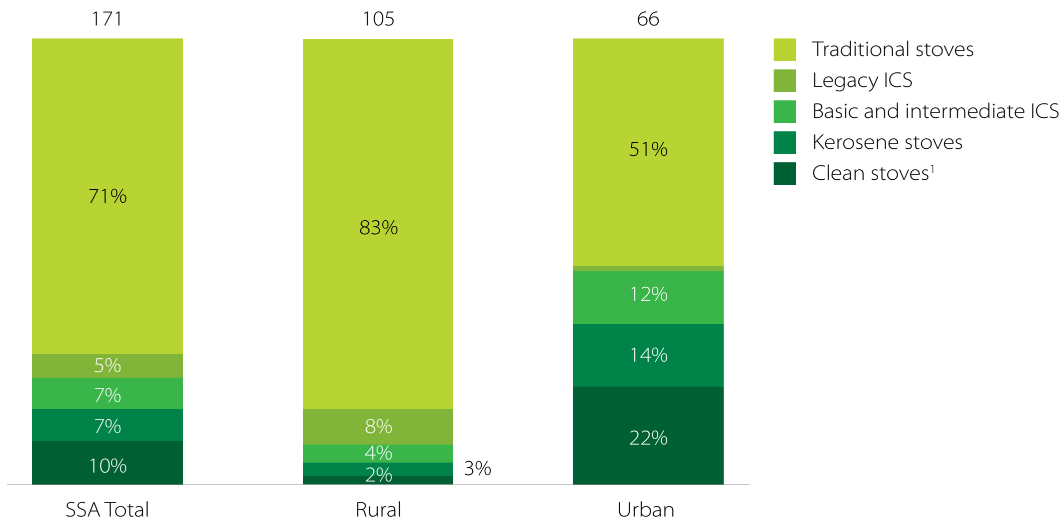
ACS and clean renewable cooking alternatives, such as biogas, solar, and liquid biofuels, cumulatively reached less than a half million African families by 2010 and as many as **1.3 million by late 2013.**[137] The most recent figures available (late 2013/early 2014) show that the penetration of advanced biomass cookstoves is at a very early stage, with **40,000–100,000** natural- and fan-draft gasifiers distributed across pilot project sites in Africa.[138] Biogas stoves **(about 50,000)**,[139] biofuel (ethanol, methanol, and ethanol gel) stoves **(about 350,000),**[140] and processed solid-fuel briquettes and pellets **(about 25,000 end-user households)**[141] have likewise seen minimal distribution across the region. Solar cookers **(about 80,000)**[142] and retained-heat cooking devices **(600,000–700,000)** also have limited penetration.[143]

In aggregate, these figures overstate the true reach of clean cooking in Africa. As noted earlier in this report, while often categorized as "clean," a large but unknown share of the SSA kerosene stoves likely should not qualify for the clean cooking designation.[144] For many of the clean cooking products, such as solar and retained-heat cookers, an additional complication is that many such solutions are supplemental to existing household stoves (i.e., their adoption rarely means transition to clean cooking).

Including all basic and intermediate ICS, penetration of clean and improved cooking solutions is roughly a quarter of the SSA market potential. National surveys and self-reported regional and country-level data sets

Figure 30: Overview of Africa clean and improved stove penetration (2011–2013)

Cookstove mix—total, urban, rural (million HH owning stove, percentage[2])



1. Includes LPG/natural gas (<5%), electricity (<6%), small renewable fuel segment of largely secondary stoves (biogas, solar, ethanol) (<1%), and ACS (<0.1%); kerosene historically categorized with clean modern fuels, but is broken out here given evidence that kerosene's clean status is questionable in SSA context.

2. Ideal supply metrics would be number of stoves disseminated and number in current use; since this data is not available, "HH with stove ownership" are used as a proxy.

Source: 2011–13 SSA market penetration estimate database; Dalberg analysis.

from manufacturers, nongovernmental organizations (NGOs), donors, and governments[145] suggest that by 2011, **20 million African households** owned biomass stoves that met the broadest possible definition of an improved cookstove.[146] This grand total included **7.4 million** households with basic ICS and **4.4 million** with intermediate ICS; another **8 million** households cooked with legacy stoves. Accounting for multiple basic ICS stoves per household, the total number of improved and legacy stoves on the SSA market was likely in the **20–22 million** range.[147] This is roughly **10%** of the more than **200 million** legacy and improved solid-fuel cookstoves globally.[148] The remainder of biomass-dependent Africans use traditional unimproved biomass stoves as their primary cooking device. Although most of these are home-built, three-stone fires (more than 75% of all traditional stoves) and unvented mud stoves, the traditional stove category also includes 15–30 million low-cost (US$0.5–5) metal unimproved charcoal stoves—like the *malgache* stoves in Burkina Faso and unimproved metal coal pots in Ghana—that are typically purchased by households directly from artisanal producers in village markets.[149]

Excluding the legacy stove segment for conservatism (because such stoves are unlikely to offer measurably stronger performance than traditional cooking solutions),[150] **the aggregate penetration of improved stoves was 7%, for a total clean and improved 2010–11 penetration of 24% of all SSA** households. As explored in the following section, the share of clean and improved stoves is growing and may surpass 27% by 2013.

COOKSTOVE MARKET DYNAMICS

The SSA clean and improved cookstove market is seeing strong overall growth; LPG and electric stoves are gaining share, and dissemination of intermediate and basic ICS is growing rapidly. Most segments of the SSA market for clean and improved cooking solutions are growing more rapidly than the region's population at large. Figure 31 provides an overview of the growth trends for major SSA cooking technologies extrapolated from self-reported sales data from dozens of stove manufacturers, distributors, and cookstove programs. These trends show that individual stove market segments are growing quickly.[151]

Figure 31: Current Africa sales and forward-looking trends, by stove technology

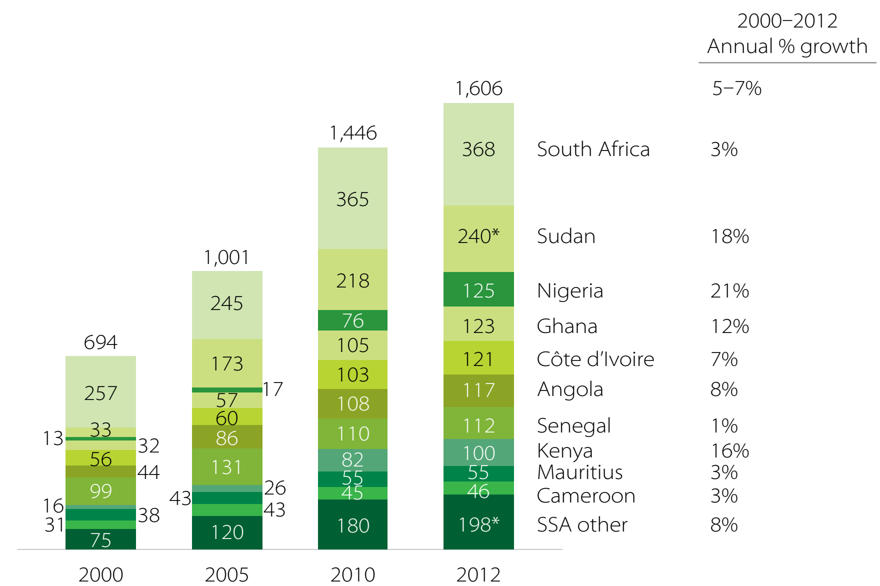
Stove type	Stoves in market, 2011 *(2013)*	Annual SSA sales in 2013	Sales growth (% y-on-y)	Key sales/ distribution trends
Legacy	8.1 mil *(7.5 mil)*	N/A *Not a commercial market*	–5% to 2.5%	• Basic chimney-stove promotion efforts slowing across region, but construction of traditional chimney stoves likely keeping pace with population growth in rural areas • DHS/MICS time series suggest that legacy chimney stoves are being abandoned at an increasing pace
Basic wood and charcoal ICS	7.5–10 mil *(11–14 mil)*	4–6 million units, largely charcoal stoves	Wood: 10–15% Charcoal: 20–30%	• Strong commercial market dynamics for charcoal ICS sales in key East and West African markets (e.g., Ghana, Kenya, Senegal, Tanzania); very wide range of quality on charcoal ICS • Wood market growth much slower and largely driven by donor dissemination efforts, rather than market forces, e.g., EnDev
Intermediate ICS (wood)	4 mil *(8 mil)*	2–2.5 million built-in stoves 150–200k portable rocket stoves	20–50%	• Very rapid growth driven by carbon revenue streams; leading players have 35–80% annual wood rocket sales growth • Growth in built-in rocket stove dissemination and some portable stoves driven by donor funding; post-intervention trajectory unclear
Intermediate ICS (charcoal)	0.1 mil *(0.6 mil)*	300–400k, depending on whether semi-industrial charcoal ICS included	30–80%	• Growth driven both by strong margins for sellers (due to high demand and ability to pay from urban charcoal consumers) and additional incentives from carbon finance revenues • 30–200% annual sales growth for individual leading players
ACS	10–50k *(40–100k)*	20k per year distributed for market pilots	n/a	• Technology and business models currently at pilot stage
LPG	8–12 mil *(9–13 mil)*	1–2 million replacements and new sales	5%	• Historical growth trend of 5%, but likely slower (2–3%) the past few years due to LPG market disruptions and lower subsidies, likely to accelerate as LPG prices fall
Kerosene	12–18 mil *(?)*	Replacements sales at ~4–6 mil	–2% to 1%	• Largely a replacement market, as kerosene use is shrinking in relative (and possibly absolute) terms across SSA
Electricity	10–15 mil *(11–16 mil)*	3–4.5 million replacements and new sales	4%	• Replacement market driven by relatively short shelf life of electric stoves; at very top of market, adoption growing for electric induction ovens • Concentrated in South Africa and Ethiopia
Biogas	10–15k *(40k)*	10k–15k	10–30%	• Historical growth rate on biogas plant construction in Africa extremely slow, but increased progress seen with Africa Biogas Partnership Programme • Market heavily dependent on subsidies for progress, so trajectory after end of currently earmarked funds is unclear
Solar	50–75k	5–10k per year	2–10%	• Slow growth thus far for leading NGOs and private-sector entrepreneurs in the Africa solar sector
Biofuels	100–150k (300–350k)	>50–100k per year	20–40%	• Ethanol and ethanol gel fuels biggest focus of activity and sales, but commercial ethanol fuel models still in early stages, with a range of distribution challenges • Alternative fuel sources (e.g., jatropha, methanol) have not gained traction

Source: Africa stove penetration database; data points on sales trajectories for two-dozen stove programs and private-sector entrepreneurs; interviews; desk research; Dalberg analysis.

Clean modern fuels: As noted in the fuel demand section earlier in this report, clean modern fuels are slowly becoming more available (Figure 32) and are stimulating stove sales as middle-class incomes rise, particularly in the LPG and electric stove markets. Extrapolating from long-term fuel-use trends, LPG and electric stove numbers are growing by 5% annually from the 2010 baseline, while the number of kerosene stove users will likely continue the slow decline experienced over the past few years, due to the suspension of kerosene subsidies in key markets, such as Nigeria.[152]

Figure 32: Domestic LPG consumption for top SSA LPG markets

Domestic LPG consumption (household, commercial, and industrial, million tons)



Sources: UN statistical abstracts; press reports; DataMonitor—Statistical Review of LP Gas; Dalberg analysis.

Contrary to the regional trend, LPG adoption has slowed in some markets, due to subsidy reductions and infrastructure bottlenecks that have led to fuel shortages and price spikes.[153] More recently, LPG adoption appears to be increasing rapidly in several markets like Kenya as consumers react to falling LPG prices against the background of continuing high charcoal prices in urban areas. Even faster growth of this market seems possible because the Global LPG Partnership—a public–private alliance with an ambitious target of transitioning

50 million developing-world consumers to LPG by 2018—is launching an intensive set of market development activities in several SSA countries, starting with Cameroon, Ghana, and Kenya.

MARKETS FOR RENEWABLE COOKING FUEL

Markets for renewable cooking fuel in Africa are at a very early stage of development. The market penetration of **biogas digesters** has grown from a few thousand units across the region five years ago to 40,000 units by early 2014, driven largely by the efforts of the Africa Biogas Partnership Programme (ABPP) in Burkina Faso, Ethiopia, Kenya, Tanzania, and Uganda. Progress has been slower than initially expected, but the program has recently secured a new round of funding and is planning to launch a second phase of work (2014–17) to promote the construction of an additional 100,000 biogas units in its core countries and in additional geographies, such as Benin, Cameroon, Rwanda, Zambia, and Zimbabwe.

The **liquid and gel biofuel** stove market has seen some significant investments in recent years. Despite the uptake of about 350,000 ethanol stoves across SSA by the end of 2013—largely in Ethiopia, Ghana, Kenya, Malawi, Mozambique, Nigeria, and South Africa—the track record of commercial efforts has been mixed. One of the best-funded ventures in this sector, CleanStar Novozymes Mozambique, was recently liquidated by its investors. Despite selling more than 30,000 stoves, the company was unable to achieve the stove penetration required to make the venture financially viable for its investors, given high marketing costs and the extensive (40–50%) subsidies embedded in the sales price of the Domestic CookClean ethanol stove used in that effort. The venture, under the NDZiLO brand, is still continuing on the ground, with some success with a new business model and under local ownership. CleanStar is also continuing its activities in the sector, with a new ethanol venture in pilot stage and is slated for a launch in Kenya in 2015. Other ethanol gel businesses, such as BioHeat/BioCorp (South Africa), Consumer Choice Limited (Kenya), and ThermoSafe (Nigeria), are seeing steady growth. Some, such as Nigeria-based Green Energy & Biofuels ("KIKE Green Cook" stove), already report reaching significant scale, with up to 200,000 stoves reported in multiple West African countries in just three years of operations.

The market for **briquette and pellet fuels**, although at an early stage, is attracting investment, with new consumer-focused pelletizing and briquetting factories launched in Côte d'Ivoire, Ethiopia, The Gambia, Ghana, Nigeria, Rwanda, Senegal, Tanzania, Uganda, Zambia, and elsewhere (Figure 33). This is a major step forward alongside longstanding artisanal briquette manufacturing initiatives promoted by NGOs.

The African **solar cooker** market is growing, but slowly. Despite efforts by a number of dedicated NGOs and entrepreneurs, it has seen few major new projects in recent years in terms of private-sector or donor investments. Cumulatively, the various NGOs (e.g., Solar Cookers International) and private-sector players in this sector are deploying fewer than 10,000 new solar cooker units annually across the region.

Finally, **retained-heat cooking,** while still a small niche, has grown with the adoption of the WonderBag in South Africa and ambitious plans by Native Balance, the WonderBag's manufacturer and promoter, to expand distribution across Africa in the coming five years.

IMPROVED AND CLEAN BIOMASS COOKSTOVES (ICS AND ACS)

The African improved and clean biomass cooking market is still dominated by legacy stoves and basic ICS, but sales of more efficient ICS are growing quickly, and much cleaner (ACS) biomass stoves are moving toward broader rollout. A review of the ICS market's composition over the past three years illustrates the region's changing biomass stove landscape (Figure 34).

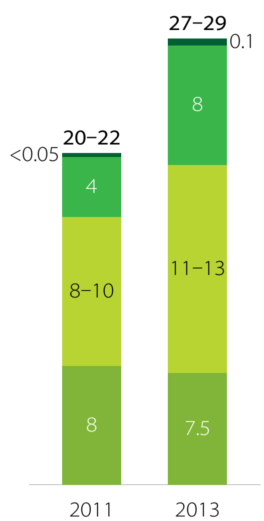
Figure 33: Africa briquette and pellet fuel business for household cooking

Figure 34: Africa ICS and ACS biomass stove mix (2011–2013)

Directional estimate of stoves in market (millions)

2011

ACS (Tier 3–4)	**5–50k**
Fan gasifier	0
Natural-draft gasifier	<0.05
Intermediate ICS (Tier 2–3)	**4 mil**
Built-in wood rocket	1.7
Rocket injera stove	1.8
Portable wood rocket	0.5
High-end charcoal stove	0.1
Basic ICS (Tier 1–2)	**8-10 mil**
Basic charcoal ICS	5–7
Charcoal mid-range ICS	0.3
Basic wood ICS	2.5–3
Legacy stoves (Tier 0–1)	**8 mil**
Legacy or traditional w/chimney	6.3
Enclosed mud/clay unvented	1.8



2013

ACS (Tier 3–4)	**40–100k**
Fan gasifier	0.02
Natural-draft gasifier	0.02–0.08
Intermediate ICS (Tier 2–3)	**8 mil**
Built-in wood rocket	3.0
Rocket injera stove	2.5
Portable wood rocket	1.0
High-end charcoal stove	0.5
Basic ICS (Tier 1–2)	**11–14 mil**
Basic charcoal ICS	7–9
Charcoal mid-range ICS	0.6
Basic wood ICS	3–4
Legacy stoves (Tier 0–1)	**7.5 mil**
Legacy or traditional w/chimney	5.7
Enclosed mud/clay unvented	1.9

Note: 2011 mix based on country-level database by stove type; 2013 mix derived by adding known (self-reported) sales, rest forecasted based on historical growth.

Sources: National energy surveys; self-reported stove sales data for 100+ organizations; interviews; Global Alliance for Clean Cookstoves market assesments and member surveys; Dalberg analysis.

Legacy stoves and basic ICS account for more than 80% of all improved and clean biomass stoves in SSA. **Legacy stoves (~8 million)** are a difficult market segment to quantify. The category includes mud chimney stoves (more than 6 million units), such as the vented mud stoves in Malawi; Malagasy chimney wood stoves in Madagascar; and enclosed low-efficiency nonchimney mud stoves of the type that have been commonly distributed in Ethiopia (less than 2 million).[156]

Within the **basic ICS segment (8–10 million)**, the most common technology is the Kenya Ceramic *Jiko* and analogous charcoal ICS, which is manufactured via artisanal and semi-industrial providers across the continent.[157] Basic wood ICS[158] were a smaller but, at 2.5–3 million units, still substantial segment in 2011. Both of these segments received strong donor support through such initiatives as GiZ ProBEC, the EnDev program, the activities of the United Nations High Commissioner for Refugees (UNHCR) and the United Nations Development Programme (UNDP), and a range of stove-dissemination projects led by NGOs, such as Practical Action, Enterprise Works/ Relief International, Mercy Corps, Peace Corps, Care International, Concern Universal, and World Vision.

The **intermediate ICS (4.4 million)** segment in 2011 consisted of portable rocket-style stoves designed for charcoal (less than 0.1 million) and wood (0.5 million) fuels and much larger subsegments of built-in rocket stoves, such as the Tanzanian *Okoa*, the Ugandan Rocket Lorena, the Kenyan brick rocket, and the Malawi TLC rocket (1.7 million), as well as specialized rocket *injera* stoves (1.8 million), such as the Ethiopian Mirt and the Eritrean *Adhanet Magogo*.

Finally, ACS were practically nonexistent in Africa in 2010–11, at a maximum numbering in the tens of thousands across various pilot sites around the SSA region.

Comparing the 2011 landscape with the situation in early 2014, it is clear that the market has undergone some significant shifts—an evolution that points to important trends for the coming years. Legacy stove penetration has continued its stagnation or decline (depending on country), as households increasingly abandon old stoves that are no longer being supported by government and NGO efforts.[159] Basic charcoal ICS penetration is growing at a rapid pace, as semi-industrial manufacturers, NGO–intermediated artisan collectives, and individual artisanal entrepreneurs continue to scale up production to meet the demand caused by growing urbanization, accelerating charcoal use, and quickly rising charcoal prices.[160] Basic wood ICS adoption has grown more slowly, with the fastest growth tracked as part of ICS promotion programs. One example of the latter is the rise of basic wood ICS penetration in urban Burkina Faso households to 10% from nearly zero over the past few years as part of the FAFASO program.[161]

In absolute terms, **the most dramatic increase in rocket stove sales and dissemination is illustrated by the doubling of the penetration rate of intermediate (i.e., rocket stove) ICS technologies** in Africa, from roughly 4 million in 2011 to 8 million by the end of 2013.[162] There are several causes for this acceleration: the maturation of international rocket stove manufacturers in the past few years as they perfect their products and extend their distribution networks; the on-shoring of production in Africa during 2012–14 by major players in the rocket stove segment, such as Envirofit, EcoZoom, and BURN Manufacturing; the growing scale of domestic semi-industrial firms, such as Ugastove in Uganda and Toyola in Tanzania (both with small but growing wood rocket stove businesses); the shift to rocket stove promotion by national programs in some geographies; and the rapid growth of carbon-financed projects across the region in 2012 and 2013, which significantly enhanced profits for distributors of wood rocket stoves.

The growth in rocket stove sales is expected to continue, given the major investments in manufacturing scale by several rocket ICS producers in 2013–14;[163] the growing portfolio of rocket stove technologies offered by the largest carbon program developers, such as Impact Carbon; and the explicit new commitments to rocket stoves (both funded and still seeking funding) by national programs—such as Rwanda's partnership with Del Agua Health and EcoZoom to distribute 600,000 rocket stoves to poor households across the country over an 18-month period starting in 2014.[164]

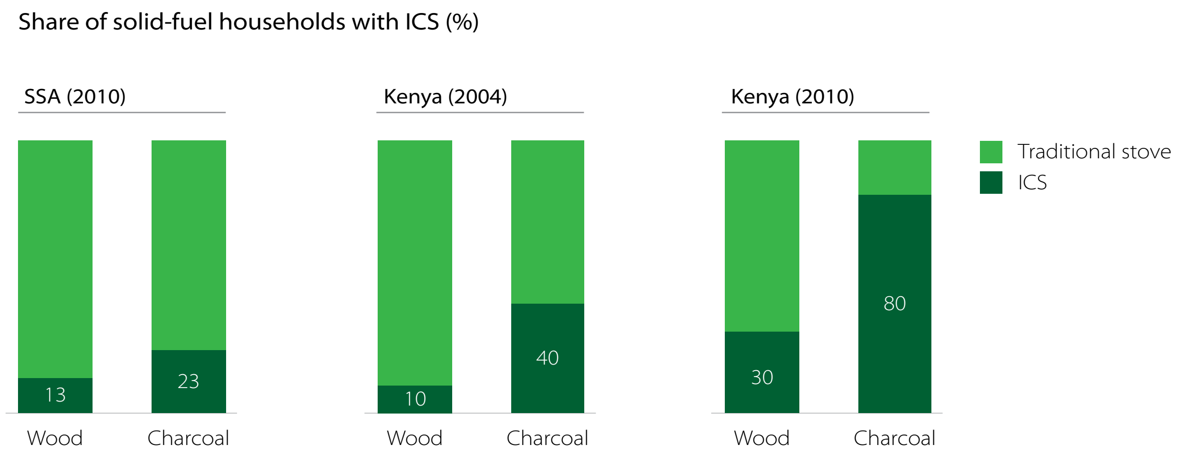
Finally, for ACS solutions, while it is premature to talk about distribution or sales growth trends, given the early stage of the marketing efforts of the key players, the number of stoves on the market has increased to up to 100,000 stoves, and a further accelerated pace of distribution is anticipated as ACS manufacturers and ACS-focused pellet fuel distribution businesses (such as Inyenyeri in Rwanda and Emerging Cooking Solutions in Zambia) scale up operations in 2014 and 2015.

TRENDS IN STOVE DISTRIBUTION

The distribution of clean and improved cooking solutions is highly uneven across SSA, skewing heavily to urban areas, charcoal users, and a handful of countries with more developed stove and fuel markets. The good news of fast-growing access to ICS and other clean cooking solutions in Africa appears less rosy when one considers the highly inequitable patterns of access.

Considered in terms of the urban/rural split of penetration and sales, access to clean and improved stoves is significantly higher in urban areas than in rural Africa. Excluding legacy stoves, nearly half of urban Africans own some form of clean or improved stove, compared with less than 10% of the rural population (Figure 35). Greater urban ICS adoption is also reflected in the much greater SSA penetration of ICS among charcoal **(23%)** rather than wood **(13%)** users**,** since charcoal is the quintessential urban solid fuel. The trend is most notable in such well-developed ICS markets as Kenya, where such basic charcoal ICS as the Kenya Ceramic *Jiko* have now become the new baseline technology (used by 70% of overall charcoal users and 80–90% of charcoal users in such cities as Nairobi and Mombasa), but wood ICS penetration among firewood users is significantly lower (less than 10% in 2004, up to 30% in 2010) (Figure 35).[165]

Figure 35: ICS penetration among users of wood and charcoal stoves

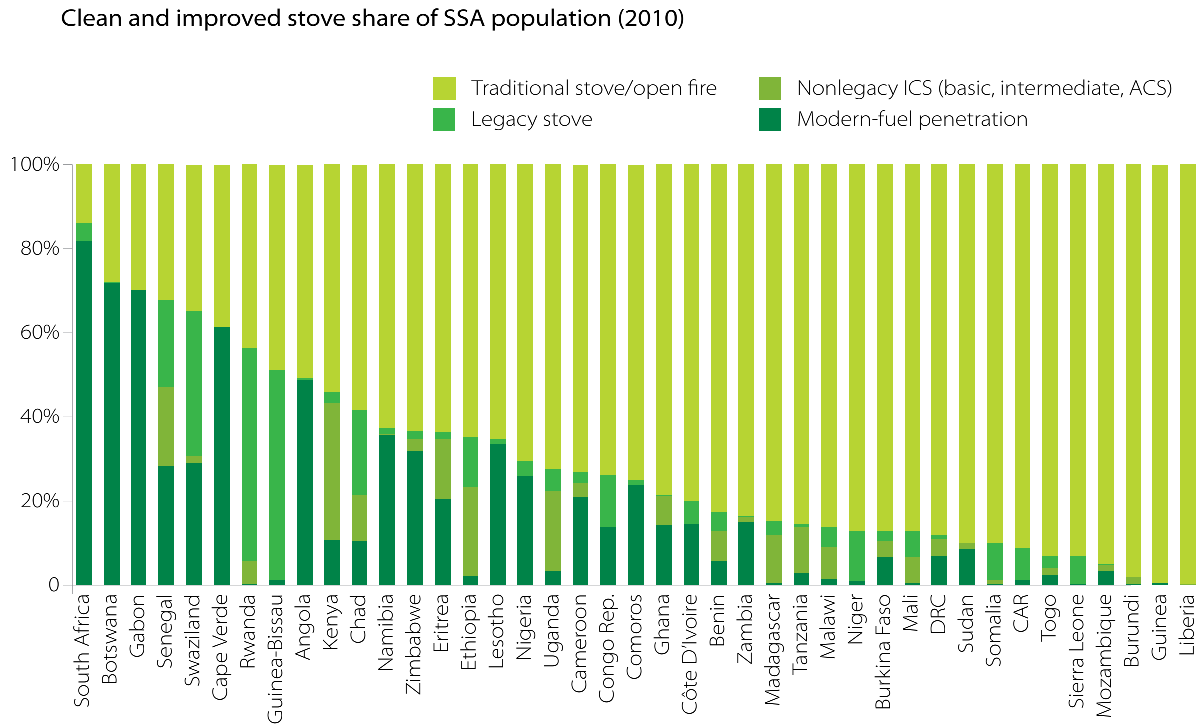


Source: Africa ICS penetration database; manufacturer and expert interviews; stove program data (ISAK); Dalberg analysis.

The uneven pattern of distribution is also obvious for stoves running on modern fuels. National household survey data show that just five countries across SSA contain 56% of LPG stove users, 74% of kerosene stove users, and 90% of electric stove users.[166]

These disparities, when both "clean" and "improved" cooking solutions are combined, translate into very uneven coverage across Africa. Penetration of clean and improved solutions stands above the 50% mark in only 10 SSA geographies, typically represented by relatively more developed nations, such as Botswana, Kenya, Senegal, and South Africa. The combined share of households using clean and improved stoves in these 10 countries is nearly half of all improved and clean stoves in Africa. In a full quarter of SSA countries, less than 10% of the population used anything other than traditional fuels and stoves for cooking in 2010–11 (Figure 36).

Figure 36: Penetration of modern fuels and improved cookstoves, by SSA country (2010)



Note: Assumes no overlap between ICS and modern fuels to demonstrate the maximum possible stove penetration. This calculation will likely significantly underestimate the population using traditional stoves in countries with large modern-fuel populations (e.g., Senegal, Kenya) due to extensive biomass fuel use by LPG users.

Sources: Country-level ICS penetration database, based on interviews and press searches; WHO global fuels database; Dalberg analysis.

Structure of the Cookstoves Manufacturing Sector

While the African cookstoves sector is currently dominated by artisanally produced cookstoves, industrial and semi-industrial manufacturers are rapidly gaining in scale and market share. Improved and clean biomass cookstoves can be categorized into three methods of production: artisanal, semi-industrial, and industrial (Figure 37).

Figure 37: Clean and improved cookstove production models in Africa

Increasing mechanization + centralization of production + quality control →

Artisanal	Semi-industrial		Industrial	
Producer networks5 & individual artisans	Central assembly of artisanal components	Local low-tech integrated production	Local high-tech integrated production	Global mass scale
Minimal or no automation; individual artisans and artisan collectives, typically with facilitating institution for training, and QC; may share workshop space and common tools	Integrated assembly workshop, central procurement, central QC, and common brand but very little automation; extensive outsourcing to external artisans; and use of local components	Basic industrial or semi-industrial tools (folding, drilling, welding); some automation; salaried staff; local to premium materials; some do flat pack assemblers; mid-range QC	Moderate to high levels of automation; high quality components; imported precision parts; strong QC often linked to global "parent" manufacturers	High-tech, mass-scale integrated manufacturing with precision tools, quality materials, world-class QC, extensive in-house design and R&D capabilities
geres; EnterpriseWorks/VITA; Practical Action; GVEP International; EnDev	Toyola Energy Limited; SYTAP Afrique; Tizazu Stoves; Man and Man Enterprise; Keyo Pottery Enterprises	New Dawn Engineering; CookClean; Rocket Works; Pre-fabricated kit assembly: EzStove	African Clean Energy (ACE)[1]; Dometic; burn manufacturing[4]; EcoZoom[2]; Envirofit[3]	Philips[1]; Greenway; BioLite; Prakti; EcoZoom[2]; Envirofit[3]; Ezy Stove

(1) Africa stoves manufactured in Africa (Lesotho) plant by ACE under license from Philips; global ND stove production currently suspended; (2) EcoZoom scaling up Nairobi manufacturing capacity in 2014; (3) Envirofit has global and Africa (Nairobi) manufacturing capabilities; (4) design/R&D within separate Burn Design team in US; (5) most are NGOs supporting individual artisans and artisan collectives, not social enterprises in their own right.

Source: Interviews; press searches; Dalberg analysis.

Terms and attributes describing industrial production models are often used inconsistently. For the purpose of this report, **industrial production** is defined as scalable manufacturing that relies on a large degree of automation, precision tools, sophisticated materials, highly skilled and trained workers, and rigorous quality control. Industrial manufacturers are also likely to have significant in-house R&D capabilities, though in the case of Africa-based production and assembly, the R&D capacity may often reside outside the continent in such locations as Europe, the United States, and Asia.

Artisanal production is manual, with self-trained or minimally trained artisans (often individual micro-entrepreneurs in the informal sector), indigenous materials, simple designs, and much weaker quality control measures. In their most sophisticated form, intermediated artisanal models (e.g., EnterpriseWorks and Tatedo) rely on decentralized production models (i.e., individual artisans), but with an overlay of centralized procurement, quality control, and sales provided by an NGO or social enterprise.

Semi-industrial production is the most difficult mode to define. It ranges from relatively low-skilled assembly of prefabricated components to domestic manufacturing with moderate levels of automation. Tools used for semi-industrial production will typically include flanging, bending, and rounding machines for metal works; folding, drilling, and welding sets for stove assembly; and extruders and improved kilns for liner production. Unlike the industrial assembly-line process, semi-industrial manufacturing will typically have a workshop workflow with multiple artisans/workers working in parallel on individual stove construction and finishing. Figure 38 reviews key features of each of these modes of production.

Figure 38: ICS and renewable stove production models range from industrial, to semi-industrial, to artisanal

Increasing mechanization, centralization, and quality control →

Artisanal	Semi-industrial	Industrial
>6–10 million units annually	*>400,000 units annually*	*350,000 units annually*
10k–15k artisans/masons	25–40 firms	<10 firms, +5 in last 2–3 years
100–5,000 units per producer/year	2k–100k units per producer/year	20k–150k units per producer/year
US$2–20 per stove	US$5–20 per stove	US$20–100 per stove
• Focus on KCJ-type technologies, clay stoves, metal stoves, and home installation of fixed or semi-portable rocket-style wood stoves • Quality controls weak or absent in some markets • Many stoves sold as part of integrated government/donor programs for artisan training and market support	• Traditional focus on basic efficient charcoal ICS and wood stoves; several have added wood rocket stoves to portfolio • Several (nonfan) gasifier entrants in 2013–14 • Manufactured using labor-intensive low-tech industrial or workshop processes • Smaller players often have heavy donor/government support	• Focus on higher-end charcoal ICS, wood rocket stoves, and gasifiers • Small sector, many at early stage of commercialization • Significant new investment in scale-up by investors and/or clean development mechanism (CDM) programs in 2011–14 • Several new manufacturing/assembly facilities in Africa, but most industrial stoves in market still designed in Europe/U.S. and manufactured in China

Sources: Interviews; press searches; Dalberg analysis.

Although each mode of production has its own sets of challenges, there are common themes. These include the growth of materials and labor costs affecting overall product affordability, the difficulty and cost of distributing stoves to the last mile, and—though the size and nature of the financing needs differ dramatically by segment—a lack of access to capital markets.

Artisanal and small-scale semi-industrial players, in particular, contend with low margins, rising materials costs (particularly for metal components), low managerial and business planning capacity, and lack of working capital financing. Most critically, there are also significant quality control issues, which include the high cost and logistical challenges of accessing stove-testing services, and the limited technical ability of producers to ensure the quality of their products as they increase production.[167]

The quality control issue—combined with the growing economic pressures on small artisans and artisan collectives, and, historically, a lack of standards in African cookstove markets—has led to widespread quality and market spoilage issues. Many artisanally produced stoves in the field suffer from significant performance and quality challenges, including poor durability (e.g., short 3–12-month shelf lives before cracking); poor safety (e.g., they flip over easily, causing burns); and weak standardization of materials and designs, leading to fuel-efficiency levels that are far below potential.[168]

Semi-industrial manufacturers, which are typically relatively sizable family businesses, share some of the challenges of artisanal markets, but have specific issues, which include limited managerial and business planning capacity to scale beyond starting models, pressure on both labor and materials costs, and very poor access to financing due to their lack of formal business banking relationships and traditional collateral.

For **industrial manufacturers**, in contrast, the biggest challenges are the high cost of materials and production relative to highly income-constrained consumers; high import duties and taxes for bringing imported stoves and components into most African geographies (in some countries, end users face a 40–60% mark-up in stove prices when all taxes and fees are accounted for); and the cost and complexity of building large-scale distribution channels (or tapping into existing channels) to reach target consumers.

The composition of the market is changing quickly across these three production approaches. Excluding legacy cookstoves, which are typically built by the users themselves, **about 90%** of biomass ICS and ACS sold in Africa annually have been produced by artisanal methods in local workshops or built on location by trained masons. Semi-industrial and industrial stoves account for roughly **5%** of annual production and sales each.

The sales mix across the three production methods is changing quickly. Manufacturer and stove program data for Africa suggest that industrial and semi-industrial stove enterprises and programs have had much more rapid annual sales growth (**35–200%**) relative to the annual sales growth trend of **10–25%** for the artisanal sector over the past five years. Factoring in replacement sales, these growth trends suggest a significant expansion of improved industrial and semi-industrial stove manufacturing capacity in Africa over the past 5–10 years, albeit from a very low base.

Such growth of semi-industrial and industrial manufacturing share is encouraging given the *relatively* higher-build quality levels of such cookstoves. Projecting these trends forward, even with very conservative growth assumptions, points to a rebalancing of the market toward industrial and semi-industrial solutions (for instance, 20–30% of annual biomass stove sales in 5 years versus 5–10% today).

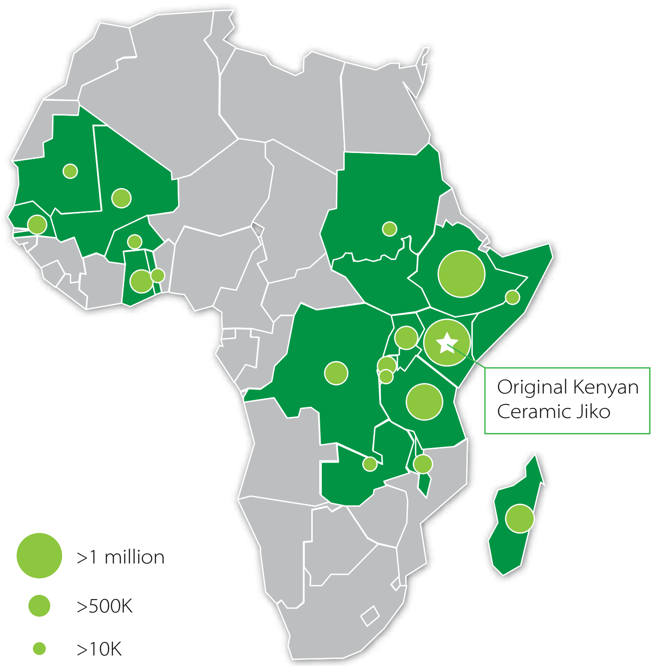
Irrespective of such rebalancing, after decades of basic ICS technology promotion by donors and NGOs, the artisanal sector in Africa is large and, in the case of such technologies as the Kenya Ceramic *Jiko*, predominantly self-sustaining. There are commercially driven artisanal production sites across the region, and particularly large artisanal production clusters exist in such countries as Ethiopia, Ghana, Kenya, Senegal, Tanzania, and Uganda (Figure 39).

In contrast, the promise of the industrial and semi-industrial production revolution in cookstoves manufacturing is reflected in the growing universe of such manufacturers across the region: **more than 40 such companies are now manufacturing or assembling their cookstoves across a dozen countries** (see partial list in Figure 40). Half of these companies started their Africa operations or entered the cookstoves market from other lines of business during the past five years. Others—such as CooksWell/Museki Enterprises in Kenya, Toyola in Ghana, and Ugastove in Uganda—are veterans of the cookstove trade, with roots in the NGO- and government-led basic ICS promotion efforts of the 1990s.

Currently, most industrial manufacturers of African improved and clean cooking appliances (ICS, ACS, and stoves running on modern or renewable fuels) are clustered in Kenya and South Africa. Semi-industrial ICS manufacturers, meanwhile, are present in two-dozen countries, chiefly Ethiopia, Ghana, Kenya, Tanzania, and Uganda (Figure 40). Francophone Africa, Burkina Faso, the Democratic Republic of the Congo (DRC), Mali, and Senegal have sizable artisanal and, in some cases, semi-industrial manufacturing hubs, but the density of private-sector enterprise is substantially lower than in East Africa, and many players that do exist are still entirely dependent on their affiliation with donor and national government programs.

Figure 39: Distribution of Kenya Ceramic *Jiko* (KCJ) and comparable solutions across Africa

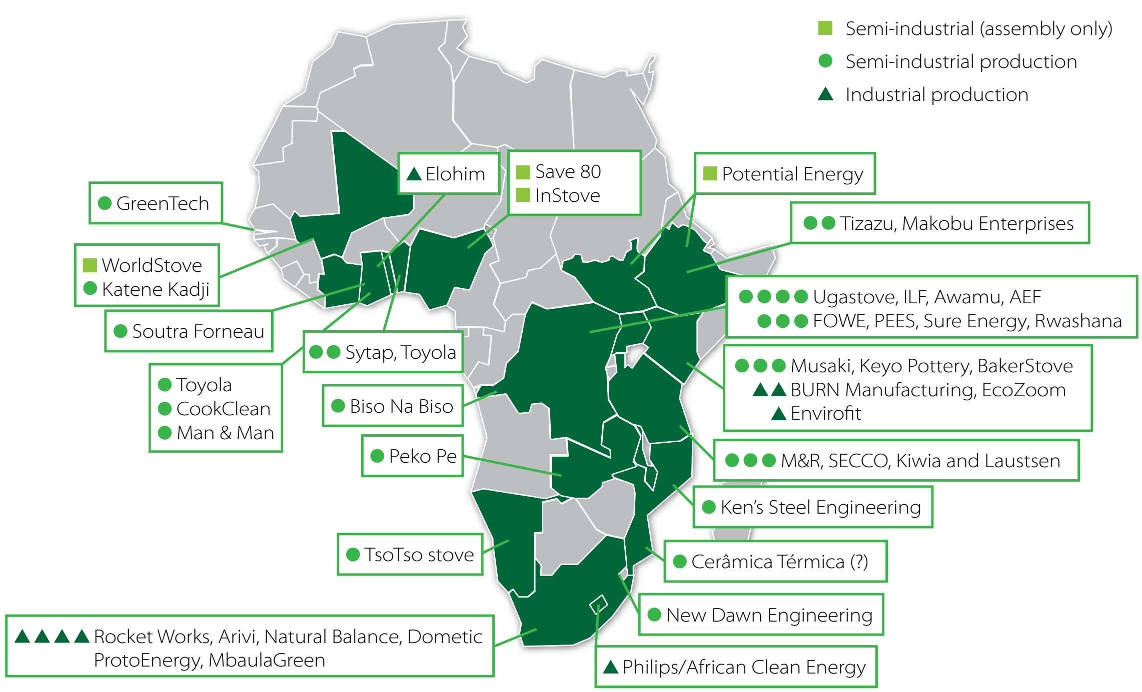
Households using ceramic *jiko* basic improved charcoal stoves and comparable models (2010)



Country	Local name
Kenya	Kenya Ceramic *Jiko*
Rwanda	Canamake
Sudan	Canun el Sarour
Uganda	Ceramic Sigiri/Usika
Tanzania	*Jiko* Bora
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.

Figure 40: Select SSA industrial and semi-industrial clean and improved stove manufacturers (2014)



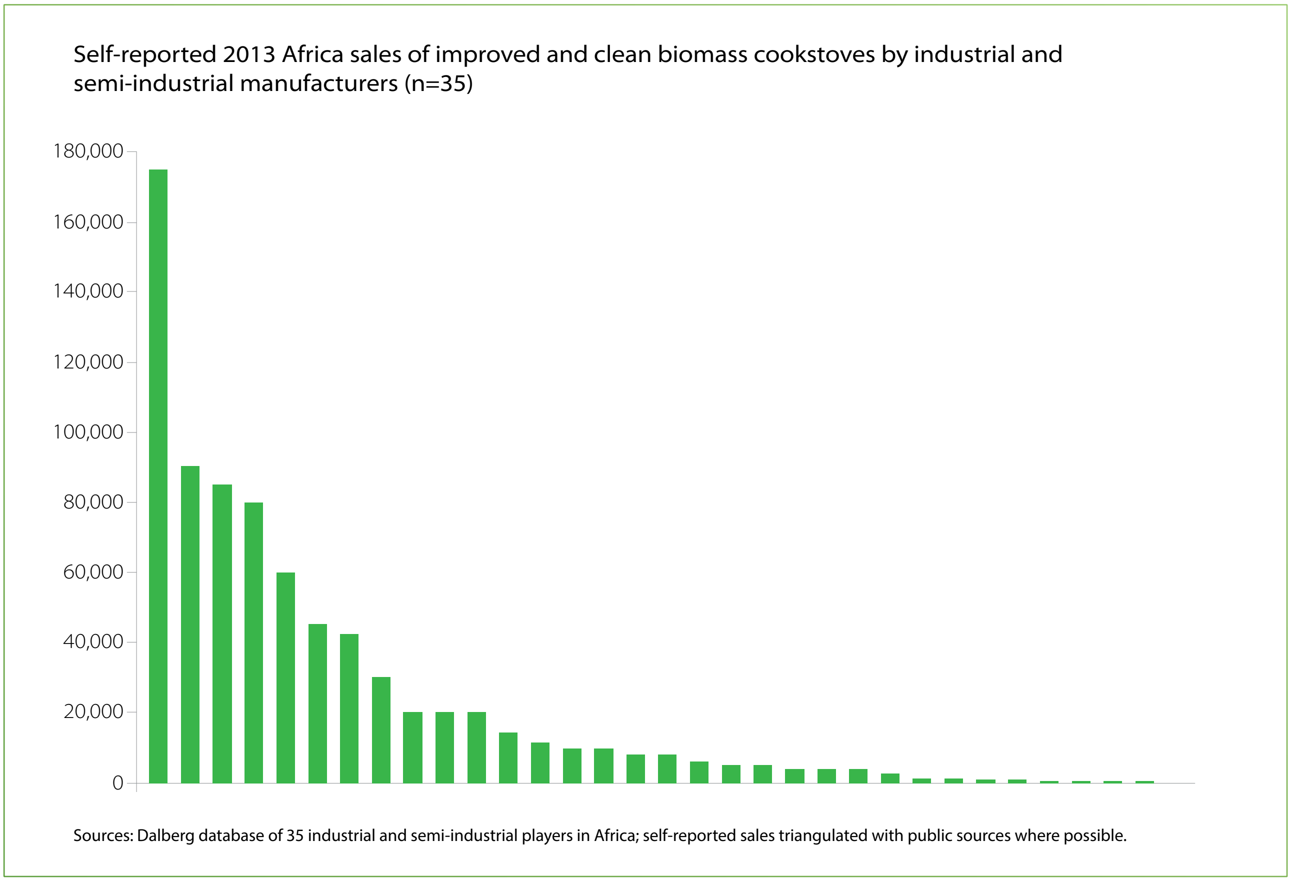
Sources: Press searches; interviews; Dalberg analysis.

Important industrial factory launches in the past two years include Envirofit's new plant in Nairobi; the launch of the ACE factory in Lesotho (with a license to produce the Philips fan gasifier stove); the opening and scale-up of BURN Manufacturing's Nairobi plant; EcoZoom's ongoing efforts to onshore its assembly and production; BioCorp's expansion of its ethanol stove manufacturing facilities in South Africa; and the launch of biogas plant manufacturing in Tanzania by SimGas in partnership with Silafrica Tanzania Ltd., the largest plastics manufacturer in East Africa.

Notable recent launches of semi-industrial manufacturing facilities include the Baker Stove/Top Third Ventures factory in Kenya, the InStove manufacturing and assembly facility in Nigeria, the Biso Na Biso basic ICS factory in Kinshasa, and the Soutra Fourneau factory in Côte d'Ivoire. The estimated scale of investments in these and other comparable businesses is north of US$25 million over the past 3–4 years, with ambitious plans by several of these players and others to move up the local production value chain from assembly to more sophisticated component manufacturing and, within the next few years, expansion of manufacturing facilities or satellite assembly hubs to new geographies.

Despite this progress, however, the industrial and semi-industrial sectors remain small and highly fragmented. Fewer than 10 industrial and semi-industrial players in the entire region have reached a scale of 50,000-unit annual sales; most produce between 2,000 and 15,000 units a year (Figure 41).

Figure 41: The industrial and semi-industrial ICS sector is highly fragmented, with only a handful of players globally exceeding 50k in sales



Furthermore, the number of models available from each industrial and semi-industrial manufacturer is limited, given the subregional or regional ambitions of many of these players and the diversity of the SSA consumer. As a point of comparison, the African solar lighting market features more than 100 solar lanterns and home system designs and more than 60 manufacturers focused on SSA.[169]

Fuel Supply Trends

On the fuel supply side, the market suffers from inefficient supply chains for biomass fuel, limited investment in alternative fuel production, and infrastructure bottlenecks for modern fuel energy. The fuel supply market in SSA is well established. Because woodfuel value chains employ **more than 15 million people** in Africa—**7 million in charcoal alone**— they are an important source of livelihoods for many of the poorest households across the region.[170]

At the same time, biomass value chains suffer from multiple market failures and regulatory challenges. These include lack of sustainable forestry management and related forestry and land rights issues, perverse incentives that impede sector reform (such as blanket charcoal-ban policies), high rates of sector informality (and related leakage of potential government tax revenues), and oligopolistic and inefficient market structures that lower overall sector efficiency and productivity (Figure 42).

The World Bank's research suggests that there is a major opportunity to improve the sustainability of biomass supply by addressing these challenges.[171] Key steps encompass reforming and modernizing the fiscal and governance framework for Africa's biomass, promoting sustainable forestry management, and aggressively promoting new, more efficient kiln technologies that reduce particulate emissions.

Figure 42: Fuel supply: Challenges for the SSA charcoal supply

	Wood production and harvest	Charcoal production	Transport	Wholesale	Retail
Challenges	• Weak forestry management • Over-harvesting of "free" resource in public forests • Land rights issues	• Waste and GHG from poor efficiency kilns (8-20% vs. 25-40% potential) • Low capacity • Health hazards	• Oligopolistic control and often limited value for small transporters • Significant informal payments • Health hazards	• Significant informal payments • Operate in shadow economy and cause tax revenue loss	• Unsustainable livelihoods due to capture of value by upstream intermediaries
Tanzania	33%		50%		17%
Uganda	34%		33%		32%
Senegal	15%		70%		15%
Malawi	21-33%		33-50%		25-33%
Kenya	20%		58%		22%
Liberia	53%		24%		24%
Cameroon	32%		40%		28%

Cross-cutting challenges
- Lack of sustainable forestry management, potentially leading to high rates of resource depletion and localized overharvesting
- Criminalization / periodic charcoal bans mean that information on sector is limited and ability to influence sustainability is low
- High rates of informality account for 30-50% of end-price instead of being captured as tax revenue
- True economic costs of charcoal production not accounted for as wood seen as a "free" resource
- Disproportionate value capture by large transporters and wholesalers at expense of producers and retailers, especially women

Sources: Country woodfuel value chain reports; AFREA (2011); World Bank (2011b); Dalberg analysis.

On the point of **woodfuel governance reform**, much-needed changes include formalizing the charcoal trade to bring it out of the shadows, promoting sustainable forest management schemes, and rolling out sustainable biomass certification programs.

For achieving **sustainable biomass production**, key aspects that need to be considered are community-based forest management; clear rules governing sustainable lots; and the launch of innovative financing mechanisms, such as United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (REDD+) and the Forest Investment Program (FIP).[172] Community-based forest management (CBFM), in this context, means that rights and responsibilities associated with sustainable forest management are transferred to the local level, technical oversight and capacity building is provided by community authorities, and a share of taxes paid to the community or local government is earmarked and reinvested for forest maintenance and local community economic development. There is a growing list of successful donor-supported CBFM projects across Africa,[173] but the scale of such initiatives and government engagement is still very limited when considered from a regional perspective.

Finally, for the objective of **improving kiln quality**, major ideas include aggressively promoting new kiln technologies (Figure 43) by creating charcoal producer groups and facilitating access to small- and medium-sized enterprise (SME) financing and carbon finance streams for sustainable charcoal producers.

Figure 43: Fuel supply market interventions example—improved charcoal kilns

	Traditional kilns	Improved kilns	Modern 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*

	Traditional kilns	Improved kilns	Modern 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: ~700 CO: ~160

Sources: World Bank (2011b); Sepp (2008); task team analysis.

Needless to say, bringing about such deep systemic reforms is difficult. Most of these activities require significant funding, multi-year commitments, and experimentation in difficult institutional settings. The importance of engaging on the *supply* side does not, therefore, reduce the need to engage on woodfuel *demand* through improved cooking technologies. Other important supply-side fuel market opportunities include the potential for improving the supply of sustainable solid-fuel alternatives to traditional biomass, such as renewably manufactured briquette/pellet fuels (i.e., carbonized or noncharcoal fuels manufactured from renewable biomass, such as sustainably harvested woods and crop waste). As mentioned earlier in the report, while full of promise, the briquette/pellet market has seen insufficient focus and investment from the clean cooking community to date.[174]

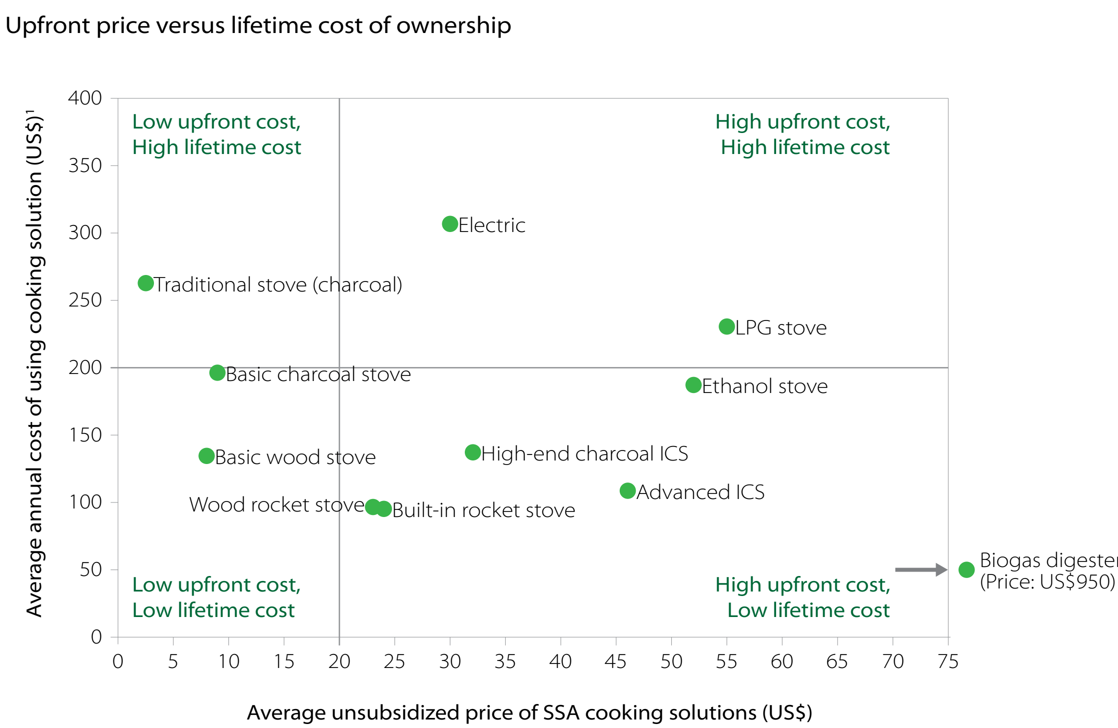
In terms of modern and renewable fuels, there is an opportunity to significantly improve the uptake of both clean fuels, such as LPG, and renewable biofuel alternatives, such as ethanol, through large infrastructure investments and supporting regulations. Current efforts by the Global LPG Partnership are designed to encourage this systemic change by improving upstream and midstream LPG infrastructure through both large-scale investments (e.g., LPG storage facilities, cylinder manufacturing, cylinder-filling plants) and demand-side interventions (e.g., consumer financing and consumer education) to drive the demand for clean cookstoves and fuels for those consumers who can afford them. Cameroon, Ghana, Kenya, Nigeria, and Senegal are likely to be the major focal points for such efforts.[175]

Cookstove Costs and Sector Economics

Improved and clean cookstove fuel and appliance costs are high and unlikely to decline over time. Relative to the population's purchasing power, most clean and highly improved cooking solutions in Africa feature both high upfront costs (US$20–100 for most technologies, US$500–1,500 for household biogas plants) and, in the case of many modern- and renewable-fuel stoves, significant annual fuel expenditures (Figure 44).

That said, cookstove prices do vary across the continent. For locally manufactured stoves, this is because of differences in the price of labor and inputs; for imports, price differences arise from significant differences in taxes and tariffs and transport costs. On average, West Africa tends to have significantly higher prices than East Africa. Simple ceramic *jiko*-type cookstoves are 1.5–3 times more expensive in Ghana and Senegal than in Kenya, for example, and West African countries, such as Nigeria, also feature some of the continent's highest effective tax and import duties for consumer durables. Across all stove types, manufacturing costs account for roughly half of the end-consumer price, followed by distribution costs (last-mile transport and retailer margins) and importation costs (Figures 45 and 46).

Figure 44: Price and annual average cost for various cooking appliances



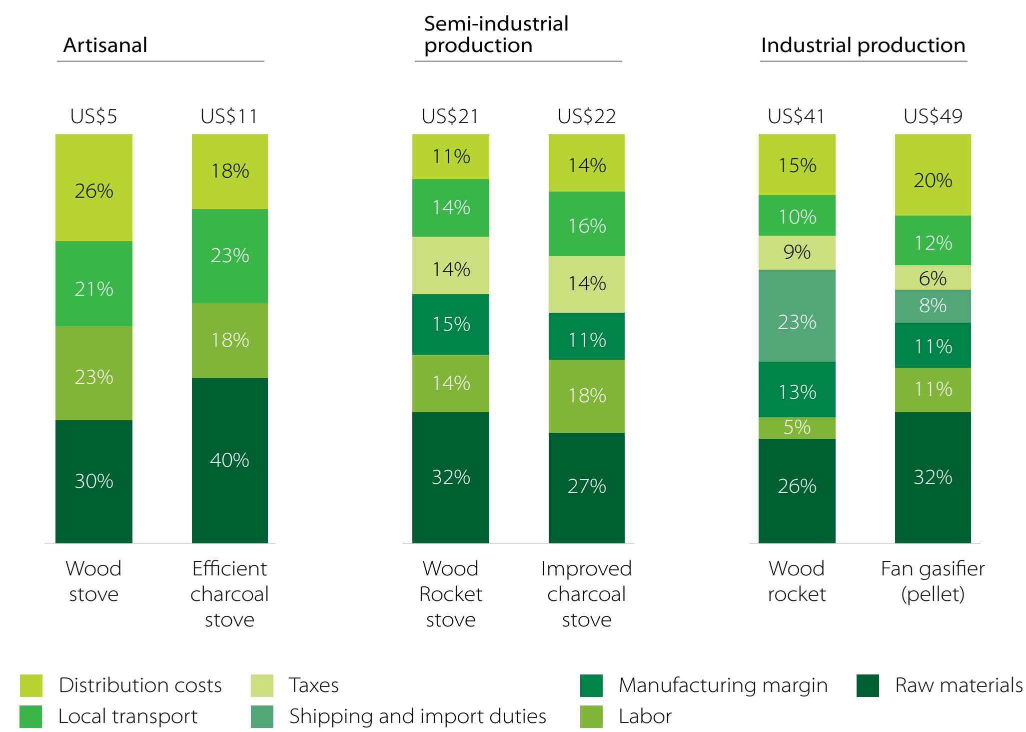
Note: Some stoves have wide range of prices and annual costs. Consult appendix for full detail.

Sources: Dalberg cookstove database; manufacturer interviews; press searches.

1. Includes fuel consumption equivalent to 320 MJ and stove price amortized over average stove life; for less commonly used fuels, such as electricity and LPG, average costs are calculated only from countries where usage of fuel is significant.

2. Assumes a life range of 10–20 years and includes US$10–20 annually for servicing/maintenance.

Figure 45: Detailed cost distribution for artisanal, semi-industrial, and industrial models



Note: Labor costs include manufacturing margin for basic artisanal stoves.

Source: Sanitized self-reported manufacturer data; Dalberg analysis.

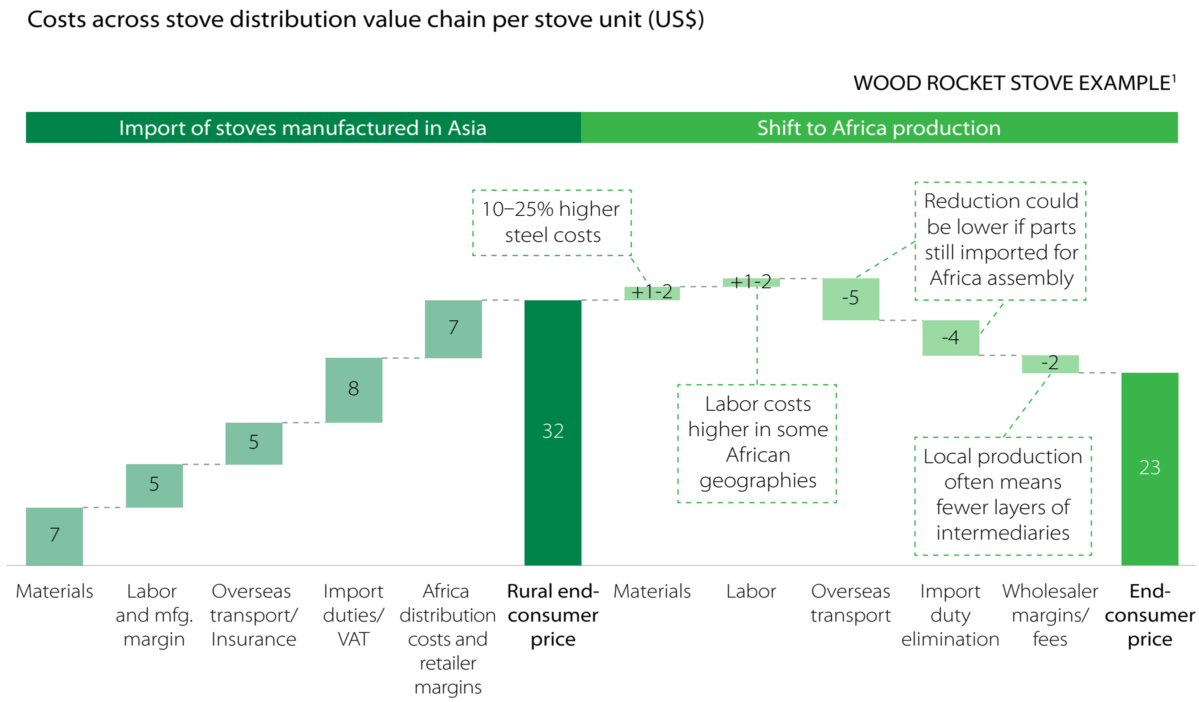
High distribution costs may decline in urban areas and as the sector reaches greater scale, but—holding quality constant—there is no reason to expect major reductions in the manufactured cost component of ICS and modern-fuel stoves, because both labor and materials costs for consumer durables are increasing worldwide in real terms (i.e., faster than the rate of inflation).[176]

Cookstove costs are particularly sensitive to the price of steel, which has witnessed large price spikes in recent years in both primary and scrap markets and will remain a key input for quality cookstoves in the foreseeable future. The trend of rising prices distinguishes stove manufacturing from other off-grid energy products, such as solar lanterns and solar home systems, where prices have fallen dramatically over the years and will continue to decline, thanks to underlying technology improvements and trends in battery and lighting component markets.

Increased domestic manufacturing and assembly in Africa are probably the best near-term lever for reducing cookstove costs. As shown in the following examples, this is because domestic production can reduce international transport and tariff costs, while at the same time fostering skills and technology transfer (Figure 46).

However, mostly because of local infrastructure and capacity constraints, domestic production will not be feasible in all African markets. Although the low-cost, scaled manufacturing of more sophisticated stove solutions—such as fan gasifiers with thermoelectric generators, or TEGs—is still best effected in Asian manufacturing centers, the potential for basic and intermediate stove manufacturing in Africa is large. Product simplification is another promising lever for price reduction, particularly in the case of ND gasifier solutions which, with appropriate controls, can be manufactured locally using semi-industrial processes (Figure 47).

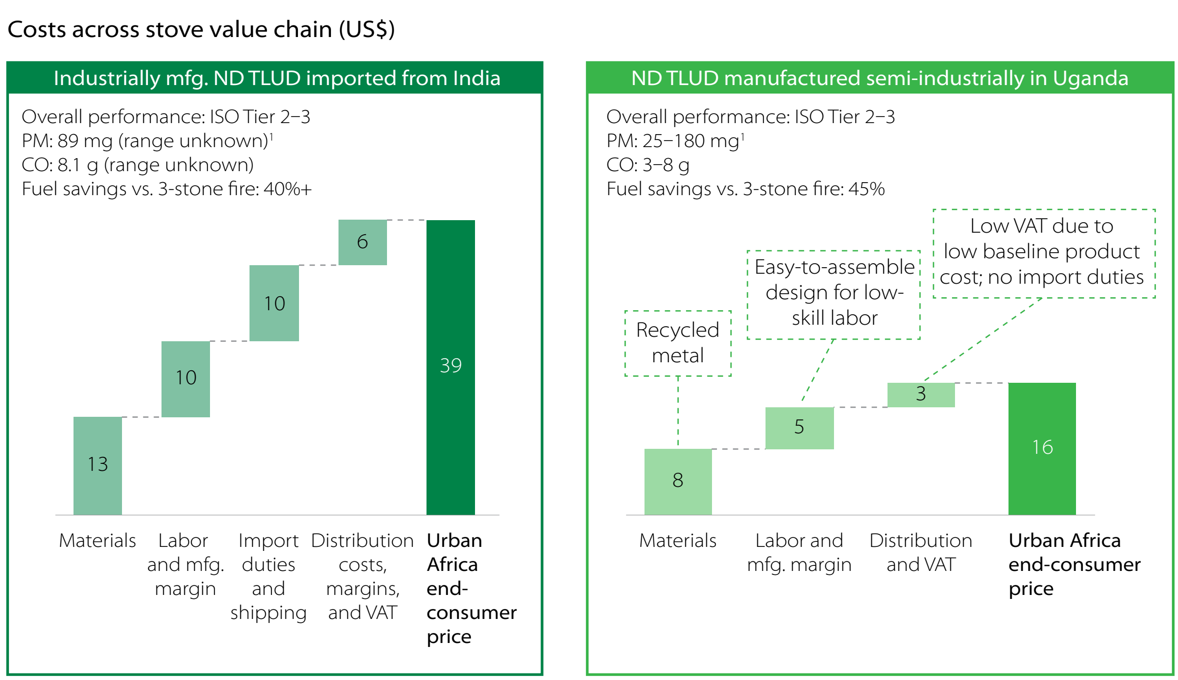
Figure 46: Impact of portable rocket stove production in Africa



1. Blended data from 3–4 manufacturers producing stoves in Asia and either considering or implementing shift of production to Africa .

Sources: Manufacturer interviews; public value chain data; Dalberg analysis.

Figure 47: Example of shifting natural-draft gasifier manufacturing to Africa semi-industrial production



1. Approvecho testing for Africa-manufactured stove; self-reported results for India-manufactured stove; results from pyrolysis only, not burning resulting charcoal.

Sources: Manufacturer interviews; public value chain data; Dalberg analysis.

Although average margins are generally low across clean and improved cookstove enterprises, many manufacturers have already achieved, or are on a path to achieving, profitability. They have done this largely by drawing on carbon revenues and/or focusing on more profitable consumer segments, such as urban charcoal users, where sustainable economics are possible without public-sector and carbon-market support.

Self-reported data from a dozen African companies across the clean and improved cooking value chain reveal that, although overall margins are low, best-in-class industrial and semi-industrial stove manufacturers can achieve a net income margin in the 15–25% range, while cookstove distributors—with their own sales forces and deep reach into the last mile—can likewise approach the 15–25% profit margin range, particularly if their businesses straddle both stove and fuel distribution (as is the case, for example, of integrated stove and pellet fuel distribution models). Local artisans typically see 5–12% margins, though higher margins are possible in new, less competitive stove markets. Semi-industrial manufacturers of basic and intermediate ICS consistently achieve profit margins of 10–15%; deeper margins are possible but difficult to achieve at scale for semi-industrial businesses once they fully penetrate their local base, as so much of their success is predicated on solutions well tailored to local markets and strong distribution relationships with local dealers and retailers. For local industrial manufacturers, while the trend may not apply more broadly, existing players are already achieving higher margins than international manufacturers bringing products into the same country. This is because local players are able to avoid taxes/import duties on their products and, all else being equal, are able to much more quickly scale up their business models at a lower cost base.

Finally, for international manufacturers, there is a wide range of outcomes today, ranging from (1) money-losing models that are heavily reliant on both donor and carbon-market revenue streams to (2) much more commercially oriented models that are able to realize 10–15% profits, both by focusing on easier-to-reach and wealthier urban segments and by supplementing their income with carbon finance profits. At this early stage of market development, a significant portion of profits is reinvested into market expansion; however, based on current profit margins, it is clear that higher net incomes are possible in the future, when these businesses mature, with some targeting 20–25% gross earnings.

Technology and Business Model Innovation

Looking forward, the supply of clean and improved cooking solutions is being transformed via the emergence of promising new technologies and business models.

In the market for nonbiomass modern and renewable cooking solutions, the most important innovations are focused on developing lower-cost cooking appliances and relevant business models.

In the **LPG market**, to improve uptake by the urban poor and mass-market segments, firms have explored business models involving small, 3-kg cylinders with integrated burners, partial cylinder refill capability, and amortization of appliance costs built into fuel prices. Oando's O-Gas and TechnoOil in Nigeria, EasyGas (Shell) EasyCooka in South Africa, National Oil and Total in Kenya, and Viva Gas's Butagaz brand in Morocco are a few examples of African businesses promoting 3-kg cylinders to poorer consumer segments. The oldest use of such models is the Blip Banekh stove/2.75-kg cylinder combination in Senegal, promoted by Senegal's butanization program since 1976. Gulf Energy's Pima Gas in Kenya, aside from promoting very small (1-kg) cylinders, dispenses LPG from a mobile pump and allows for partial refills with an automatic switch-off mechanism once the desired amount has been filled. These approaches are innovative in the African context, but have precedents globally.[177] While uptake of small cylinders has been relatively slow, ongoing experimentation with lower-cost LPG cylinders and stoves is an important sign of long-term cooking-sector commitment to expanding LPG access to poorer consumers.

Liquid and gel biofuel promoters, in an effort to manage supply-chain risks and reduce fuel costs, have piloted new approaches to sustainable, decentralized fuel supply, such as micro-distilleries and feedstock outgrower programs. At the same time, they have aggressively promoted the adoption of biofuel stoves for urban kerosene and charcoal users. Building on its earlier African pilots, Project Gaia is continuing its micro-distillery and stove promotion efforts in such countries as Ethiopia and Nigeria.[178] Thus far, biofuel production models have been attempted with limited success for such fuels as jatropha and methanol. In the ethanol cooking fuel market, there is increasing innovation in ethanol feedstock and production processes—most notably, the innovative approach from Green Energy & Biofuels in West Africa to produce ethanol from low-value biomass, such as water hyacinth and sawdust, and ongoing efforts by multiple ethanol producers to improve the quality of their products. From a cooking appliance perspective, the ethanol cooking market is still dominated by just a few stove models, but ongoing research suggests that the efficiency and emissions performance of current ethanol and ethanol gel stoves can be improved significantly with moderate investments in stove design.[180]

The **biogas digester** sector is seeing the arrival of household biogas plants that are cheaper, modular, and easier to install. It is also benefiting from new distribution, promotion, and subsidy models that may accelerate biogas household adoption, though evidence from the field is still at an early stage, and the results such efforts as the Africa Biogas Partnership Programme have so far fallen below target. From a technology standpoint, the most exciting innovation in this sector is the small-scale biogas plants from SimGas, a Dutch firm operating in Kenya, Tanzania, and Zambia that is promoting mass-produced, low-cost, easy-to-install biogas digesters prefabricated from polyethelene.[181] Other innovative, lower-cost, prefabricated digester technologies at various stages of commercialization include plastic bag digesters from EcoFys, piloted in South Africa and Tanzania,[182] and plastic or fiberglass solutions from AGAMA Biogas in South Africa.[183]

Some of the most important technology and business-process innovations are taking place in the biomass cooking sector. New biomass cookstove technologies include better-performing and more durable basic ICS developed over years of trial and error by specialist NGOs and donors, such as the range of products distributed by GIZ/ProBEC and EnDev; and a growing number of intermediate ICS rocket stove models with advanced materials, precision engineering, and market-specific design adaptations (e.g., Envirofit, EcoZoom, and Prakti Design). Most critically, the biomass cookstove sector is seeing the emergence of semi-industrially and industrially produced natural- and fan-draft gasifier cookstoves (Figure 48) that hold the promise of truly transformative health and environmental benefits.

Figure 48: Advanced biomass stove innovation—examples of ACS models for sale in Africa

Sources: Roth (2014); press searches; interviews; Dalberg analysis.

While none of the current gasifier stove models fully reaches the particulate emissions performance of modern fuels, the best-performing fan gasifiers, particularly in combination with high-quality pellet fuels, already achieve IWA Tier 4 for efficiency and can come close to IWA Tier 4 indoor emission standards.

Many of the stove designers interviewed for this report believe that a Tier 4 biomass gasifier stove, in terms of both efficiency and emissions, is technically feasible and—on the basis of current R&D efforts in the region—predict that several Tier 4 biomass stove models will be ready in prototype form in 2015. Such stoves will initially be highly expensive (US$100–200) due to a range of likely features, including the presence of multiple burners (i.e., to reduce the number of times the stove needs to be lit for each cooking session); the use of high-end materials and precision engineering for the stove body and combustion chamber; and the need for a chimney to maximally reduce household PM levels. Although stoves at this level of cost will not be commercially viable for most consumers as an upfront lump-sum payment, the possibility of Tier 4 performance from biomass cooking is a potentially transformative development when seen in the light of pay-as-you-go business models, which can theoretically resolve affordability barriers for relatively expensive products.

Another important technology development is the rise of electrically powered or electricity-generating biomass stoves. Stoves with built-in sources of electric power (e.g., electricity-generating stoves or stoves powered by external power sources, such as solar panels) have several potential advantages. First and foremost, they enable the fan functionality essential to reaching the very low emissions levels of the best-performing gasifier stoves. They improve the economic value to the end user by allowing for phone charging (which can cost more than US$0.25 per charge in many African markets), and potentially saving household lighting expenditures on inefficient and expensive fuels, such as kerosene, by powering light-emitting diode (LED) lights, as in the case of the new ACE-1 Ultra-Clean Biomass Cookstove.[1]

Furthermore, stoves with an electric power component offer the option of integrating low-cost, stove-use monitors (SUMs) or more sophisticated particle and temperature sensors (PATS) into the stove design. In the case of the BioLite stove, for example, SUMs enable data capture of time-stamped usage metrics that can be tracked over time, including frequency of stove use, duration of use, approximate firepower profiles, and charger usage.[ii] The use of more complex built-in particle sensors (US$12–20) can further allow the monitoring of a stove's emission signatures in real time.[3]

The presence of a stove power source—in a functionality that has not yet been tapped—also creates the potential for integrating clean biomass cookstoves into remote-controlled utility business models. For example, this could involve embedding a low-cost mobile chip (i.e., Global System for Mobile Communications [GSM] module) into a stove, allowing for remote stove activation or deactivation. In combination with SUMs, GSM chip functionality theoretically allows for instantaneous remote data collection on millions of stove users—a boon for any large-scale stove carbon-finance program where stove-use monitoring is a requirement—the possibility of much deeper insights into consumer behavior, and potentially a tool for stove entrepreneurs to help adjust their strategy and tactics to maximize clean stove adoption.

Within the general trend of biomass stoves with electric functionality, the most exciting development is the introduction of TEG technology, illustrated in greater detail in Figure 49. TEG stoves eliminate the need for replaceable batteries or such alternative stove power sources as solar panels. In Africa, the technology is currently only available in BioLite stoves, but the lineup of such products is expected to grow. Already, "generic," lower-quality TEG fan-gasifier stoves are available from Chinese manufacturers, and a number of BioLite's Africa-focused competitors have explored TEG functionality, though the ability of branded manufacturers to release new TEG products is constrained, given some of the patent protections regarding TEG use in stoves.[187] Other important developments for electric fan-assisted stoves beyond TEG include the introduction of stoves with long-lived batteries and alternative charging options, such as solar panels (e.g., the ACE-1 stove), which allow for a broader array of functionality, such as using the stove as a device to power household lights; and the inclusion of GSM chips that allow for remote stove activation and monitoring.

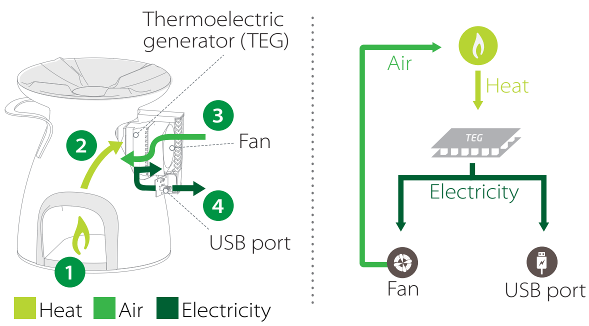
Several entrepreneurs are also exploring the potential of retrofitting existing African cookstoves (traditional or ICS) with TEG units to tap into the potential economic benefits (e.g., phone charging) of TEG functionality.[188] In 2014, BioLite introduced a new product in the market with such functionality called the KettleCharge; using TEG principles, this product is an electricity-generating kettle that draws power from a variety of heat sources, such as open fires and stoves, to produce 10 watts of power.

From a business model perspective, the most important innovation in the improved and clean biomass cooking sector is the emergence of integrated fuel/stove project designs. Developed by such companies as Inyenyeri in Rwanda, Emerging Cooking Solutions in Zambia, the African Briquet Factory in Ethiopia, Awamu in Uganda, and Greentech in The Gambia, this model has the potential to dramatically improve both manufacturer and end-user economics, while achieving high levels of health and environmental benefits.

Figure 49: TEG technology—BioLite example

Operating process

BioLite HomeStove
Behind the design



Operating process

1. Wood, pellets, or other biomass are burned as fuels
2. Excess heat is converted into electricity by the TEG
3. Electricity is used to power a fan, which oxygenates the fire and increases burning efficiency
4. Excess electricity is used to power the stove-use monitor and can be used to charge mobile phones or LED lights

Overview

- Fan-gasifier stoves generate secondary draft of air through an internal fan, which force feeds additional oxygen onto the flame, eliminating smoke, and leading to the near-complete combustion of the fuel
- Thermoelectric-powered rocket stoves do not require an external power source because they use a TEG to convert heat from the fire into electricity
- TEG technology enables the stove both to autonomously power an internal fan and to generate surplus electricity to charge mobile phones, LED lights, and potentially other devices (e.g., stove-use monitors, GSM chips)

Pros/Cons

+ Reduces fuel consumption by more than 50% compared with open fire, and also cuts emissions by up to 95%
+ Charges electronic devices, such as mobile phones and LED lights in under- or unelectrified regions
+ Allows for more precise remote stove-use and performance monitoring, and creates potential for remote activation and pay-as-you-go functionality
- Fans/electronic components increase price
- Components like TEG may reduce durability over the long term, though their track record to date is very strong
- Large amount of time taken to charge electrical appliances without additional power sources (e.g., solar panels)

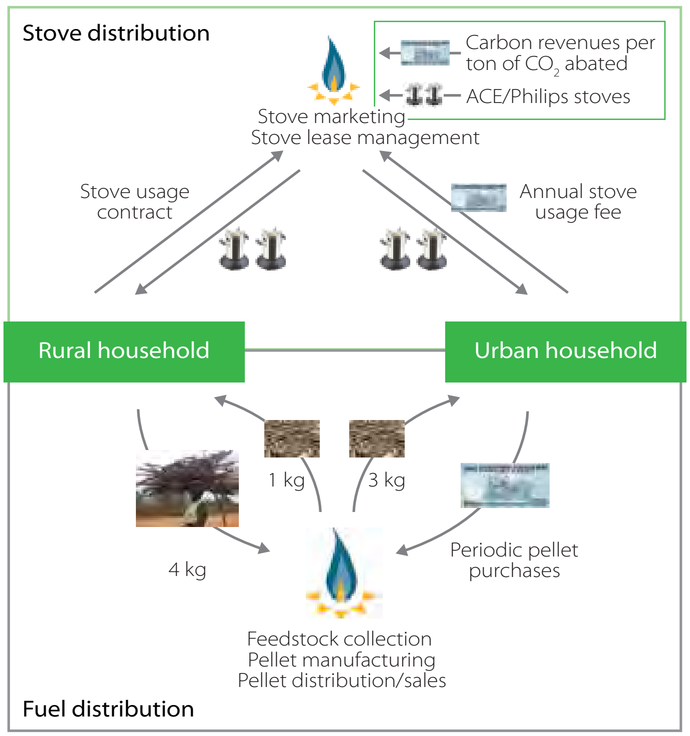
Sources: Press searches; interviews; Dahlberg analysis. Graphic courtesy of BioLite.

Inyenyeri, for instance (Figure 50), operates more like a cooking-fuel utility company than a typical cookstove distribution venture. The company distributes high-performance Philips fan-gasifier ACS (US$70 wholesale price) to urban and rural households in Rwanda. The vast bulk of revenues comes from the sale of densified (compressed) biomass fuel pellets to urban customers, with stove-leasing fees (US$7 per stove annually in urban areas) and carbon credits contributing to a lesser degree. All household customers are offered a fuel-supply and stove-lease contract, in which Inyenyeri retains ownership of the stoves and is obligated to train the customer how to use them with fuel pellets. The company absorbs all future repair and maintenance costs, thus eliminating risks that might otherwise inhibit adoption.

Rural households opt to sign a version of the contract, whereby they bring clean, dry biomass to regional "collection hubs" in exchange for a no-cost lease of stoves and fuel pellet supply, thus working for the clean benefits that they receive.[190] Training in the use of a fan-gasifier stove with pellets is an intensive process—particularly as it pertains to how to use several stoves in a household to eliminate the charcoal fuel and charcoal *jiko*-type stoves that are common in urban Rwanda. Thus, it is essential to recreate the retail distribution ubiquity of charcoal down to the neighborhood street level and even into evening hours, as customers must be able to purchase pellets quickly to match the convenience of charcoal. Inyenyeri operates its own retail shops, which also serve as training sites. However, these are too few and are spaced too far apart to meet customer needs, so pellet distribution is expanding to include charcoal vendors, small shops, and umbrella street vendors working on a commission basis.

The Inyenyeri model, which is now being replicated in different variations by half a dozen businesses across Africa and Asia, simultaneously addresses a number of problems. These include high upfront stove costs and liquidity constraints for the poor; lack of willingness to pay and experience with new technologies; household tendency to combine old cooking solutions with new ones (the Inyenyeri model distributes 2–3 stoves per

Figure 50: Integrated fuel/stove model—the Inyenyeri example



Key features of the Inyenyeri model

- Inyenyeri markets and distributes Philips/ACE HD4012 gasifier stoves (two per household) to displace harmful baseline cooking technologies
- Rural households receive clean stoves for free in return for a contractual obligation to provide an ongoing supply of biomass feedstock, equivalent to amount they typically collect
- Urban households receive stoves in return for a low annual usage fee (e.g., US$6–7 per stove) and an obligation to use Inyenyeri pellet fuel
- Rural households deliver feedstock periodically to a network of rural hubs/collection centers where the fuel is pelletized using large-scale off-grid (self-powered) pelletizing plants
- Rural households obtain free processed pellets from collection centers upon delivery of feedstock; urban households purchase pellet fuels from urban stores
- Inyenyeri continuously monitors stove uptake, stove quality, and fuel usage, offering stove repairs/replacements when issues arise
- Inyenyeri receives supplementary carbon revenues for CO_2 abatement that are used as working capital for scale-up

household from the very beginning and, potentially, a multi-burner biomass gasifier stove in the future; and—via focus on the lucrative urban charcoal markets—lack of commercial sustainability. Perhaps the most noteworthy aspect of such business models is that the gross profit from pellet sales can pay for the capital cost of two or even three high-cost, high-performance stoves per household in 1–1.5 years.

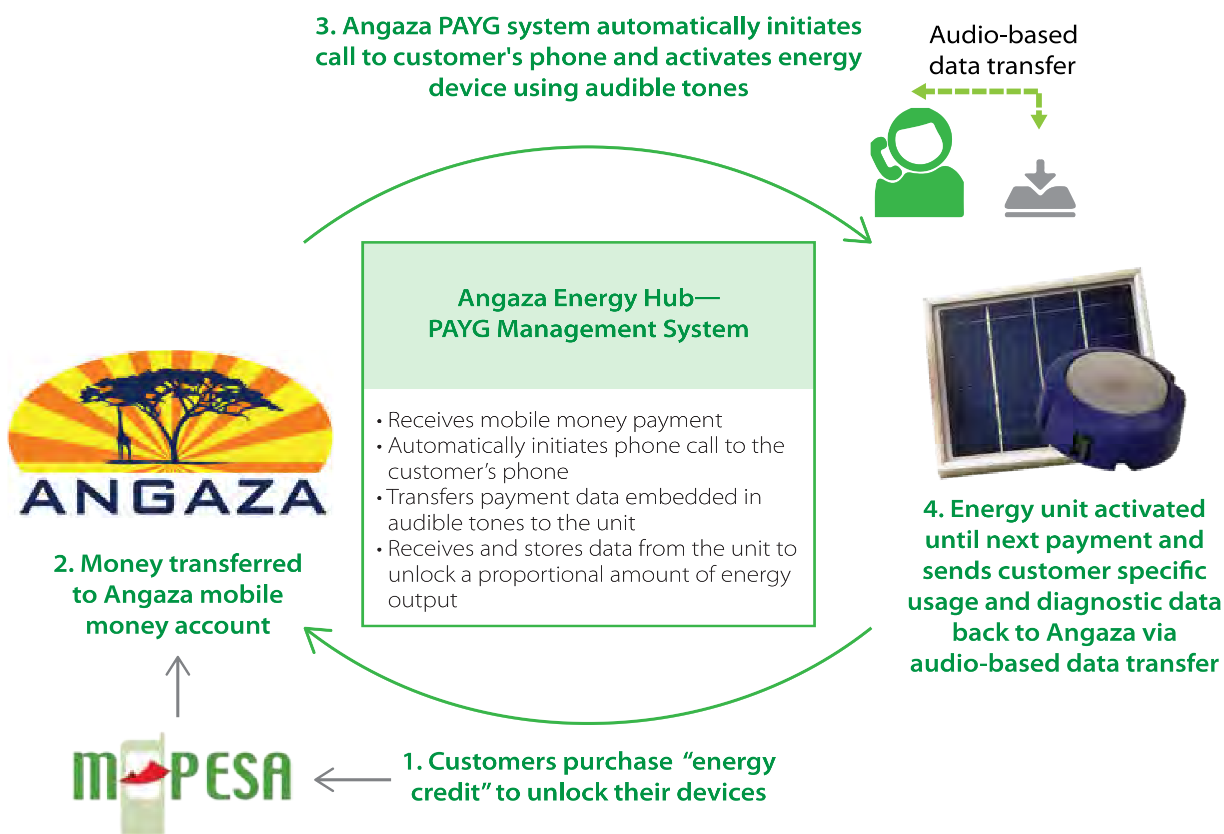
Another new development that is further out on the horizon is the potential to apply mobile pay-as-you-go models to cookstoves, including remote stove activation and monitoring. The major challenge of traditional pay-as-you-go models, particularly for stove businesses that have less proximity to the end customer, involves the transaction costs of extending credit to and collecting payments from end users. Although the market for TEG-enabled or battery-powered fan stoves is still embryonic, the rise of stove technologies with autonomous electric power sources (such as the BioLite and the new ACE 1 Ultra-Clean Biomass Cookstove) creates the possibility for mobile solutions to address the transaction cost issue and, at least theoretically, to launch cooking utility businesses.

While the potential for success for such models is highly speculative, it is becoming clear that the mobile activation, monitoring, and payment technologies that are currently being applied to such off-grid BoP appliances as solar home systems could soon be piloted for cookstoves. The core idea of such concepts is to use mobile payments and remote appliance monitoring to manage long-term leasing or utility arrangements. Upon receipt of payment from the end user, the off-grid appliance can be activated for a discrete period of time (e.g., a week of cooking), at which point a new payment is required to avoid disactivation.

One option for bringing such models to life—leveraging the technology of information and communications technology (ICT)-enabled energy-access companies, such as mKopa and Mobisol—could involve embedding a GSM module into a stove or a linked stove-activation controller. The stove utility manager could track the periodic mobile payments for stove use and enable the system to be locked remotely in case of overdue accounts—thus decreasing the risk of payment default. Another approach is to link the stove to an off-grid activation controller that lacks GSM capability, but can be activated through pre-set activation codes.

One example of such an approach from the solar lighting sector is Angaza Design's Energy Hub system. After depositing funds into Angaza's mobile money account, the end user receives a phone call from the automated energy hub system. Customers holds their phone near the Angaza activation unit in their home, allowing for audio-based transfer of data to the unit (to trigger activation) and audio-based transfer of usage and diagnostic data from the unit back to Angaza (Figure 51).

Figure 51: Mobile-enabled, off-grid model for an energy utility—the Angaza example



Features of Angaza's Pay-As-You-Go Model

- *Low cost (US$2)*
- *Fits customer's cash flow*
- *Recurring revenue*
- *Bi-directional communication: usage and diagnostic data are sent back to Angaza*

Note: PAYG = pay as you go.
Source: Angaza Design (2014).

The low cost of the Angaza household unit (US$2) suggests that this approach could be piloted in the cookstoves context as long as the stove has an autonomous power source, such as the TEG on such stoves as the BioLite. Aside from enabling pay-as-you-go models, the two-way flow of information in such systems as Mobisol, MKopa, and Angaza allows for usage tracking that helps companies with after-sales maintenance support, ongoing product improvement, and—important for the cookstove context—remote usage data capture for monitoring carbon finance compliance.

Clean and Improved Cooking Distribution Models

Market players use diverse distribution models, with no single channel offering the "key" to all SSA consumers, given the diversity of the market. SSA cookstove market players pursue a variety of distribution models, ranging from direct sales to third-party dealer-distributor networks, micro-franchise models, and institutional sales strategies (Figure 52).

Figure 52: Emerging distribution channels for clean cookstoves

Direct sales	3rd-party private dealer-distributors and retailers	Social sector partners	Institutional bulk sales	Carbon project developers
Sell direct to consumer via sales staff, branded commission-based agents, or proprietary store network	Sell to third-party (e.g., fast-moving consumer goods) distributor networks or direct to dealers and retailers (large or small format)	Run sales and order fulfillment via microfinance institution (MFI)/ NGO workforces, government extension agents, or social micro-franchise networks (e.g., Living Goods)	Bulk purchases and redistribution by institutional clients, such as relief agencies, schools, and government programs	Wholesale distribution via carbon project developers who have access to proprietary sales forces or third-party distribution relationships

Sources: Press searches; interviews; Dalberg analysis.

The vast majority of ICS have been distributed either via direct sales to consumers—a highly effective but resource-intensive option—or via third-party dealer distributor networks. Micro-franchising pilots are generally at an early stage. Institutional sales and social-sector partnership channels (i.e., distribution via partner NGOs) have likewise seen smaller volumes to date, but are an important channel for accessing the lowest-income and most excluded segments of the rural population. Given the complexity and fragmentation of the SSA market, many successful players tend to work across multiple sales channels or—if they have the local presence, relationships, and know-how—focus their energy on building out their own direct distribution strategies.

Direct models are the preferred options for local semi-industrial and artisanal manufacturers that are closely integrated with their customers and are able to break down behavioral WTP barriers through intensive engagement. Toyola Energy in Ghana is a perfect example of this model. The Toyola sales staff provides stoves on credit to consumers and gives them time to learn about the technology, thereby reducing potential adoption barriers. The PERACOD project in Senegal similarly markets stoves to consumers via the *bëccëk* daily installment sales system, stretching out a typical charcoal stove payment over a period of 12 days.

The direct model is also pursued by large carbon project developers, such as UpEnergy and the Paradigm Project. These players have realized that reaching the last mile is a highly thought-out capability that international manufacturers are neither able nor willing to invest in sufficiently, even once the carbon-financing streams are secured. As a result, these players have deployed their own door-to-door sales forces (e.g., the Avon model) in order to drive stove adoption.

Large industrial players, on the other hand, prefer indirect distribution models. They will typically distribute either through the existing infrastructure of ongoing carbon projects with their own distribution channels, or through other third-party distributors that can provide rapid access to the market (though at the cost of heavy markups).

To date, the majority of stoves, and in particular artisanal stoves, are sold and distributed through direct channels (Figure 53), an approximate analysis in the absence of robust Africa-wide sales data. Manufacturer data available to the report team suggest, however, that products from industrial manufacturers are being channeled primarily through third-party dealer/distributor networks, which account for 50-90% of Africa sales for most players in this segment.

Figure 53: Overview of Africa cookstove distribution models

Distribution models	Sales share	Pros	Cons
Direct sales channels	<80%	• Offers a great deal of control to the producer	• Costly without scale, which is difficult to achieve in large rural markets
Third-party dealer-distributor networks	<10%	• Leverages existing warehousing and salesforce of an established partner • Convenient and low-cost	• Producers have minimal control and must compete with others in the same channel • Limited by partners' reach, which may not include remote or rural areas
Micro-franchise networks	<1%	• Leverages on-the-ground networks of franchisees who are likely familiar with local market	• Producers lose some control • Franchisees' sustainability unlikely with just cookstove sales; needs to be part of a broader scheme to add sufficient value to franchise owners/micro-entrepreneurs
Social-sector partners	<5%	• Leverages NGOs (MFIs) to couple access to finance with strong reach into an existing customer base	• NGO may not be planning for scale and sustainability once program ends • Lack of sales skills in NGO staff • NGOs unwilling to take on reputational risks by associating themselves with experimental products
Institutional sales	<5%	• Ease of sale for producer in large quantities	• Producers have minimal control • Institutions do not have the reach for fast scale-up that stove entrepreneurs aspire to • Long and expensive sell cycles for most cookstove enterprises to engage with institutional buyers

Note: Includes semi-industrial and artisanal stove; distribution mix for industrial stoves skews heavily to third-party distribution.
Sources: Press searches; interviews; Dalberg analysis.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THE ENABLING ENVIRONMENT

chapter 4

THE ENABLING ENVIRONMENT

Having reviewed the supply and demand landscape for improved and clean stoves and fuels in SSA, we now turn to a review of the "enabling environment"—the ecosystem of institutions and policy initiatives, including funding, surrounding the sector.

Overview of the Cooking Ecosystem in Sub-Saharan Africa

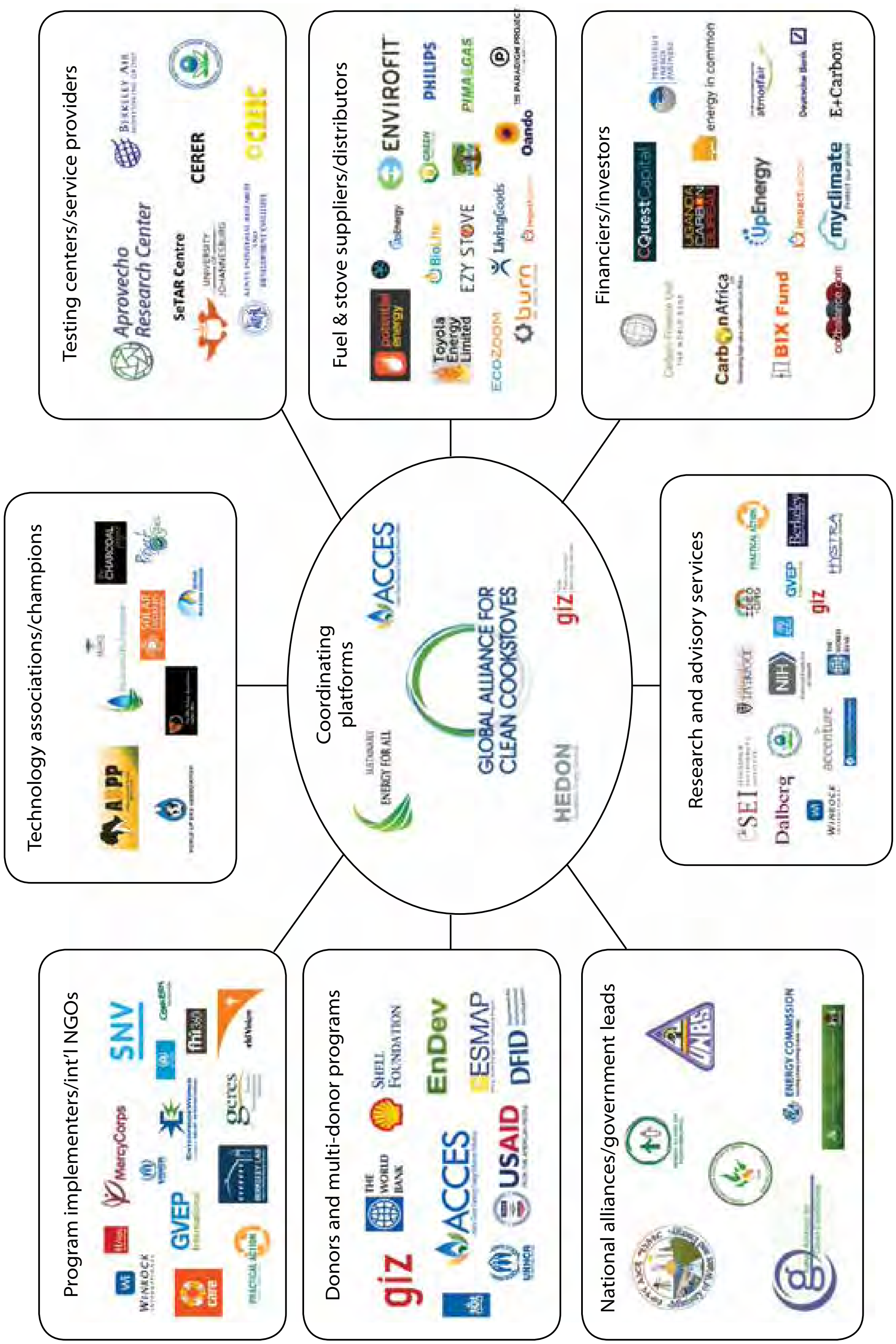
The enabling ecosystem for clean and improved cooking solutions is evolving rapidly. The clean and improved cooking sector in SSA is a complex ecosystem in which hundreds of institutional and private-sector players focus on different, often overlapping market niches and interventions. Figure 54 illustrates the range of sector participants, with a focus on region-wide or subregional examples, but is not meant to be exhaustive.[191]

From a sector coordination standpoint, **coordinating platforms and advocacy initiatives** have contributed to improved sector transparency; increased collaboration across donors, governments, and the private sector; and the continued mobilization of funds and raising of global awareness for clean and improved cooking solutions. These initiatives include the Global Alliance for Clean Cookstoves (GACC) and associated subregional and country-level clean cooking associations (e.g., in Ghana, Kenya, and Nigeria); the United Nations' (UN's) Sustainable Energy for All (SE4All); the World Bank's Africa Clean Cooking Energy Solutions (ACCES) initiative; new knowledge networks, such as HEDON; and specific technology and fuel champions with an Africa-wide mandate, such as the Global LPG Partnership, the Africa Biogas Partnership Programme (ABPP), and Project Gaia.

Funding for cooking initiatives and interventions in SSA is growing steadily, with the most active region-wide donors being the governments of Germany, the Netherlands, the United Kingdom, and the United States via a range of programs and funding vehicles. Among multilateral institutions, the World Bank is the primary funder via ACCES, the Biomass Energy Initiative for Africa (BEIA), the Energy Sector Management Assistance Program (ESMAP) multi-donor trust, and a number of sector-lending operations with dedicated biomass energy and/or cookstove components. Drawing on funding from these donors and others, the most **prominent international NGOs and implementation agencies** in the Africa cooking sector include EnDev, the Global Villages Energy Partnership (Clough 2012), Mercy Corps, SNV, World Vision, Practical Action, EnterpriseWorks, and such UN implementing agencies as UNDP and UNHCR.

Having significantly scaled up their capacity in the past 1–2 years with the help of the GACC and other donors, **stove-testing centers** have become important players in the regional ecosystem and are active in Ghana, Kenya, Nigeria, Senegal, South Africa, and Uganda. **Providers of wholesale finance** are also a dynamic subsector, with increasing numbers of impact investors and, most notably, carbon finance project developers emerging over the past 2–3 years. Finally, a growing number of **research and advisory institutions** are regularly contributing to Africa cooking-sector knowledge development. The most important, aside from the GACC, are the World Bank; GiZ; United States Agency for International Development (USAID);[192] NGOs, such as GVEP, SNV, MercyCorps, and Practical Action; health researchers across several institutions globally, typically funded by the U.S. National Institutes of Health;[193] and independent research organizations, most prominently the Stockholm Environment Institute (SEI).

Figure 54: Overview of the SSA landscape for clean and improved cooking stakeholders



Note: List is not exhaustive, but is meant to illustrate the biggest and most active cooking-sector stakeholders across the SSA region.

AFRICA CLEAN COOKING ENERGY SOLUTIONS INITIATIVE

The objective of the Africa Clean Cooking Energy Solutions (ACCES) initiative is to promote the enterprise-driven, large-scale adoption of clean cooking solutions throughout SSA, with the goal to reduce poverty, health-related risks, and adverse environmental impacts associated with traditional cooking technologies and practices.

ACCES was established through a consultative approach to identify the main barriers that impede market-based development of the clean cooking sector in SSA. It builds on experiences and lessons learned from donor, government, public, and private investments in clean cooking solutions; the World Bank's own operations; as well as the Lighting Africa off-grid lighting market-transformation program. ACCES supports World Bank project design and implementation by leveraging funding from project operations and by providing its own technical support in order to maximize the impact of clean cooking activities. It has designed a set of tools and mainstreaming approaches that reflect varying country priorities and sector policies to help build momentum and economies of scale needed for market transformation. It operates using the following three main lines of support:

"Delivering Products"—facilitating the creation of catalytic linkages between industry leaders and distributors

The implementation of country programs will include supporting commercial distribution models that are more likely to rapidly achieve economies of scale, strengthen the sustainability of the sector, and support the market-based approach of the initiative. Support will include:

- Facilitation of manufacturer-distribution partnerships.
- Design of distribution roadmaps and national rollout plans for cleaner stoves and fuels.
- Design of "challenge funds" and incentive packages for development, implementation, and scale-up of distribution models.

"Managing Quality"—establishing a comprehensive quality assurance and technical support (QA&TS) system

The regional QA&TS program helps provide a level playing field for market competition and more coherent support aligned with ongoing global efforts for developing ISO standards and testing capacity in the sector in order to enhance product information and consumer confidence in quality products. To help steer clean cooking markets in ACCES countries toward higher-quality products that present a strong value proposition to consumers, the ACCES initiative has developed:

- Baseline assessments of performance for the most prominent cooking technologies in its target countries.
- Definition of quality and tools for assessing the adequacy of quality control measures for stove manufacturers, distributors, and testing centers.
- Minimum performance thresholds for stove quality that vary in their level of ambition according to national and/or sectoral priorities and policy agendas, with the goal of supporting progressively higher-performing technologies over time.
- Technical support to manufacturers for improving quality and performance.

"Activating Customers"—engaging consumers through targeted commercial marketing and promotion campaigns

This line of support will include a differentiated and narrowly targeted approach to enhancing consumer awareness through below-the-line marketing efforts for key consumer segments, as well as broader information campaigns, depending on country context. More specifically, support in this area may include:

- Improving field-based evidence of adoption though country-specific reviews of consumer engagement efforts, identification of best practices, and key socioeconomic and contextual drivers.
- Design of country-specific communication action plans and roll-out of high-impact marketing campaigns.
- Development and field testing of sales-promotion and consumer-finance schemes.

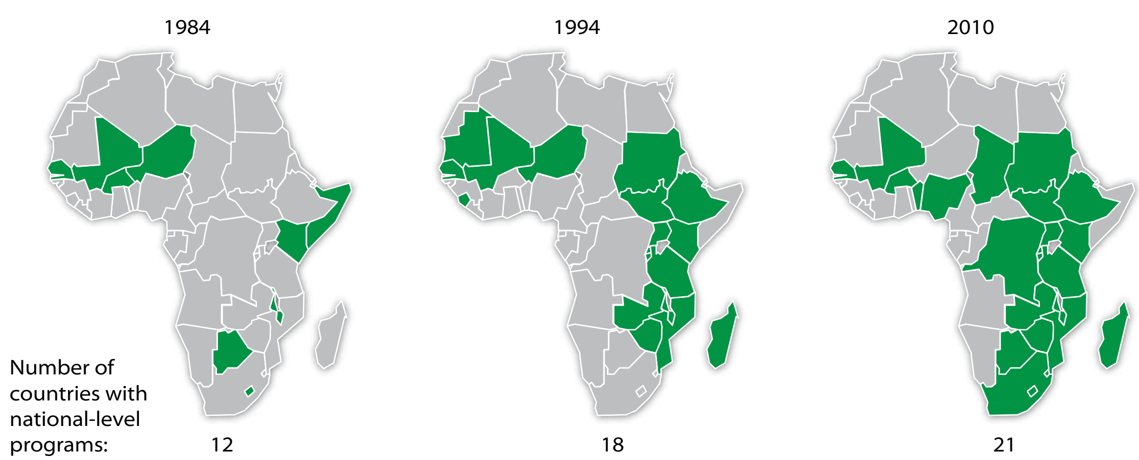
Source: World Bank ACCES team.

Beyond the growing number and sophistication of regional cooking-sector stakeholders, various cross-cutting developments are trying to address systemic supply-side gaps. These developments include increasing industry convergence on ICS quality with the establishment of provisional IWA 11:2012 standards for ICS performance tiers and progress toward the adoption of ISO standards based on these guidelines;[194] the evolution of new cookstove monitoring and performance-measurement techniques, such as growing use of SUMs to assess household-level performance;[195] and the broader adoption of experimental and quasi-experimental techniques to assess stove impact and refine distribution and marketing approaches. On the policy side, there is increased government focus on regulating biomass fuel production[196] and some movement on regulatory barriers, such as cookstove taxes and tariffs.[197] Better market intelligence resulting from new investments in consumer and market research is also an important cross-cutting development.[198]

National Programs

Another important cross-cutting trend is the continued growth of national programs promoting clean and improved cooking solutions across the region. The number of country-level African cookstove programs has grown significantly over the past few decades (Figure 55). Since 2010, half a dozen new programs have been launched with the impetus of the GACC and new efforts by leading cooking-sector donors, such as EnDev and the World Bank.

Figure 55: Overview of SSA clean and improved national cookstove programs



Sources: Giffords (2010); Dalberg analysis.

African countries with large active national-level programs currently include Burkina Faso, Ethiopia, Malawi, Nigeria, Rwanda, Senegal, and Uganda. Some of these programs are in fact supranational, with international donors supporting a range of large-scale cookstove interventions across the continent. Older national cookstove programs in countries, such as Kenya and Tanzania, and regional programs, such as GIZ's ProBEC, have already generated significant impacts and have often transitioned into market-based initiatives or have been handed off to NGOs and industry associations. Figure 56 provides an overview of the most active national programs; Figure 57 reviews the major regional and subregional programs, such as ACCES, EnDev, ProBEC, and the West African Clean Cooking Alliance (WACCA).

Figure 56: Overview of SSA clean and improved national cookstove programs

Country	Status/target	Lead organizations	Key program features
Ethiopia	**25% penetration (>3 million ICS in use)** in 2013, primarily Mirt *injera* stoves and lakech charcoal stoves; few high-efficiency wood stoves; 3.4% modern-fuel penetration Target: **9 million ICS in use by 2015** reaching 4.5 million rural households **(~35% penetration), 31 million ICS (100% penetration) by 2030**	The Ministry of Water and Energy Alternative Energy Technology Promotion and Distribution Directorate (AETPD) is the lead agency across all public- and NGO-sector entities; earlier rounds of efforts were led by the Ministry of Water and Energy, Rural Energy Technology Centers, and Ministry of Agriculture, with extensive GIZ support	• Primary objective of current program (2012–15) is environmental impact (i.e., reduced forest degradation and GHG emissions) through the distribution of fuel-efficient wood stoves (both basic ICS and intermediate ICS) with a focus on rural areas; secondary objectives include job growth, public health, and rural development. • Program is core part of Ethiopia's long-term Climate-Resilient Green Economy strategy and builds on earlier phases of the national program (2005–11), which focused on the creation of sustainable, efficient stove markets in urban and peri-urban areas. • Current program components include capacity building for government institutions at all levels; a productivity improvement program for stove producers with financing and technical assistance; and a stove promotion and distribution effort that involves stove subsidies for end users (up to 20%), stove distribution with the help of public health and agriculture extension agents, and awareness-raising campaigns.
Rwanda	**>50%** basic ICS penetration for wood and charcoal uses in 2013; **0.3%** modern-fuel penetration Target: 600,000 rocket ICS in rural areas by 2015 (**30%** penetration); the national strategy targets **100%** ICS penetration by 2018	The Energy, Water and Sanitation Authority (EWSA) is the lead on government cookstove program implementation, the Rwanda Environment Management Authority (REMA) is the lead on clean development mechanism (CDM) projects, and the Ministry of Health is the lead on the Del Agua/EcoZoom project	• The Ministry of Health and Del Agua have reached an agreement with EcoZoom to distribute 600,000 wood rocket stoves (EcoZoom Dura) to poor rural Rwandans by 2015; the primary focus of the effort is on health, which is unique in an SSA national program context; the program is not market based (i.e., stoves are distributed to consumers free of cost). • Government efforts on market promotion, under EWSA leadership, are encouraging the adoption of basic wood ICS in rural areas and basic charcoal ICS in urban areas, with the most recent campaigns in 2010–12; continuing SNV/ EWSA partnership to promote Canamake and Canarumwe stoves; REMA is developing several stove CDM projects for Rwanda; the Rwanda National Climate and Environment Fund is likely to be a key future player on R&D funding.
Nigeria	**<0.2%** biomass ICS penetration, not counting unimproved chimney stoves; **28%** modern-fuel penetration in 2013 (~2% without kerosene); 0.1% ethanol stoves Target: 10 million ICS households by 2020 (i.e., **25%** penetration)	Nigerian Alliance for Clean Cookstoves (NACC)/International Centre for Energy, Environment, and Development (ICEED) is serving as the lead organization for the Nigeria Cookstove Program (NCP), with the support of the Federal Ministry	• Nigeria's NCP, launched in 2014, will apply a market-based approach to encourage state and nonstate actors to build on the achievements of the National Clean Cookstoves Scheme and other government initiatives to promote clean cooking in Nigeria. • Fuel interventions focus on clean fuels (LPG and ethanol) and green charcoal; the biomass ICS effort is heavily focused on enabling rocket wood stove promotion (e.g., Save80, Envirofit).

Country	Status/target	Lead organizations	Key program features
		of Environment and Nigerian Investment Advisory Facility	• Key program components include certification for quality cookstoves from ICEED, promotional and awareness campaigns to drive adoption, operational subsidy system to stimulate stove replacement, verification processes for monitoring and evaluation, and support for local stove producers (technical and financial).
Malawi	**<2%** ICS penetration, not including legacy stoves; **1.6%** modern-fuel penetration Target: 2 million ICS and clean stove households by 2020 (i.e., **50%** penetration)	The Ministry of Environment and Ministry of Energy (co-chairs), Concern International (secretariat to the National Cookstoves Taskforce), and EnDev	• The National Cookstoves taskforce is a public–private partnership entity launched in early 2013 to build on activities from 2005 to 2008. • Objectives include conducting a national cookstoves market assessment, developing a national adoption strategy, preparing a national communications/consumer education strategy, providing producer commercialization support, promulgating national standards and standards monitoring mechanisms, and scaling up current cookstove and carbon credit activities.
Uganda	**~10%** biomass ICS penetration by 2013, evenly split between urban basic charcoal ICS and intermediate wood ICS (Rocket Lorena, Envirofit); small ACS segment; **2.1%** modern-fuel penetration (1.1% kerosene, 0.6% LPG 0.6%) in 2011 Target: 5 million households by 2020 (**55%** penetration) with "clean and efficient" cookstoves	Uganda National Alliance for Clean Cookstoves (UNACC), working in coordination with the Ministry of Energy and Mineral Development (lead government agency); most active donors and NGOs include GiZ, World Bank, EnDev, International Lifeline Fund (ILF), and Global Villages Energy Partnership (GVEP)	• Starting in 2014, the newly established UNACC is the nonprofit national coordinating partner and implementation agency with the mandate of establishing an enabling environment for equitable universal access to clean cooking solutions in Uganda by facilitating increased innovation in design, testing, production, marketing, and use of clean cookstoves and fuels; government policies and increasing public awareness; downstream and upstream access to finance; and producer and distributor technical capacity. • Key older programs include the Renewable Energy and Energy Efficiency Programme (PREEEP) (2007–14), implemented by GiZ with the objectives of increasing access to improved biomass energy technologies through the dissemination of household mud stoves, capacity building to private stove companies, and promotion of sustainable charcoal production; EnDev Uganda (2008–14), a multi-donor program to promote basic ICS and rocket ICS (Rocket Lorena) stove production and distribution and seen as a major success; GVEP's Developing Energy Enterprises Program (DEEP) (2008–13), which focused on capacity building and market creation for artisanal biomass stove and fuel producers; Biomass Energy Initiative Africa (BEIA), a World Bank-funded project focused on market research and innovation efforts, such as the piloting of a locally manufactured TLUD gasifier.

Country	Status/target	Lead organizations	Key program features
Senegal	**<280,000** basic charcoal and wood ICS, **20,000** intermediate ICS in 2011, for total ICS penetration of **~30%**; **33%** modern-fuel penetration in 2011; cumulative penetration likely **<50%** due to duplication (i.e., >50% of urban ICS households are primary LPG users) Target: **450,000** ICS target under PROGEDE; **130,000–150,000** ICS households target by 2016 for PERACOD/FASEN; cumulative penetration target is **60–70%** clean and improved stove penetration	The Ministry of Energy and Mines Is the lead government agency for all clean and improved cooking solution efforts; the Ministry is the implementation partner for PROGEDE and is actively involved in the PERACOD/FASEN effort	• PERACOD, a program for the promotion of sustainable energy, rural electrification, and sustainable supply of household fuels, is funded by BMZ and led by GIZ under the supervision of the Senegalese Ministry of Energy. It started in 2004 and is due to end in 2015. Its objective is to contribute to a lasting improvement in access to rural energy services, with a focus on renewable energy (such as home solar systems) and sustainable household fuel supply. - More than 100,000 stoves in use by households by 2013 due to PROGEDE and an additional target of 25,000–30,000 stoves to be distributed by 2015 with funding from ProCEAO (Programme pour l'Energie de Cuisson Economique en Afrique de l'Ouest). - Initial focus on urban and peri-urban markets; more recently reoriented to rural Senegal. - Mid-term review in 2009–10 showed significant overlap between owners of PROGEDE ICS and LPG users, reducing the relative impact of PROGEDE on health and environment outcomes. • One of PROGEDE's objectives is to increase the availability of diversified household fuels and stoves through community-based approaches. The program's primary focus has been the creation of a sustainable charcoal cooking market in Senegal. PROGEDE is implemented by the Senegalese government (first phase 1999–2008) with funding from the International Development Association (World Bank), the Netherlands' Directorate-General for International Cooperation, and the Global Environment Fund. Its second phase (2010–16) is being funded by the World Bank and the Nordic Development Fund. PROGEDE seeks to modernize the household cooking fuels and cookstove markets through the differentiation of a range of fuels, improvement of the supply chains, and support for appropriate energy regulations.

Note: PROGEDE = the World Bank's Sustainable and Participatory Energy Management Project.

Sources: Press searches; GACC market assessment reports; Ethiopia Fuelwood-Efficient Stoves Investment Plan: 2012–2015 (2012), Project Document for National Clean Cookstoves Programme for Nigeria (2013); Malawi National Clean Cookstoves Taskforce launch documentation (2013); Dalberg analysis.

Figure 57: Large regional cookstove programs in Africa

Agency—program	**Overview**	**Geographic focus**	**Focus within the clean cooking sector**	**Funding source**	**Africa results/ targets**
World Bank (WB) Africa Clean Cooking Energy Solutions (ACCES) (2012—ongoing)	The World Bank's ACCES initiative promotes the enterprise-driven, large-scale adoption of clean cooking solutions throughout SSA	Sub-Saharan Africa	• Market intelligence • Creation of catalytic linkages between industry leaders and distributor • Targeted efforts to engage consumers in key segments • Establishment of a regional QA and technical support system	Technical support funded by the Africa Renewable Energy Access Program and implementation funding leveraged through the World Bank's energy investment projects in select countries	Status: Working in several WB country projects by providing support through analytical pieces, project design, increased lending/grants, and setting up implementation arrangements; upon successful completion of projects, looking to scale across the regions
Global Alliance for Clean Cookstoves (GACC)	GACC is the leading global platform for clean cooking energy promotion with regional Africa activities	SSA focus countries in Phase 1: Ghana, Kenya, Nigeria, Uganda	• Market intelligence in focus countries and additional geographies (e.g., Ethiopia, Rwanda, South Africa, Tanzania) • Set-up of national alliances to coordinate local agenda • Targeted investments and market development activities	Range of donors	Status: Local clean cooking alliances established in key geographies; market development activities launched Target: 100 million households globally with clean cooking by 2020; >20 million from Africa
Energizing Development Program (EnDev) (2005–19)	EnDev seeks to support energy-business entrepreneurs with knowledge transfer, technical assistance, and capacity building	Benin, Burkina Faso, Burundi, Ethiopia, Ghana, Kenya, Mozambique, Rwanda, Senegal, Uganda	• Conducting baseline surveys for technology adaptation; training producers; quality control and stove marketing • In Africa, EnDev is promoting only non-subsidized stoves, hence targeting sustainable markets	Funded by the Dutch and German governments, European Union (EU), and Irish Aid; since 2011 also funded by the Norwegian government	Status: 1.3 million in Africa (out of 3 million EnDev stoves in use globally by end of 2011); >1.5 million African households reached by 2014

Agency—program	Overview	Geographic focus	Focus within the clean cooking sector	Funding source	Africa results/ targets
West African Clean Cooking Alliance (WACCA) (2012—ongoing)	WACCA, under leadership of the ECOWAS Centre for Clean and Renewable Energy and Energy Efficiency, aims to provide access to efficient, sustainable, and affordable cooking energy; implemented with ETC-ENERGIA, GACC, Africa Energy Agency, GERES, GIZ, and ICEED	Member of the Economic Community of West African States (ECOWAS)	• Promotes the implementation of regional policies on clean cooking • Capacity building for clean cooking initiatives • Support on harmonizing standards and labeling practices • Promotion of networking and knowledge sharing	ECOWAS	Status: Regional framework development; two national pilots launched Target: Aims to reach 13 million households (20% of households) in the ECOWAS region with clean and efficient cooking energy by 2020
Global LPG Partnership (GLPGP) (2014, ongoing)	GLPGP is a public–private partnership that aims to enable governments, the private sector, and consumers to scale up access to and use of clean-burning LPG for cooking in Africa, Asia, and Latin America	Ghana, Cameroon, Kenya; expansion likely to Nigeria, Tanzania, Uganda	• Joint planning with national stakeholder to plan transition strategies for LPG adoption • Policy advocacy • Investing in infrastructure, SMEs, and consumer finance	KfW, LPG industry	Target: Transition 50 million people in Africa to LPG by 2016–17; transition 1 billion people globally to LPG from cooking with solid fuels by 2030
Africa Biogas Partnership Programme (ABPP) (2009–14; 2014–17)	The ABPP is a partnership between Hivos and SNV supporting national programs on domestic biogas in five African countries, with the aim of sustained construction of domestic biogas plants as a local, sustainable energy source and, ultimately, development of a commercially viable and market-oriented biogas sector	Burkina Faso, Ethiopia, Kenya, Tanzania, Uganda	• Results-based program working with local country partners • Works to build an enabling environment allowing the biogas sector to flourish • Provides training for private companies and local organizations • Engages with local financial institutions • Raises awareness among potential end users	Directorate General for International Cooperation of the Dutch Ministry of Foreign Affairs and SNV (Netherlands development organization)	Status: >40,000 biogas plants installed by 2014 Target: 100,000 target by program completion in 2017

Agency—program	Overview	Geographic focus	Focus within the clean cooking sector	Funding source	Africa results/targets
Biomass Energy Initiative for Africa (BEIA) (2010–15)	BEIA was an effort implemented by the World Bank's Africa Energy Team to test innovative and promising biomass energy initiatives that have the potential to be incorporated into the future WB lending portfolio	Benin, DRC, Ethiopia, The Gambia, Kenya, Rwanda, South Africa, Tanzania, Uganda	• Creating enabling market conditions for high-quality and high-performance modern cooking stoves • Modernizing the charcoal industry • Demonstrating the feasibility of social biofuels • Increasing power capacity with bioelectricity • Building capacity and strengthening leadership in biomass energy	AFREA supported by US$28.75 million from the Netherlands in 2008 under the Energy Sector Management Assistance Program's Clean Energy Investment Framework Multi-donor Trust Fund	Results: Nine pilot projects completed across Africa; five of the nine have secured additional funding from different donors for scale-up activities
Global Village Energy Partnership (GVEP)—Developing Energy Enterprises Program (DEEP) (2008–12)	DEEP was a five-year initiative promoting the development of a sustainable and widespread industry of micro and small cooking energy enterprises in East Africa	Kenya, Tanzania, Uganda	• SME capacity building • Policy engagement • Financing for entrepreneurs • Market linkages	EU and the Dutch Ministry of Foreign Affairs	Results: >400 cookstove/liner enterprises created and supported; >200,000 ICS distributed annually by 2012
United Nations Environment Programme (UNEP)—Africa Rural Energy Enterprise Development (AREED) (2000–8, 2009–12)	UNEP operates in Africa to develop new sustainable energy enterprises that use clean, efficient, and renewable energy technologies; E+Co served as the implementing agency during the first phase of the program	Ghana, Mali, Senegal, Tanzania, Zambia	• AREED provided early- and later-stage financing to peri-urban LPG and rural ICS suppliers • Equity and debt investments were made in higher-risk enterprises; financing often was provided jointly with local and microfinance institutions • Microfinance lending to end users	Funding from UNEP and the Swedish International Development Cooperation Agency in most recent phase of AREED	Results: 24 sustainable rural energy enterprises in place by 2009; >50,000 ICS and LPG households reached; US$7–10 million of financing mobilized

Agency—program	Overview	Geographic focus	Focus within the clean cooking sector	Funding source	Africa results/ targets
Gesellschaft für Internationale Zusammenarbeit] (GIZ)—Programme for Basic Energy and Conservation (ProBEC) (1998–2010)	ProBEC was a decade-long initiative supported by GIZ that ended as a supported program in 2010; some activities have since continued as a Southern African Development Community (SADC) initiative	Botswana, DRC, Lesotho, Malawi, Mozambique, Tanzania, South Africa, Swaziland, Zambia	• Promoted various stove and fuel technologies: wood, charcoal, biofuels, biogas and solar cookers • Trained local producers • Offered policy advisory to improve stakeholder coordination • Monitored sector progress via consumer and producer surveys	The governments of Germany and The Netherlands	Status: 250,000 households using ICS by program completion in 2010

Sources: Press searches; program documentation; interviews; Dalberg analysis.

Despite their increasing number, few national programs in SSA have achieved large-scale stove distribution or created sustainable markets. Among the larger, more successful programs have been those in Ethiopia, Kenya, Senegal, Tanzania, and Uganda. Tanzania's program, led by NGO TaTeDo with initial support from GIZ, distributed an estimated 2 million stoves from 2000 to 2010. As of 2006, national programs in Kenya, Senegal, and Uganda reached approximately 3 million, 200,000, and 80,000 households, respectively. Ethiopia's national program, which is ongoing, has reportedly reached several million households and has been the biggest success at scale to date in increasing basic and intermediate ICS penetration.

While the various SSA national programs vary in terms of national government role, business model, and level of ambition, there are similarities. Most national cookstove programs pursue commercial or hybrid models; very few, like the Rwanda initiative to distribute 600,000 rocket stoves to poor rural end users, are entirely covered by subsidies. The focus of early national programs in Africa has almost exclusively been the environment (deforestation and climate change) and rural livelihoods, but improved health outcomes are increasingly becoming an important focus. Other important trends for the more successful national programs include intensive focus on R&D, increasing attention paid to standards, and diversification from a focus on stove subsidization toward more holistic approaches involving the entire supply chain. Common problems include overreliance on subsidies and inadequate consumer training to complement stove distribution.

Looking across the range of models, approaches, and tools used by the various national and regional cookstove programs, there are a variety of lessons to be drawn. From the experience of both governments and donor agencies, it is apparent that in the early stages of stove promotion programs, subsidization—in some form or another—played an important role. The question of whether subsidies should be provided has been hotly debated in the sector. The experience of various national-level programs shows clearly that, despite the dichotomous "yes or no subsidies" debate by some stakeholders, the impact of a subsidy depends enormously on elements of its design—that is, its mode of provision (direct/indirect), its value (high/low), and the time for which it is provided (full time/phased out). Ultimately, this experience has shown that some degree of subsidization may be required in the early stage of any effort to increase improved stove adoption. However, there are three key caveats: subsidies should be introduced with a very clear phase-out plan and should not be permanent; they should be of the lowest possible value to provide the needed support while not diminishing the value of the product; and they should clearly target the appropriate consumer and product segments—namely, the very poor (and often rural) communities and the high-performance, high-cost stoves where the benefits of use are significant but upfront costs are prohibitive.

A second set of lessons can be learned about the importance of early and sustained consumer engagement across the value chain. African cookstove programs have been most successful where product design has been carefully developed to accommodate user preferences, cooking practices, and behaviors. Conversely, adoption has been difficult where this was not the case, requiring multiple iterations of design and pilot. Particularly important in the design phase is consultation with women: where programs actively engaged women (as the ultimate users and often buyers of the stoves) in the design of the product, adoption has been more successful. Overall, where communities were engaged in the whole process of program design and inception, training, and development of artisans and enterprises, marketing and sales—as well as the crucial stage of feedback and monitoring—programs have had a deeper and more sustained impact.

Finally, crucial to note from the programs outlined in this section is the importance of engaging in the sector with a medium- to long-term time horizon. Most successful national programs take 5–10 years to achieve meaningful scale, with the greatest impact often seen after program completion.

Although scaling up improved cooking solutions in Africa has historically relied heavily on both direct and indirect subsidies, the more market-based approaches have worked best. Modern cooking fuels have had the widest reach in Africa in places where governments have injected significant fuel subsidies into the sector. This includes Angola, Cameroon, Côte d'Ivoire, Ghana, and Senegal in the case of LPG; Nigeria in the case of kerosene; and South Africa, Zambia, and Zimbabwe in the case of electric cooking. While tens of millions of households have gained access to modern cooking energy in the past few decades as a result, many of these countries have eliminated or lowered fuel subsidies in recent years because of fiscal pressures, with the result being slower growth or retrenchment in the number of low- or moderate-income households with access to clean fuels. The distribution of renewable stoves has likewise been based on direct subsidies. Most solar cookers, for example, have been distributed at no cost via NGO efforts, and African biogas digester installations involve substantial subsidies (20–50%) for upfront system costs.

In contrast, the biggest African successes in scaling up access to improved biomass cooking solutions have involved public-sector or donor-driven cookstove programs with strong market-based logic. The Kenya ceramic *jiko* technology, for instance, after two decades of donor and government promotion, cross-border replication, and transition to market-based distribution, now reaches more than **25 million Africans in at least 14 countries** as the baseline charcoal-cooking solution in many urban centers. Other successful examples of improved cookstove distribution at scale include Mirt *injera* stoves in Ethiopia (more than 2 million units distributed, greater than 60% urban household penetration); Rocket Lorena stoves in Uganda (more than 500,000 households); and brick and mud rocket stoves in Kenya (more than 1 million households). Self-reported data from the GIZ/ProBEC and EnDev programs linked to a number of these stove technologies show that the programs have extended access to basic and intermediate ICS to more than 15 million Africans in less than a decade. Although indirect subsidies and market facilitation were required at early stages of all of these programs, the most successful efforts have minimized direct subsidies and relied on enterprise-based and market-based mechanisms for growth.

Challenges to the Enabling Environment

Despite promising trends, many policy and institutional challenges remain in the stove and fuel markets. The most notable gaps in the enabling environment have to do with tax and tariff policies, the infrastructure for cookstove quality testing, regulations on biomass and modern fuels, and access to finance.

STOVE TAXES AND TARIFFS

Taxes and import tariffs in many countries are set at levels that significantly reduce consumers' access to high-quality clean cooking appliances. Alternative domestic products are unavailable in most of SSA because of technical and infrastructure constraints. Paradoxically, taxes and tariffs may also impede the development of domestic assembly markets by taxing the import of stove components.

INFRASTRUCTURE FOR COOKSTOVE QUALITY ASSURANCE

Despite the development of new ISO IWA stove standards and the launch of four regional testing centers across Africa with the support of the GACC, cookstove quality standards and testing are still a significant gap. The provisional ISO standards, while an important step forward, have limited awareness and buy-in among local African stakeholders; local standards are not aligned to the provisional ISO guidelines; many local African stove models remain untested; and the build quality of artisanal products distributed via pure private-sector channels (e.g., Kenya ceramic *jiko*-style stoves) is often low. Regional testing centers have limited funds and human resource capacity, testing costs are prohibitively high for many potential users (e.g., artisanal and semi-industrial manufacturers), and reliable in-field testing programs involving cookstove usage monitors and field emission meters still require the involvement of costly international experts.

Even in the future, when stove test results will be obtained and regularly updated for a comprehensive set of clean and improved SSA cooking solutions, the major challenge will remain of ensuring that sector stakeholders integrate them into stove design and distribution decisions. There is therefore a need for a sector quality assurance program, such as the activities of the World Bank ACCES initiative on this issue, that can ensure that such results provide incentive for improvement, reveal technical support areas, and guide quality control measures that need to be put in place.

REGULATION OF BIOMASS AND MODERN FUELS

African governments have focused their domestic cooking energy policy efforts on promoting modern fuels, rather than the sustainable harvesting and use of woodfuel biomass. Policies, such as charcoal bans (in place throughout the continent), insufficient investment in forestry management, and poor incentives throughout biomass fuel supply chains, impede more rational biomass fuel use that can complement demand-side efforts to reduce biomass consumption and supply-side policies that promote modern and alternative renewable fuels.

With regard to modern fuels, stronger regulatory frameworks and investment are needed across the SSA region to ensure consumer safety and channel capital to large-scale infrastructure development (i.e., storage and transport infrastructure). Safety is a particularly important concern for LPG markets, where weakly defined certification and licensing policies, the absence of training for fuel distributors, and limited enforcement of existing regulations are major obstacles to consumer uptake. Additionally, tax and subsidy regimes for modern fuels are often poorly implemented, with unsustainable subsidies that have regressive outcomes and contribute to sporadic fuel shortages.

Specific protocols are required for transporting, storing, and using such liquid fuels as LPG and kerosene safely. Appropriate training must extend through the value chain to small-scale distributors to prevent accidents. SSA countries lack the certification and licensing 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.[201] Malfunctioning LPG canisters can cause explosions, and improper fuel storage poses risks to the entire household; 60% of child-poisoning incidents in Kenya and South Africa are a result of accidental ingestion of kerosene.[202] As such fuels as LPG become increasingly affordable, SSA governments will need to work with companies to disseminate safe-use guidelines and minimize risks to public health.

LACK OF ACCESS TO FINANCE

Lack of access to finance is another major, cross-cutting obstacle to faster market-based growth. At the micro level, the challenge cuts across the value chain. Manufacturers and distributors, like any SME in Africa, are often unable to access credit to fund product innovation, distribution network development, and consumer marketing. For cash-strapped consumers who often lack disposable income for upfront purchases of improved cookstoves, few microfinance institutions (MFIs) or retail banks focus on clean cooking—and, in any case, traditional financing solutions often do not work in this sector because of the high transaction costs involved relative to cookstove costs.

Despite these challenges, there is great promise in a number of existing and innovative financing mechanisms across the cookstove and fuel supply chain. Carbon financing has played an important role in accelerating improved cookstove uptake in Africa in the past few years—particularly for more expensive (US$30–100) industrial and semi-industrial ICS or clean ACS, most of which have been sold via manufacturers or distributors that have access to CDMs and voluntary carbon market schemes. The continued and growing importance of the carbon market is well illustrated by the fact that, despite depressed carbon prices, half of the 8.2 million stoves distributed and sold in 2012 (as tracked by the GACC) received some support from carbon finance projects. This support is up from 15% in 2010–11.[203]

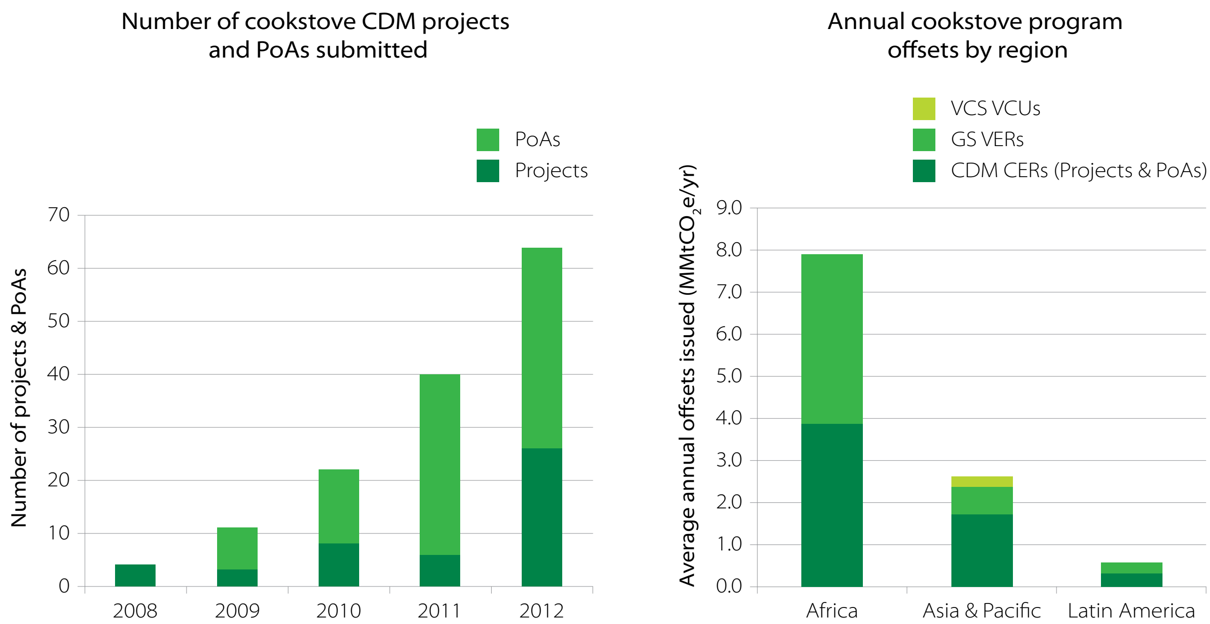
Carbon credits, via 21 registered CDM projects[204] and 33 registered and listed Gold Standard VER (verified emission reduction) projects[205] covering 19 SSA countries[206] have allowed manufacturers to reduce end-user prices by 20–50% and/or use the proceeds from carbon financing to invest in distribution and generate higher returns for their investors.

While the prospects for the carbon market are uncertain in a post-Kyoto scenario, stove CDM project registrations are continuing at a fast pace (nine SSA projects in 2013), and the voluntary market for stove projects is booming, with Africa overall accounting for a disproportionate share of global cookstove program offsets (Figure 58).

Carbon credits will not, however, pay for the incremental health benefits of clean cooking solutions. The carbon reduction potential of most ACS, such as fan and ND gasifiers, is often proportional to fuel efficiency—which, in many cases, is comparable between intermediate ICS and ACS. For instance, a high-performance wood rocket stove, despite its relatively limited health benefits, may be able to generate 50–70% carbon savings—a result comparable with some of the best ACS. Against this background of comparable carbon emissions performance, the 1.5–4-times price differential between industrial ACS (US$75–120) and high-quality industrial rocket ICS (US$20–80) suggests that carbon project developers interested solely in carbon impact will prefer technologies that have fewer positive health impacts.

To avoid such outcomes, **new financial incentives**—social impact bond revenue streams, for example, or results-based financing (RBF) facilities linked to health—are needed to drive socially desirable investment toward the sector. The Department for International Development is already experimenting with an RBF approach through a dedicated RBF fund, with an RBF pilot in progress to facilitate the extension of cookstoves to 200,000

Figure 58: State of ICS carbon finance market (2013)



Note: Annual cookstove offset data include both registered and validation-stage projects. Gold Standard (GS) projects include registered and listed projects. Verified carbon units (VCUs) are credits issued under the verified carbon standard (VCS). PoA = program of activities.

Source: Lee et al. (2013), drawing on data from UNEP Risoe Centre, and the gold and verified carbon standards.

rural households in Ethiopia.[207] The feasibility of applying RBF mechanisms for clean and improved cooking solutions in Africa is also currently being explored in World Bank-sponsored research in Uganda,[208] Indonesia, and elsewhere.

While there is no commercial market for clean cooking impacts, there are a number of important efforts under way to explore such approaches, with immediate potential application to Africa. The C-Quest Capital team, for instance, drawing on its carbon finance market expertise, is exploring the potential to create a CDM-like market for cookstove health impacts, and is working on piloting a potential new RBF methodology.[209] 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.[210]

Although downstream financing for micro-entrepreneurs and consumers is also a major need, affordability challenges are more likely to be addressed through innovative pay-as-you-go models. Further downstream, micro-entrepreneur financing programs for last-mile cookstove retailers are beginning to generate interest from large African MFIs, such as FINCA. They have already been piloted by financial institutions, such as KUSSCO and FAULU in Kenya, though as yet few dedicated cookstove-financing programs are in place.

For end-consumer finance, extensive cooking-sector interviews and examples from other industries (such as solar lighting) suggest that the biggest potential resides in (1) replicating pay-as-you-go schemes of the type piloted by Toyola Energy in Ghana; (2) extending new mobile-metering/payment models, such as those from M-Kopa, IndiGo, and Angaza to the cookstove sector; and (3) integrating the fuel/stove business model (i.e., building upfront stove costs into the fuel price) that Inyenyeri has pioneered in Rwanda for biomass pellet stoves and that CleanStar and Green Energy & Biofuel have applied to ethanol stoves in Africa. Figure 59 summarizes the more recent innovations in financing models.

Figure 59: Clean and improved cookstove funding

Option	Details	Example
Installment/PAYG plans	• Consumers can pay for a stove in installments • Pay-as-you-go systems lower upfront costs for consumers, but transaction costs of collection are high and difficult to scale	Toyola Energy Limited, UpEnergy, Multilink
Carbon finance (CDM)	• US$20–80 carbon credit is claimed by the manufacturer as income over the stove's life and partly passed on to consumer as a subsidy • US$42 million in CDM funds channeled to stoves projects last year, but viability at scale unclear given state of carbon credit markets	CQuestCapital, The Paradigm Project, myclimate, ImpactCarbon
Microfinance	• Small loans for stove purchase disbursed through MFIs and savings and credit cooperatives, and typically bundled with distribution arrangements • No demonstrated capacity for scale today due to logistical challenges and low MFI appetite for financing <US$60 products	Faulu, KUSCCO LTD., FINCA
Noncarbon "buy-down" performance-based grant/results-based finance	• 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, World Bank, BIX Fund
Mobile-enabled utility model	• Potential for mobile financing and utility-based models with remote stove activation/deactivation (e.g., pay for two weeks' use) • Models are currently being trialed for solar lighting; potential exists for extending model to cookstoves	 M-KOPA SOLAR, ANGAZA
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, CleanStar Mozambique

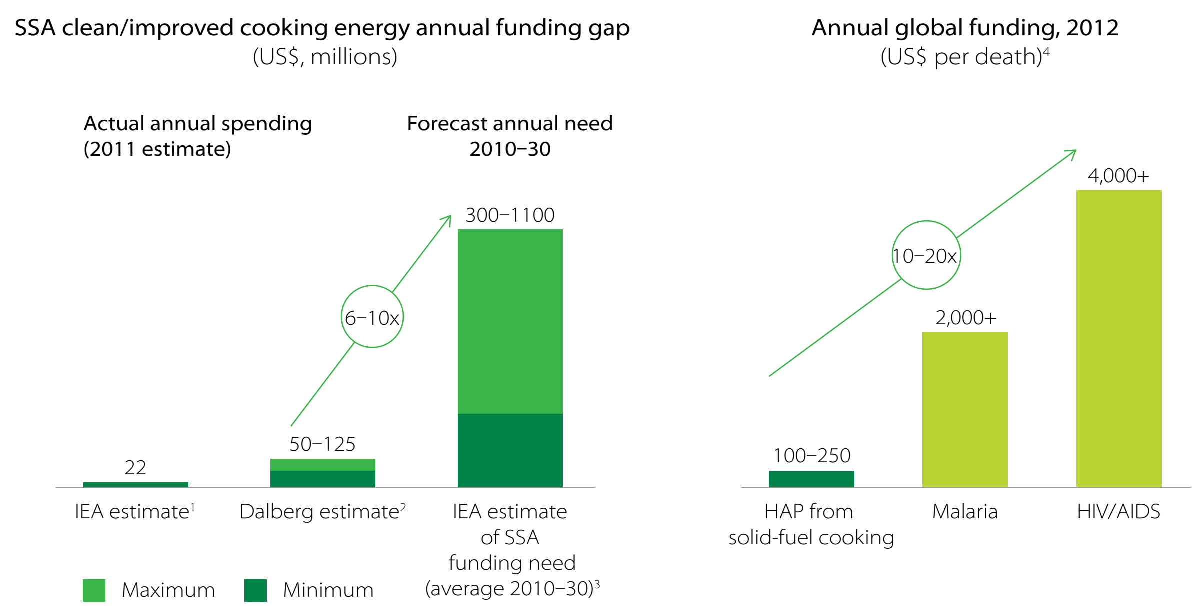
Sources: Press searches; interviews; Dalberg analysis.

Funding for SSA Cooking Sector

At the highest macro level, the key issue is the still-inadequate supply of funding for clean and improved cooking interventions. Current funding in SSA for clean and improved cookstoves is US$50–125 million annually—less than a tenth of what is needed on an annual basis for the next decade (US$22 billion from 2010 to 2030, or more than US$1 billion annually, according to the International Energy Agency [IEA]) to move the region to universal clean cooking energy access.

Finally, from a public health standpoint, it is important to point out that the funding currently made available for combating household air pollution from traditional cookstoves is only a minute fraction of the amount channeled globally to such public health crises as HIV/AIDS and malaria on a per-death basis (Figure 60).

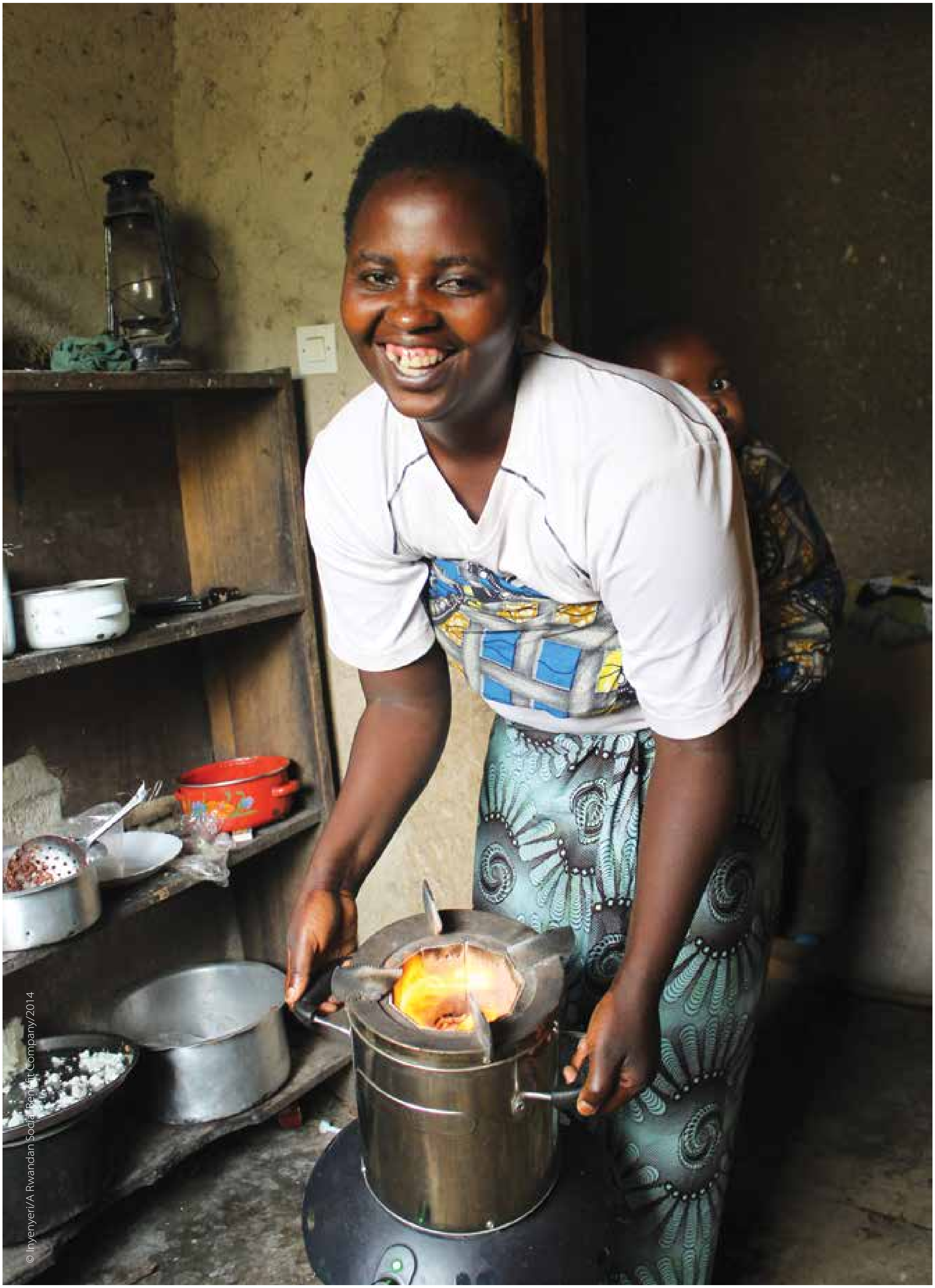
Figure 60: Clean and improved cookstove funding



1. SSA share of US$70 million estimate by IEA based on SSA proportion of global solid-fuel users. 2. Dalberg estimate based on tally of known and estimated donor, CDM, and private-sector investments in the past year (or, where applicable, historical annual average). 3. IEA funding need based on Minimum: "New Policy Scenario" and Maximum: "Universal Modern Energy Access Case" (UMEAC); 4. US$500-1000 million global public and donor funding for clean cooking (LPG, biogas, ICS) vs. 4 million deaths, US$6 billion for malaria vs. 1.2 million deaths, US$8 billion for HIV/AIDS vs. 1.5 million deaths.

Sources: Dalberg analysis; IEA.

As the case for clean and improved cooking solutions becomes stronger in the coming years, there should be increasing opportunities to dramatically scale up funding for the sector through public health investments from international donors and national governments.



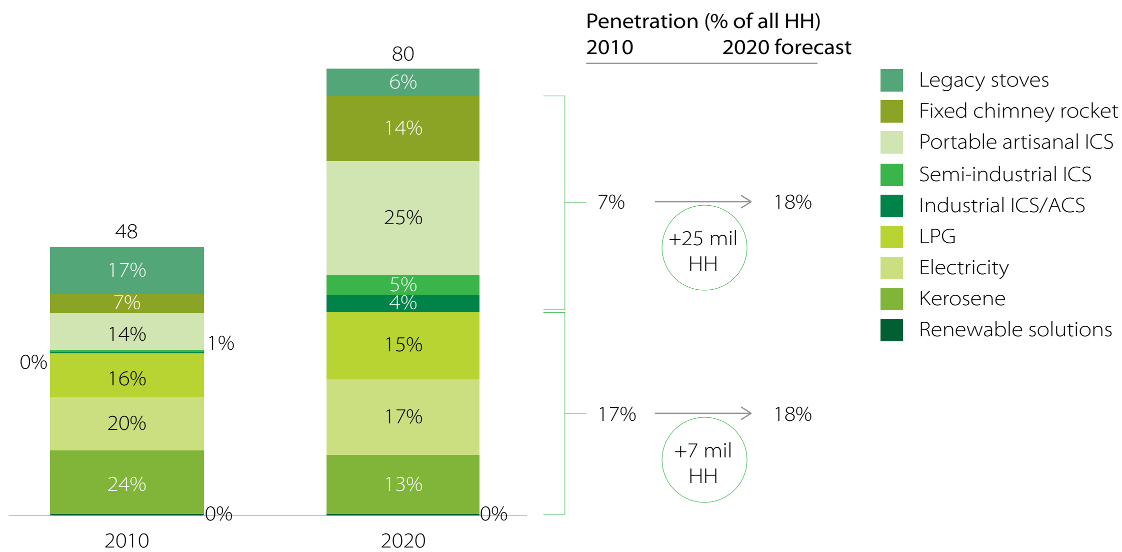
LOOKING FORWARD

chapter 5

LOOKING FORWARD

The clean and improved cooking sector in SSA is poised for solid growth. The evolving demand and supply environments and historical uptake trends suggest that, even under conservative assumptions, the penetration of improved and clean cookstoves (excluding legacy stoves) will rise from **24% (48 million households) in 2010 to 36% (80 million households) in 2020, a net addition of more than 32 million households** (Figure 61).

Figure 61: Base-case forecast for market growth (2010–20)



Sources: Forecast based on historical growth rates; Dalberg analysis

However, this business-as usual-scenario still leaves the vast majority of Africans without access to truly clean cooking solutions. Barring major interventions, the penetration of such clean cooking solutions as LPG, renewable biofuels, and ACS will remain less than **20% of the SSA population**. Moreover, any gains in access to clean cooking will be highly unequal across geographies and income tiers—leaving the very poor further behind.

This 2020 projection would still represent a much lower level of access than what is currently seen in such regions as South Asia, where the lack of clean cooking solutions is being addressed as a major crisis. Furthermore, in the absence of significant public- and private-sector investment, the spread of clean cooking solutions across SSA will be highly uneven—with successes in such countries as Ghana, Kenya, Senegal, and South Africa (where the combined penetration of ICS and clean fuels is already above 50%) serving as exceptions amidst the overwhelming majority of SSA countries still mired in traditional solid-fuel cooking. In places where ICS adoption is growing quickly, much of this growth is still in basic and intermediate ICS, rather than in clean cookstoves and fuels. Furthermore, the vast gap in clean cooking access between rural and urban areas is likely to widen further in the absence of new targeted investments. African governments, the development community, and the private sector can and must do better.

Major obstacles remain on the path to accelerating the uptake of clean and improved cooking solutions. Consumers' limited willingness to fully adopt new cooking solutions and limited ability to pay for higher-cost clean and improved cookstoves and fuels are the greatest long-term obstacles to broader adoption of clean cooking in Africa.

From a willingness-to-adopt standpoint, limited consumer exposure to new technologies and low awareness of their benefits cause limited demand. Even when consumers are educated about stove benefits, however, willingness to adopt often remains low because of the new solutions' lack of fit with consumers' cooking preferences (due to the reality or perception of inappropriate design), lack of consumer trust in stove performance and durability, unreliable fuel supply and after-sales support, and the behavioral (e.g., risk aversion, present bias) and cultural obstacles of new technologies. The willingness-to-adopt challenge is not just an obstacle to initial stove uptake, but affects sustained adoption and use—as manifested in the near-universal phenomenon of stove and fuel stacking (i.e., end users retaining traditional cooking solutions for use alongside clean or improved solutions to accommodate both diverse household cooking needs and the force of tradition). Even where households are willing to adopt improved and clean cookstoves and fuels, they often lack the ability to pay for the stove and fuel due to insufficient disposable incomes and/or the lack of savings. The affordability challenge is particularly acute for higher-priced clean cooking solutions.

Many of these issues can be addressed via consumer education and awareness building, marketing solutions that enhance end-user trust (e.g., warranties, right to return), and—assuming that the underlying technologies are appropriately designed—distribution and financing approaches that build up end-user comfort through exposure (e.g., free trials). In addition, innovative financing techniques can address the liquidity constraints of those consumers whose income levels can sustain stove purchases, but who lack the near-term savings needed for stove purchases; these techniques include installment payment plans, pay-as-you-go/utility business models, and consumer financing.

For many cooking solutions, even when such approaches are applied, willingness to pay will remain a barrier to adoption. There is strong evidence that most African consumers are not willing to pay price premiums for stoves and fuels that generate incremental long-term health benefits—a factor that inherently limits the market-based potential of clean solutions that cannot compete with traditional or improved stoves on purely economic terms. Willingness to pay is also an issue for intermediate ICS technologies where actual willingness to pay can be significantly below the stove's fair market price. Even after willingness to pay is improved through marketing, many ICS providers will still need to subsidize the upfront cost of their stoves (with carbon revenues, for example) to see adoption at scale, particularly in rural areas.

On the supply side, corresponding barriers to wider adoption of improved and clean cooking solutions include the cost and complexity of last-mile distribution; the limited business management capacity and financial constraints of cooking-sector entrepreneurs; the still-limited adoption of uniform quality standards and product certification to minimize market spoilage; biomass supply market failures limiting fuel sustainability; and regulatory constraints to improved stove uptake, such as high taxes and duties on clean technologies or perverse subsidy incentives for the ongoing use of harmful fuels. Oversubsidized donor programs that crowd out private-sector investment and, in some cases, contribute to market spoilage as well, must bear a share of the responsibility for skewing private-sector incentives for market entry.

Funding the sector while addressing these various barriers is a cross-cutting challenge that involves providing financing for fuel supply chains, working capital for improved stove producers and distributors, public-sector funding for market transformation programs and enabling market infrastructure, and—where sensible—targeted subsidies and incentives tied to access, health, and climate change goals. Based on IEA estimates, the funding needed for universal access to clean cooking energy in SSA exceeds US$1 billion annually through 2030 versus the current fund flow of US$50–125 million. Public- and donor-sector funding, in particular, is far below levels that can realistically address the immensity of the health challenges caused by household air pollution: current SSA funding levels are an estimated US$100–250 per death for HAP versus US$2,000–4,000 per death for public health crises, such as HIV/AIDS and malaria.

Figure 62 rates each of these barriers in terms of its significance for various types of improved and clean stoves and fuels, while Figure 63 summarizes many of the cross-cutting barriers described in detail in the preceding sections of this report.

Figure 62: Barriers to the adoption of clean and improved cooking solutions

	Significance of barrier for technology	Improved cookstoves (biomass)			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)	◑	◑	◕	◑	●	●	●
	Consumer awareness	◔	◑	◕	◑	◕	◕	●
	Access	◔	◑	◑	◕	◕	◕	◕
	Appropriate design	◔	◑	◕	◑	◑	◑	◕
	Product quality/safety	●	◕	◑	◔	●	◕	◑
Supply	Cost effective distribution	◑	◕	●	◑	◕	◕	◕
	Producer/distributor finance	◕	●	◕	◑	◔	◑	◑
	Producer technical capacity	●	◕	◔	◕	○	◑	◕
	After-sales support/warranties	◔	◔	◑	◔	◔	◔	◕
Enablers	Policies and regulations (i.e., duties)	◔	◔	◕	◔	◕	◕	◕
	Quality standards/testing	◕	◑	◑	◔	●	◕	◑
	Consumer/market intelligence	◔	◑	◕	◔	◑	◑	◑
	R&D and technical innovation	◑	◑	◕	◔	◔	◑	◑
	Sector coordination	◔	◔	◑	◔	◑	◑	◔
	Monitoring /impact assessment	◔	◔	◑	◑	◔	◑	◑

Note: ● denotes a major challenge for expanding the market for this technology.
Sources: World Bank regional consultations; GACC market assessments; sector interviews; desk research; Dalberg analysis.

Figure 63: Overview of market barriers

Affordability and willingness to pay	In the case of ICS, ACS, and modern fuels, affordability to the end consumer is a major barrier to adoption. Cost is likewise a critical obstacle for the bottom 15–30% of SSA consumers, even where low-cost artisanal ICS solutions are concerned. WTP is an even more important cross-cutting issue: even when the affordability challenge can be removed via subsidies, there is abundant evidence that Africans are unwilling to pay for the health benefits of clean cooking and have substantial behavioral barriers to replacing their existing stoves with clean cooking technologies.
Consumer awareness	Consumer awareness of the harmful effects of traditional solid fuels and knowledge of the availability and benefits of improved, affordable alternatives are low. This market failure cannot be addressed by the private sector alone; it will require significant government and donor support to drive consumer demand and change the surmountable behaviors holding back the adoption and use of improved and clean cookstoves.
Last-mile distribution	Distribution of clean cooking products is costly, with no easy answers to the challenge of reaching rural consumers; progress will require both experimentation with new institutional and retail approaches and significant investment in channel development. In the immediate term, commercially oriented ventures likely need to focus on more profitable urban and charcoal users; reaching the rural consumer requires cross-subsidization from more profitable urban market segments or less commercially driven business models.
Producer capacity	Domestic producers of clean fuels and improved stoves lack the business management and technical skills that would allow them to improve quality and performance; for international industrial manufacturers, technical capacity challenges are less of an issue. Overall, producer capacity is a less significant challenge in the cooking market than in other donor-supported off-grid product markets, such as solar home systems and solar lanterns.
Producer finance	Building successful last-mile clean cooking businesses in Africa is a costly endeavor. This is due to product importation hurdles, logistic and transport challenges, the need for intensive consumer marketing, and the importance of extending credit to both last-mile retailers and end users (i.e., via pay-as-you-go schemes). Although lack of access to working capital is generally a challenge for African SMEs, the issue is compounded for cooking solution enterprises, because they are often promoting new technologies in markets with uncertain or still-limited consumer demand and limited understanding by financial institutions of their products and economics.
Cookstove quality and performance	The number of improved cookstove models and fuel-production solutions customized for local environments is still low. There is evidence that many basic ICS have poor quality in the field, at least in part due to the difficulty of accessing high-quality materials. Moreover, systemic support remains limited for innovation and R&D on breakthrough solutions offering higher performance (e.g., fan gasifiers) and, even more important, designs that are more attractive, functional, and adapted to the end user. For solutions that do reach the market, access to standardized testing is limited or unaffordable for many producers.
Policy environment	Ineffective or perverse incentives are common in regulations governing solid-fuel production and improved biomass cookstoves; incentives for scaling up clean fuels are often absent or, in the case of large, direct modern-fuel subsidies, unsustainable; and high, poorly targeted import duties currently hold back the development of more effective domestic clean cooking sectors. Donors programs can crowd out private-sector investment and compound policy challenges.

Recommendations

Disrupting the status quo will require stepped-up investment and a differentiated approach. To ensure that the current revival of interest in clean cooking does not become a passing fad, new approaches and large investments are needed to accelerate the uptake of clean, high-quality cooking appliances and fuels.

While a major push is needed in all countries in SSA, sector approaches, intervention priorities, and technologies will need significant tailoring based on the development stages of target markets and the specific needs of each consumer segment.

A differentiated approach to improved and clean cooking energy promotion must acknowledge that, **although market-based efforts to promote clean cooking technologies are the preferred approach in the quest for universal and sustainable clean cooking energy access, markets are not a panacea; in many cases, "transitional"—improved, but not clean—cooking technologies will remain the best feasible solution in the near term.**

For poor consumer segments, clean cooking solutions, such as LPG, electricity, biogas, or ethanol, and near-clean technologies, such as biomass gasifiers will likely remain unaffordable at sufficient scale for many years to come without large public-sector subsidies or innovative utility business models. The path forward for the poorest African consumers will therefore need to involve the continued promotion of low-cost artisanal and intermediate ICS that—while generating both significant fuel savings and associated social, economic, and environmental benefits—have no or minimal health benefits. When appropriately tailored to local context, such basic and intermediate ICS solutions should not impede—and should even facilitate—future adoption of cleaner stoves and fuels. From a supply market perspective, the distribution of "transitional" improved solutions involves investment in last-mile distribution infrastructure, credit extension, and logistics—all activities that should facilitate the promotion of even cleaner technologies at a later stage. From a demand perspective, while empirical data for such transition effects are lacking, basic and intermediate ICS distribution should in theory help sensitize consumers to the benefits of commercially manufactured, quality-controlled, fuel-saving, and smoke-reducing appliances and fuels—something that should improve consumer willingness to purchase more expensive and cleaner appliances and fuels in the future.

Early-stage "market-seeding" efforts—such as basic awareness campaigns, build-out of distributor networks, and the establishment of local stove-testing infrastructure—are extremely time- and resource-intensive activities in which the private sector is typically less willing and able to invest in nascent markets. While market-based approaches are preferred for basic and intermediate ICS promotion, for the very poorest consumers and for marginalized groups like refugee camp populations, ICS market-creation efforts will in many instances take years to develop, justifying the application of more direct subsidy models, despite some risks of market distortion.

In contrast, market-led approaches hold much greater promise for expanding access to clean cooking solutions in more developed markets that are characterized by growing segments of middle-income consumers with disposable incomes. The optimal strategy for such consumers, at the higher levels of the income distribution, involves expanding uptake of modern fuels and renewable biofuels, such as ethanol.

Poor urban consumers, who already often face significant fuel costs, similarly present growing opportunities for the private sector. Reaching them, however, will likely require different strategies and challenges, such as (1) capitalizing on carbon finance markets and growing demand via businesses that generate fuel savings (e.g., via highly efficient charcoal stoves), or (2) offering competitively priced alternatives to expensive biomass (LPG, biofuels, biomass briquettes) that can also create significant health co-benefits.

Figures 64 and 65, on the following pages, summarize key recommendations that reflect this differentiated approach by focusing on **consumer segment and technology**. The remainder of this section reviews a number of additional cross-cutting recommendations that are independent of these two areas.

Figure 64: Recommended approach for policy makers, by SSA consumer segment

Modern fuel (17%)*	• Promote increased or exclusive use of modern-fuel stoves within the household fuel/stove stack via education campaigns on the health benefits of modern-fuel cooking • Create policy incentives for reduced reliance on less-clean or unsafe modern-fuel cooking solutions (e.g., reduce kerosene subsidies, strengthen LPG and kerosene safety standards) • Improve affordability, accessibility, and reach of modern fuels through increased infrastructure investment (e.g., LPG storage terminals and distribution networks) • Promote clean biomass stoves (ACS) and fuels (e.g., renewable charcoal) as a secondary solution for modern-fuel users to transition their fuel/stove stack to cleaner cooking
Urban middle class charcoal (11%)	• Promote transition to modern fuels, such as LPG or electricity, potentially with well-targeted subsidies for appliance and fuel costs • Promote commercial adoption of biomass gasifier ACS and renewable briquette/pellet biomass fuels, potentially via integrated fuel/stove utility models • Target replacement of traditional and basic (*jiko*) charcoal ICS with advanced charcoal ICS models that can generate greater household savings and reduce CO_2 emissions • Align policies and boost investment in sustainable biomass pellet/briquette fuels and renewable alternatives, such as ethanol
Urban poor charcoal (4%)	• In markets where the costs of charcoal cooking already exceed clean alternatives, promote modern-fuel (LPG, electricity) and biofuel (ethanol) adoption by the urban poor, even if such solutions initially constitute a secondary technology with little daily use; for this segment, targeted, ongoing fuel subsidies (e.g., voucher schemes) may be appropriate • Promote highly efficient, high-end charcoal ICS from industrial manufacturers • When charcoal prices are not sufficiently high, promote low-cost, high-quality basic charcoal ICS produced by reputable artisans and semi-industrial manufacturers • Align policies and boost investment in sustainable biomass pellet/briquette fuels
Firewood purchasers (20%)	• Promote migration (1) to LPG and gasifier ACS for the highest-income wood purchasers and (2) to low-cost natural-draft gasifiers (semi-industrially produced) for the urban poor • Experiment with integrated fuel/stove utility models that have potential to extend fan-gasifier ACS access to poor firewood purchasers with no or limited stove appliance costs • Where clean cooking solutions are infeasible due to local market economics or other barriers, promote best-in-class rocket ICS, preferably multiburner with chimneys • Invest in local artisanal and semi-industrial rocket ICS market creation and growth (e.g., by creating a trained cadre of built-in rocket stove masons/installers or promoting local manufacturing/assembly of portable rocket stoves and ACS to reduce costs) • Align policies and boost investment in sustainable biomass pellet/briquette fuels
Middle-income wood collectors (15%)	• Trial the fuel/stove integrated utility models for ACS, requiring service in kind (e.g., biomass collection) in return for free or very-low-cost ACS stove and fuel access • Promote fuel-efficient and low-cost rocket stoves and natural-draft gasifiers, with a heavy marketing emphasis on fuel-collection time savings, fast cooking, durability, and the aspirational value of modern-looking stoves • Invest in domestic (semi-industrial and industrial) rocket stove manufacturing to drive down the costs of more efficient technologies • Support shift from wood to renewable biomass pellets/briquettes, particularly where such consumers are beginning to adopt charcoal in peri-urban areas • "Free trial" marketing is particularly important for this segment to drive willingness to adopt and pay, given the lack of financial pressure on such users to shift to more efficient stoves
Poor rural wood, dung, and crop waste collectors (31%)	• Trial the fuel/stove integrated utility models for ACS, requiring service in kind (e.g., biomass collection) in return for free or very-low-cost ACS stove and fuel access • For the very poorest segments (e.g., bottom 10% of rural population, Israel Defense Forces camp refugees), consider free or highly subsidized distribution of gasifier ACS • Promote adoption of basic ICS for households where there is much to be gained, even with switch from three-stone fires to basic ICS

* Share of households using fuel as their primary cooking solution; overall number of HH in each segment is higher.

Figure 65: Recommended approach for policy makers, by technology segment

Technology segment	Donors/public sector	Private sector
Modern fuel and biofuel (LPG, electricity, kerosene, ethanol)	• Conduct consumer awareness campaigns about benefits of clean cooking • Provide consumer finance for modern-fuel stoves • Target subsidies (e.g., vouchers) for urban poor with no other options • Target campaigns to reduce incidence of fuel/stove stacking • Improve safety/regulations to improve consumer confidence in technology • Create public–private partnerships for development of clean fuel distribution infrastructure • Change policy to reduce adverse incentives (e.g., kerosene subsidies)	• Create public–private partnerships for development of clean fuel distribution infrastructure (e.g., LPG storage) • Invest in downstream fuel ecosystem (e.g., cylinder suppliers/fillers/after-sales support) • Promote small-cylinder filling models and other technology and business approaches designed to drive down appliance costs • Provide incentives for households who replace/eliminate traditional technology (e.g., traditional stove buy-back schemes or trade-in discounts)
Advanced biomass cookstoves (ACS)	• Conduct consumer awareness campaigns about benefits of clean cooking • Create results-based financing incentives for biomass solutions with health benefits • Provide R&D funding on impact and consumer acceptability for new ACS solutions • Develop policies to facilitate the creation/growth of value chains for renewable biomass fuel • Reduce taxes/tariffs for ACS imports	• Focus commercial efforts on urban charcoal consumers and users of biomass as a secondary target market, since these segments can sustain commercial distribution models • Experiment with integrated fuel/stove models to better address liquidity constraints for poorer consumers and maximize ACS health and environmental impacts • Continue to invest in R&D to improve value for end users
Intermediate ICS	• Promote intermediate ICS as a fallback option from modern-fuel stoves and ACS, rather than the preferred default solution when cleaner technologies are feasible • Promote domestic manufacturing of rocket stoves (including artisanal built-in rocket stoves and semi-industrial portable stove assembly/manufacturing) to lower costs and improve access • Reduce taxes/tariffs for rocket stove imports/ component imports	• Focus intermediate ICS marketing on middle-income urban and rural woodfuel users, a segment that can sustain commercial distribution due to savings generated by stoves • Pursue cross-subsidy models, linking more profitable urban markets and less profitable rural ones for rocket stoves • Continue to work on reducing rocket stove costs through local assembly, domestic manufacturing, and frugal design/simplification of industrial rocket stoves
Basic wood/ charcoal ICS	• Continue to support the growth and development of commercially sustainable basic ICS industries, particularly in rural areas where sustainable wood ICS markets are largely missing • Promote improved standards among artisanal and semi-industrial basic ICS manufacturers, with a focus on thermal efficiency and durability • Support centralization and automation of basic ICS enterprises (e.g., through financing) to unlock potential for scale • Avoid distortionary direct subsidies focused on basic ICS, saving subsidy funds for cleaner and/or more efficient technologies	• Improve basic ICS durability and emission performance by investing in more mechanized production, better materials, and best-practice quality-control mechanisms • Work with governments and NGOs to seed basic ICS ecosystems (e.g., organization of ceramic liner and metalsmith workshops) in countries or cities where such markets are underdeveloped

RECOMMENDATIONS FOR GOVERNMENTS, DONORS, AND NGOS

1. Increase support for clean cooking solutions, while maintaining momentum for intermediate and basic ICS technologies where cleaner alternatives are not feasible in the near term. The scale of the HAP public health crisis calls for a revision of donor priorities, with a need for expanded investment in clean cooking technologies. As noted in this report, achieving proportionality to investments in such public health challenges as HIV/AIDS, tuberculosis, and malaria requires at least a tenfold increase in public-sector and donor funding for clean cooking technologies. At the same time, the slow pace of transition to clean solutions, combined with the unaffordability of these solutions for the rural poor, dictates sustained ongoing investment in intermediate and basic biomass ICS.

Growing evidence for the negative health effects of solid-fuel cooking suggests that full technology neutrality is not a viable option for donors and policy makers. Only the cleanest modern-fuel, renewable biofuel, and—pending further evidence from the field—ACS can meaningfully mitigate the HAP-linked deaths and DALYs of millions of Africans over the coming decade. Interventions should therefore prioritize the uptake of high-performing clean cooking solutions that—due to their cost or 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 in RCTs and field performance studies focused on emerging range of ACS), distribution capacity, and end-user finance.

While precise numbers are unavailable, current public- and donor-sector funding for clean and improved cooking efforts in Africa is heavily biased to basic ICS and, in a shift to rocket technologies apparent over the past 3–5 years, to intermediate ICS solutions. ACS projects have only recently began to attract donor attention, but most funds have thus far flowed to fundamental R&D projects and public health RCTs, rather than funding for ACS business models and market pilots. Public-sector and donor financing for modern-fuel and alcohol biofuel projects is likewise still extremely limited.

Increasing the penetration of clean cooking technologies consequently requires a large shift in current donor and government funding trends and priorities. The shift must entail both an increase in overall funding levels and a reallocation of funding share across different cooking technologies. In practical terms, this means significantly boosting overall annual funding across the improved and clean cooking technology spectrum—from more than a hundred million to several billion U.S. dollars annually—with a relative reallocation of funds from basic ICS and intermediate rocket stove solutions to cleaner modern-fuel, biofuel, and biomass gasifier technologies, where health impacts can be proven and market circumstances allow for distribution at scale (e.g., a middle class exists to anchor more sustainable market-driven clean stove and fuel interventions).

Despite the fundraising successes of the GACC and renewed attention to clean stoves and fuels from major clean energy donors, such as the World Bank, effecting this funding shift will require the entry of "nontraditional" clean cooking funders. Incremental billions of dollars of funding will remain unavailable from energy and environment budgets. A redirection of donor and public-sector public health funds that are currently allocated to such conditions as malaria, HIV/AIDS, and TB—and increased attention from public health thought leaders, such as the Bill and Melinda Gates Foundation and WHO—are likely needed to truly transform Africans' access to clean stoves and fuels.

Although a rebalancing of sector investments toward cleaner solutions is needed, as noted above, the public sector and donors should continue to support fuel-efficient solutions, such as intermediate and basic ICS, particularly in poorer, less developed cooking markets and for excluded populations. Some basic and, in particular, intermediate rocket ICS can generate fuel-saving benefits of clean biomass stoves at much lower price points; have moderate health, environment, and climate benefits; and in many cases remain the only improved solution that is reasonably accessible and affordable for Africa's poor. Furthermore, short payback periods for fuel-efficient ICS and possible positive externalities from the development of artisanal and semi-industrial stove markets suggest that establishing an intermediate technology baseline will not impede—and may even accelerate—consumer migration toward cleaner cooking.

2. Design interventions to drive consumer behavior change; simply distributing cleaner cooking solutions and fuels will not lead to optimal health and environmental outcomes. The challenge of achieving the benefits of universal clean cooking in SSA is not simply one of technology and economics. Like water and sanitation programs and other public health initiatives, **clean cooking solution promotion efforts can achieve**

health impact objectives only when accompanied by large-scale behavior change in the target end-user population.

As reviewed in depth throughout this report, challenges linked to consumer behavior include the all-pervasive phenomenon of stove and fuel stacking, which reduces the actual benefits of any clean cooking technology; the dependence of cookstove performance on the quality and characteristics of the fuel used (e.g., health effects of dung vs. firewood vs. charcoal vs. quality-controlled biomass briquettes for any given biomass stove); and the wide variability in improved and clean cooking solution performance, depending on the skill of the end user in starting and sustaining a fire, cooking preferences (e.g., types of dishes prepared), and cooking setting (e.g., cooking outdoors vs. indoors, indoor airflow in the dwelling). Furthermore, health and environmental outcomes of clean cookstoves are subject to community effects, whereby the reduction of household air pollution by select households in densely populated areas will result in few climate benefits and in only partly improved health outcomes if the levels of household air pollution are high in neighboring dwellings.

Even when consumer behavior is the underlying driver of variability, donors and governments can address some of the variability in cooking solution performance by **promulgating locally appropriate standards and by supporting appropriate stove and business model design.** For instance, donors can support stoves that constrain variability in emissions during different use patterns (e.g., some stove designs can minimize emissions in both low and high heat settings); encourage the adoption of clean multiburner stoves that may mitigate the incidence of stove stacking with inferior cooking technologies); and promote integrated stove-fuel distribution models (e.g., Inyenyeri in Rwanda) that lend themselves to more controlled stove emission outcomes for end users.

In most cases, however, **behavior change cannot be managed through technology selection alone.** The public, donor, and NGO sectors must complement private-sector stove and fuel distribution initiatives with **intensive consumer awareness efforts**—similar to the hand washing, public defecation, and vaccination campaigns already familiar in the public health setting—that can educate end users about the harms of stove and fuel stacking; encourage outdoor cooking and better indoor ventilation; and train end users on optimal cooking techniques, including fuel preparation (e.g., biomass drying prior to cooking), kindling, fire tending, and optimal heat adjustment and dish sequencing for best fuel efficiency and emissions.

Aside from encouraging appropriate technology and supporting consumer education initiatives, consumer behavior change also requires **new incentives and accountability requirements** for donor and public-sector efforts. This should include, for instance, rigorous metrics for tracking multifuel and multistove use (i.e., rather than just total numbers of households reached or the penetration of clean and improved technologies as the "primary" household cooking solution). Such metrics should link to increased support for those initiatives that have greater potential to address the stove- and fuel-stacking challenge. As an example of the challenge, despite nearly universal recognition by sector experts about the harmful effects of stacking on lean and improved cooking solution interventions in Africa, there are few incentives for stove project developers to reduce stacking behavior. In the case of carbon projects, there are diminishing marginal returns to developers from distributing multiple improved stoves to the same household (i.e., the carbon credit received for the "second" stove is significantly lower than that received for the first stove). Donor-supported market-driven and subsidy-orientated stove distribution projects likewise often focus incentives on top-line reach metrics (i.e., number of households with one clean or improved stove), rather than on multistove or multiburner clean stove adoption that is likely to more fully displace traditional cooking solutions and, as a result, lead to better health outcomes.

3. Prioritize market-based approaches, but also deploy direct subsidies linked to health and climate impacts. Market-led models should be emphasized wherever feasible to ensure sustainability. However, maximizing climate and health benefits might also require targeted subsidies delivered through carbon markets and focused "pull" mechanisms (e.g., results-based credits for health benefits).

Indirect subsidies for cooking market support and facilitation (e.g., consumer awareness, testing centers, industry associations) have been an essential feature of all successful clean fuel and cookstove programs, both in Africa and globally to date. The results of direct subsidies for producers have been more mixed, however, and subsidies for consumers have been the most problematic in both modern-fuel and ICS markets—with some evidence of slower longer-term cookstove uptake than via purely commercial approaches, higher risks of promoting technologies that are not desired by consumers, and serious sustainability challenges when fuel subsidies are withdrawn.

Despite these dangers, direct incentives via CDM and voluntary carbon schemes and new incentives tied to health outcomes are needed to scale up genuinely clean cooking technologies, especially given their high costs and the resulting affordability barriers. The logic of fuel savings, combined with larger and better-targeted investments in 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 US$25–70 that separates high-quality industrial rocket stoves (US$25–50) from truly clean advanced biomass gasifier solutions (US$50–100). If CDM markets recover, they may bridge a part of this gap (e.g., lowering the end-consumer price by US$5–20), but additional measures will be needed to compensate producers 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. Support sustainable production of clean-biomass and renewable-fuel alternatives alongside efforts to improve stove efficiency and reduce emissions. Given rapidly rising demand, more efficient cooking solutions alone will not be enough if the sustainability issues in African woodfuel value chains remain unaddressed.

Historical trends make it clear that the rapid growth of woodfuel consumption in Africa, particularly charcoal, will not be resolved via the adoption of more efficient ICS. Even universal adoption of basic ICS, for instance, will only maintain the status quo of overall charcoal consumption by 2020, as it would simply cancel out the projected 30% increase in charcoal use. Mitigating the harmful environmental and climate change effects 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); renewable solid fuels from new sources (e.g., agricultural waste 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 and retained-heat cookers.

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 on stoves. Furthermore, some fuel interventions have the advantage of the large labor force involved in producing and distributing cooking fuels—which can, in theory, be co-opted into value chains for new improved and clean cooking fuels. In contrast, in the case of modern fuels, such as LPG, and liquid biofuels, such as ethanol, fuel interventions can contend with significant opposition from vested interests and may be politically sensitive whenever they compete with traditional biomass fuel sources that are large drivers of employment.

5. Focus on providing critical public goods to accelerate the development of the clean cooking sector. Policy makers should emphasize consumer education, access to finance, funding for R&D, the expansion of standards and testing, and enabling fiscal and trade reforms (e.g., tax, tariff, and subsidy reform).

Despite numerous ongoing efforts of actors, such as the GACC and the World Bank, there is still a great deal of debate about the role of donors and governments relative to 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—with particular emphasis on consumer education, access to finance for producers and distributors, quality standards, policy reform, and market intelligence.

Publicly funded consumer education and marketing campaigns to promote awareness of solid-fuel harms and new clean cooking solutions are an important complement to private-sector marketing efforts—as seen in other market-transformation interventions focused on behavioral change (e.g., solar lanterns, malaria bed nets, water filters, hand-washing campaigns). Aside from supporting "above-the-line" mass media campaigns for clean cooking, governments also have a role to play in supporting the "below-the-line" experiential marketing efforts of first-mover industrial stove promoters in rural and peri-urban areas. This can be achieved through public–private partnerships that leverage the rural reach and consumer-education capabilities of government agricultural and health extension agents who number in the several hundred thousands across SSA. While such support will create private benefits for cookstove promoters, government and donor support for stove marketing on a cost-sharing basis is an appropriate measure for jumpstarting nascent markets for quality cooking appliances.

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 midstream finance bottlenecks (e.g., in-country producers, importers, and distributors), via their engagement with financial institutions and SME promotion activities. As for many other relatively low-cost consumer durable products, downstream access to finance is less promising, given the high transaction costs of financing sub-US$100 products in Africa, with no successful examples of downstream cookstove financing at scale. Downstream finance is important, however, for higher-cost cooking technologies (US$500–1,500), such as biogas digesters.

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 such new solutions as gasifiers under real-world conditions; the weak base of knowledge on the systemic health, climate change, and livelihood impacts of clean biomass and modern-fuel stoves; and a poor understanding of the potential African clean energy consumer. Private-sector firms are poorly positioned to generate such market intelligence, given the high cost of deploying large-scale consumer surveys in rural Africa. Donors have stepped up their market intelligence activities, most notably in the market and consumer reports currently being funded by the GACC and the World Bank's ACCES program. In most cases, such investments are one-off contributions to improving the state of the sector's data. Longer-term government engagement (e.g., incorporation of more data on household cooking into national energy, health, and demographic surveys) is therefore still needed to create a repeatable baseline for clean and improved cooking solution penetration and use data.

On quality and standards, despite ongoing support from the GACC, the WB ACCES program, and other donors, much more still needs to be done to facilitate a robust stove- and fuel-testing infrastructure. The capacity of local testing laboratories is still constrained, and access to regional and global testing facilities is cost prohibitive or impractical for many smaller cookstove enterprises, including the majority of artisanal and semi-industrial ICS SMEs in Africa. High-quality stove emissions testing is costly and difficult to implement—an argument for ongoing investment and technical assistance for a small subset of regional testing centers in Africa that will likely have the capacity to carry such activities forward in the long term. On the other hand, stove efficiency testing and field-testing know-how to verify the activities of stove manufacturers and carbon project developers are important capabilities to build at a national level across the region.

Even with much more widespread stove testing in coming years, market participants interviewed for this report uniformly reported that quality standards will remain an important issue, so long as artisanal stove manufacturers, distributors, and—most critically—consumers are poorly educated about stove products and unable to differentiate between the various performance and quality levels of stoves on the market. Governments can play an important role in linking stove-testing results to consumer-labeling provisions and awareness-raising interventions, in order to improve the overall quality profile of the African cookstove and cooking fuel market over time. An important caution on donor efforts for quality assurance is that excessively burdensome standards and testing procedures, if poorly deployed or if improperly interpreted by governmental standard-setting bodies, may serve as a disincentive to market entry for high-quality producers.

Trade policy is also a major a barrier in many fuel and stove markets. For industrially produced cooking appliances, taxes and duties often exclude the best technologies from domestic markets. For example, the combination of value-added tax and tariffs tops 30% in a dozen markets across Africa, leading to 50–100% increases in the end-user cost of stove appliances when all distribution value-chain margins are accounted for. Even more important, such policies often adversely affect domestic cookstove assembly and manufacturing because of the high cost of imported components. Retaining trade barriers to protect domestic artisanal stove manufacturing is in many cases not a sensible approach, since artisanal stove markets and imported industrial stoves often target different consumer segments. As in the case of other renewable and clean technologies, such as solar lighting, a far better approach is to maximize the entry of high-performing stoves into the market through tax exemptions for clean technologies and their components, while encouraging investment in local assembly and manufacturing of clean and improved cooking solutions.

Supply-side policies also play an important role in fuel markets where better regulation of traditional biomass supply chains is needed to bring woodfuels into the formal sector—and where government support and public–private partnerships are vital for the development of modern (e.g., LPG) and renewable (e.g., ethanol) fuel market infrastructure (e.g., transport routes and storage infrastructure) and standards (e.g., LPG cylinder revalidation and certification standards).

RECOMMENDATIONS FOR PRIVATE-SECTOR STAKEHOLDERS

1. Invest to capture the opportunity. Despite many challenges, the untapped SSA demand for clean and improved cookstoves is immense—an opportunity further enhanced by a resilient voluntary carbon finance market and attractive margins for market leaders. The market has tremendous potential, with more than 90 million fuel-purchasing households, including a growing middle class (more than 15% of consumers have a per capita income of more than US$1,500) and spending of more than US$20 billion on cooking fuel annually.

Despite high prices and affordability constraints, the use of modern fuels is growing at a quick pace in several markets (e.g., 16% year-on-year volume growth in Kenya); clean solid biomass production and liquid biofuel enterprises are showing encouraging early results; and industrial and semi-industrial ICS manufacturers are experiencing rapid year-on-year sales growth (30–200%), attractive margins (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 with other analogous markets. For example, fewer than 10 sizable international manufacturers are focused on improved cookstoves, compared with more than 80 international manufacturers focused on solar lanterns. This does not mean that the market lacks challenges; rather, the opportunity for early entrants, including both multinational corporations and social entrepreneurs, is large.

2. Focus on cooking-fuel opportunities, not just cookstoves. The US$20 billion market for cooking fuel in SSA is orders of magnitude larger than the market for cooking appliances. However, it is also more complex due to often perverse regulatory incentives, vested interests, significant investment requirements (in the case of modern fuels), and fragmented and informal markets for biomass fuel.

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 from artisanal producers to mid-sized industrial enterprises manufacturing thousands of tons of fuel annually. 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 throughout Africa, and the early results are encouraging.

3. Grow market share by addressing the affordability challenge. Producers can reduce stove prices via low-cost design and economies of scale, transitioning to local production or assembly, and embracing innovative distribution and financing models that can lower upfront stove costs.

Affordability, while it is 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 Africa. 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 Africa cooking-sector stakeholders suggests that even small reductions in cost can have major uptake implications, with many suggesting that a US$15–25 price point for highly efficient and clean stoves (US$15–75 lower than current prices) is required to ensure much broader market volumes. The importance of price-reduction strategies is also clearly evidenced by other SSA product markets, such as LPG, solar lanterns, and mobile phones, though as described earlier in this report, any parallels to the mobile market must be drawn with caution.

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, such as the ability to add separate accessories, pot holders, or 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 US$10–20 range (e.g., semi-industrial metal rocket ICS in such markets as Ghana, Kenya, Malawi, and Uganda) and an emerging tier of US$15–25 natural-draft gasifier stoves in multiple pilots across the continent (e.g., GreenTech stove in The Gambia and Awamu/Mwoto in Uganda) are important illustrations of the opportunity.

Given the scale economies of Asia-based manufacturing, domestic production in Africa is not necessarily a path to lower costs, but should be explored by industrial manufacturers of higher-cost ICS, ACS, and clean-fuel stoves serious about the Africa market. Because transport, insurance costs, import duties, and related expenses (e.g., warehousing, importer margins) represent a large share (20–35%) of the final cost of international ICS products, domestic production or assembly may be the answer in those SSA geographies that have sufficiently large markets, low labor costs, sufficient labor quality, and access to quality materials. Africa-based production may be most sensible in well-connected regional hubs (e.g., Kenya, Senegal, South Africa) where infrastructure linkages and regional customs unions can ensure a large potential market for the logistics and tax exemption benefits of local solutions. For low-tech/low-cost ICS, production is already predominantly local, so the more important levers for cost control (while maintaining or boosting quality) are improved monitoring, mechanization, and scale for existing artisanal enterprises—which in some cases may mean shifting from artisanal to semi-industrial forms of production.

4. Address willingness-to-pay barriers head on. Focus on adapting marketing, distribution, and financing models to address such willingness-to-pay challenges as low consumer awareness, trust gaps, and liquidity constraints through proven approaches, including consumer education, field demonstrations, trial periods, warranties, and pay-as-you-go schemes. At this stage in the market's development, answering the willingness-to-pay challenge calls for replication and scaling investment, more than it does for innovation. We already know a great deal about marketing and distribution techniques that can boost consumer adoption, though such approaches are still used by only a minority of market participants due to the siloed nature of many stove markets and the poor understanding of the African consumer by many new market entrants.

5. Use a variety of distribution channels, with an emphasis on getting closer to the consumer. Reaching scale will require exploiting a range of models—direct, third-party, institutional—with the greatest scale seen by those who either take on the expense of building direct bridges to consumers or partner with third parties possessing direct-sales or demand-aggregator capabilities (e.g., distributors of synergetic products and household appliances, or carbon project coordinating/managing entities). The experience of the African cookstove sector to date suggests there are no quick shortcuts to distribution scale. In rural areas, in particular, appropriate distribution channels often simply do not exist and must be built from scratch by market players serious about reaching such consumers. One important implication for the private sector is the need either to built one's own distribution networks or, for those players who wish to specialize in manufacturing and design, to partner with large-scale distributors, such as carbon finance project managers, micro-franchising experts (e.g., Living Goods), or even other off-grid energy device companies (e.g., solar lantern manufacturers). These distribution partners typically have already gathered significant experience with constructing last-mile distribution channels, comparable consumer segments, and equivalent behavior-change challenges.

6. Design products with an emphasis on the complete end-user experience and attention to quality at every ISO performance tier. Most consumers, including the poor, are willing to pay for improved "aspirational" stove designs that require minimal behavior change, while maximizing fuel savings, end-user convenience (e.g., cooking time), and durability.

While market spoilage stemming from consumer disappointment with low-quality products is only a concern for the cookstove sector in a few countries, experience in other household energy markets (e.g., solar home systems, solar lanterns) shows that the African consumer is mindful of product quality in terms of durability, shelf life, and safety. There is also anecdotal evidence that better-performing cookstoves see faster sales growth than products with inferior fuel efficiency and emissions performance. This is confirmed by the much faster growth rates of semi-industrial and industrial stove enterprises in comparison with artisanal versions of the same technologies. Consumer surveys likewise suggest that product design matters with 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 in SSA today (at least for high-end ICS solutions) is correlated with products that are perceived by the sector to have better design features.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APPENDIXES

APPENDIX 1: OVERVIEW OF SSA COOKING SOLUTIONS

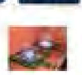
BASIC BIOMASS ICS					
Stove type	**Description**	**Examples and illustrative prices**	**Performance indicators**	**Advantages**	**Disadvantages**
Legacy improved stoves	• Some improvement over traditional 3-stone fire, e.g. closed firebox, chimney, but typically uninsulated • Made from locally sourced materials like sand, clay, cement, mud, or just from scrap metal • Typically assembled on site	• Mud mbaula in Malawi, non-Rocket Lorena in Uganda, brazero in DRC, Malagasy and Cire Stoves in Senegal, etc. ($0–5)	• Tier 0–1 for efficiency and total emissions; Tier 1–2 for indoor emissions for chimney stoves • 0–20% fuel savings over 3 stone fire; minimal emission reduction	• Usually tailored for local cooking practices • Easy to produce and easily accessible • Cheap and "disposable" enough to replace after breakage • Addition of chimneys reduces HAP and directs smoke away from user	• Modest fuel efficiency gain • Negligible emission reductions • Stoves are not durable • Chimneys may break due to poor maintenance, undermining emissions benefits
Basic efficient charcoal ICS  	• Most stoves are portable Kenya Ceramic *Jiko* (KCJ)-style stoves—metal body with a heat-retaining lining (clay, sand, vermiculite) • Include both artisanal and branded semi-industrial designs (e.g., Tizazu Lakech in Ethiopia, Cookswell KCJ in Kenya, Toyola coal pots in Ghana)	• KCJ (Kenya): $3–7 • Jika Boro (Tanzania): $7 • Lakech (Ethiopia): $1–8 • Mali charcoal: $5 • Toyola coalpot: $6–8	• Tier 2 for efficiency and Tier 0–1 for indoor emissions (Tier 1–2 for $PM_{2.5}$, Tier 0 for CO) • Up to 45% fuel savings, average of 20–30% fuel savings in the field; moderate PM emissions but CO can be considerable	• Often include gates to control air flow into combustion chamber • Some stove models contain replaceable parts • More durable than legacy stoves, especially if produced semi-industrially	• Though considerable fuel savings might be achieved, the use of charcoal does not lead to a huge improvement in GHG; high CO emissions • Quality challenges common for artisanal basic charcoal ICS
Basic efficient wood ICS 	• Several improvements over 3-stone fires: improved insulation, heat transfer, air flow • Usually made of clay or insulated metal, some are purely metal designs	• Jambar (Senegal): $8–15 • Ouaga Metallique (Burkina Faso): $4–8 • Kuni Mbili (Kenya): $8–10	• Tier 1–2 for efficiency, Tier 1 for indoor emissions • Fuel savings can vary between 20% and 50%, but rarely exceed 25–30%	• Some stove models contain replaceable parts • Tailored to local cooking practices	• Notable improvement in fuel efficiency over traditional and legacy stoves; but little impact on emissions

Stove type	Description	Examples and illustrative prices	Performance indicators	Advantages	Disadvantages
Basic efficient wood ICS cont'd  	• Could be both built in and portable; occasionally combined with chimneys			• Portable, and can be produced at scale in a central location • Some stove models contain replaceable parts • More durable than legacy stoves especially if produced semi-industrially.	• Artisanal stoves in this category often have significant quality and durability challenges
Basic efficient multifuel ICS 	• Typically metal stoves; design most common in West Africa	• Sakkanal (Senegal): $8 • Multimarmite (Burkina Faso): $5	• Tier 1–2 for indoor efficiency and emissions	• Similar to basic efficient wood and charcoal ICS, with added advantage of adaptation for the stacking behavior of many urban African households (i.e., concurrent charcoal and wood use)	• Similar to basic efficient wood and charcoal stoves • Multifuel feature does not allow for sufficiently targeted performance improvements
INTERMEDIATE BIOMASS ICS					
Built-in rocket ICS   	• Rocket-type (L-shaped) combustion chamber to allow for better air flow • Built in and semi-portable stoves are mostly fixed/large stoves made of mud, bricks, cement • Often attached chimney and better insulation • Stoves installed on location by artisans; occasionally with prefabricated semi-industrial parts	• Rocket Lorena (Uganda): $10–15 • Mirt Stove Ethiopia: $7–10 • Brick rocket stoves (Kenya): $15–30 • International Lifeline Fund rocket stoves (Uganda)	• Tier 2–3 for indoor emissions, tier 3 for fuel efficiency • 40–65% fuel savings; high end of range typically for multiburner ICS	• Often tailored for local usage incorporating components, such as a cast iron griddle, ash trays, extensions for making *injera* flat breads in Ethiopia	• Stoves typically fitted with chimneys are large and more durable; built-in versions can be expensive • Requires ecosystem of installers/ masons which is robust in only a few African countries
Portable rocket ICS (semi-industrial)	• Stoves have a rocket-type , L-shaped combustion chamber	• Ugastove (Uganda): $12–18	• Tier 2 for indoor emissions, Tier 2–3 for efficiency	• Improved combustion, thermal efficiency, and often significant fuel savings	• Relatively high cost for the poor

Stove type	Description	Examples and illustrative prices	Performance indicators	Advantages	Disadvantages
Portable rocket ICS (semi-industrial) cont'd 	• Materials used include bricks, clay, metal • Most portable rocket stoves, are produced at local factories or via domestic assembly of prefabricated components (e.g., Save 80) • Degree of product quality varies widely in this category	• Tikikil (Ethiopia): $9–12 • Ken Steel Engineering Rocket (Malawi): $20–40 • Save 80: $80–100 • Roumde: $7–9	• Particulate matter emissions and CO emissions can be reduced by 30–50%		• PM emission abatement is moderate and rocket stoves may actually release more black carbon (relative to overall emissions) than traditional stoves
Portable rocket ICS (industrial) 	• In addition to the L-shaped rocket combustion chamber technology, these stoves have high-quality components • Stove body is made of improved metal, stainless steel, or alloy, with improved refractory properties • Some designs (e.g., EcoZoom Dura) allow for multiple fuel usage (wood, crop waste, charcoal) but are typically calibrated for wood use	• Envirofit (G-3300): $18–50 depending on market and level of subsidy • EcoZoom: $25–80 • Ezy Stove: $30–50 • *Jiko* Poa: $16–25	• Tier 2 for indoor emissions, Tier 3 for fuel efficiency • Significant fuel saving: 40–70%	• As with all rocket stoves, the major advantage is the potential for significant fuel savings • Use of alloys allows for improved life of stove, higher efficiencies, and lighter weight than semi-industrial rocket stoves	• Can be very expensive—may require subsidies, e.g., Save 80 stoves subsidized to $100 through CDM • Standardized designs might not suit local needs • Moderate emission reduction from health standpoint; some industrial rocket stoves concentrate BC emissions
High-end industrial charcoal ICS 	• Utilize rocket design principles (L-shaped chamber) and high-end, machine-tooled metal components • Range from a performance that is slightly better than basic charcoal ICS to very dramatic efficiency and emissions improvements for newest top-end design	• *Jiko* Koa: $35–50 • EzyChar: $40 • Envirofit CH4400: $50–100, CH2200 >$25	• Tier 1–3 for indoor emissions, Tier 3 for fuel efficiency • Significant fuel savings: 40–70%; up to 80% CO reduction compared to traditional charcoal stoves	• Significant fuel savings compared both traditional and basic charcoal ICS • Large CO reductions combined with modest PM decreases (relative to already low charcoal PM levels) mean that stoves can approach gasifier emission levels at very top of range	• Unless combined with renewable biomass briquettes/ pellets, burn unsustainable fuel • Very high cost (though the payback period can be rapid in high-cost charcoal markets)

ADVANCED BIOMASS COOKSTOVES (ICS)					
Stove type	**Description**	**Examples and illustrative prices**	**Performance indicators**	**Advantages**	**Disadvantages**
Natural-draft gasifier ACS   	• These stoves use gasification principles due to the shape of their combustion chamber—fuel (wood/charcoal/ agricultural waste) is pyrolyzed in the gas chamber, the flue gases then are allowed to mix with a fresh draft of air and burned • Stove is usually made of metal: stainless steel/aluminum; artisanal/semi-industrial versions will often have wood parts (e.g., Awamu Troika) • Typical natural-draft gasifiers are top-lit up-draft (TLUD) designs, but some side-loading "rockifier" designs (e.g., GreenTech stove in The Gambia) also exist	• Awamu Troika TLUD: $18 (at manufacturing site) • Sampada Gasifier stove: $20 • TLUD stove (Servals): $32 • Lucia WorldStove: $30–50 • Peko Pe/ Wandelbo TLUD: $10+ (not widely available commercially, but $2–5 production cost) • Vesto: $30–50 • Greentech (The Gambia) "rockifier": $15	• Tier 2–3 for indoor emissions, Tier 3 for efficiency	• Highly efficient stoves with low levels of emissions • Often produce bio-char/ charcoal—can be used for fertilizer or sold • TChar variants can be integrated with charcoal cooking (i.e., char produced during gasification can be used as charcoal) • Often use a variety of fuel: wood, agricultural waste	• Relatively high price and still few local production models • Often requires significant behavior change, including top loading of fuel and fuel preparation (e.g., breaking wood into little pieces) if pellets not used • High variability of performance across models
Fan ("forced-updraft") gasifier ACS 	• Stoves that rely on gasification principles with the secondary draft of air aided by a battery-powered fan component • Usually made of stainless steel/ aluminium and could include a rocket-type combustion chamber	• Philips/ACE smokeless stove (Philips HD4012): $75–100 • Philips/ACE AE-1 stove • Oorja stove	• Tier 3 for indoor emissions, nearly approaching Tier 4 at top end of range; Tier 3–4 for efficiency • Up to 95% reduction in emissions, can reach 70–80% fuel savings, particularly with pellet fuels	• Made of light-weight and advanced materials and are ultra-portable • Fans enable effective mixing of air, and gasification helps reduce incomplete combustion • Stove can charge LEDs and phones	• Stoves optimized for pellet fuel use; perform less well if wide variety of fuels needed • Instructions must be closely followed to realize efficiency gains • Addition of fans increase price by $5–10 and may reduce durability
Electricity-generating ACS	• Fan gasifiers that convert heat to electricity and power stove's fan and, potentially, other appliances like mobile phones	• Biolite TEG Home Stove: $45–65	• Tier 3 for emissions, Tier 3–4 for efficiency	• All of the pluses of battery-powered fan-gasifier stoves, plus additional advantages of reduced cost of	• Same disadvantages as broader fan-gasifier stove family, with particular challenge on

Stove type	Description	Examples and illustrative prices	Performance indicators	Advantages	Disadvantages
Electricity-generating ACS cont'd    	• Currently only one model on the African market, BioLite HomeStove, a side-loading gasifier that powers fan with thermoelectric generation (TEG); BioLite's new Kettle Charge product utilizes TEG technology to generate 10W of electricity from any stove/hot surface. • Other new stove technologies with electric device charging capabilities are powered by solar panel/battery combos (e.g., ACE 1)	• New ACE 1/ Philips uses 5W solar panel/battery technology to deliver solar lighting and mobile charging functionality • Score-Stove thermoacoustic stove (prototype only, tested in Africa) • Several manufacturers exploring launch of TEG models in 2015 and off-brand models are marketed in China, but feasibility of new large-scale entrants with this technology is unclear due to BioLite patent restrictions		• ownership (i.e., no need for battery replacement) and improved value proposition due to mobile phone-charging capabilities	stove cost due to the need to include both fan and electricity-generating components • Long-term durability requires ongoing testing, as prototypes are relatively new and have only recently been deployed with some scale in African conditions • Some stove models in this category incorporate batteries into the design, which require periodic replacement (e.g., every 3–4 years)
MODERN FUEL AND RENEWABLE FUEL STOVES					
LPG   	• Single and multiburner stoves burning liquefied petroleum gas (LPG) from pressurized cylinders • Stainless steel/metal stove • Some LPG stove manufacturing based in Africa (e.g., South Africa, Togo), but vast majority imported from Asia	• Single-burner LPG stoves: \$10–50 • Multiburner stove: \$50–90	• Tier 4 for efficiency, Tier 4 for indoor emissions • Clean cooking fuel at point of use; very low emissions and high efficiency	• High calorific value, delivers double the heat for the same amount of kerosene • Fast cooking time	• Expensive cooking solution and very expensive fuel • Danger of explosion • Stove usage is heavily dependent on fuel supply, which is limited in most of Africa
Kerosene 	• 2 types: pressure stoves and wick type stoves (wick-type can be single wick or heater-type circular wick)	• Basic kerosene stoves: \$5–20 • More advanced kerosene stoves (e.g., Servals, Arivi): \$10–40	• Tier 3–4 for efficiency, Tier 3–4 for indoor emissions • Kerosene stoves produce little or no CO emissions	• Fast cooking • Inexpensive stoves	• Wick stoves burn with a lot of soot as opposed to pressure stoves • Expensive fuel

Stove type	Description	Examples and illustrative prices	Performance indicators	Advantages	Disadvantages
Kerosene cont'd 	• In pressure stoves the fuel is preheated before undergoing combustion; pressure is provided by a pressure pump • In wick stoves, the wick drives fuel to burner; usually made of metal, such as brass			• Widespread fuel availability in most parts of Africa, given the lighting uses of paraffin/ kerosene	• Danger of kerosene burns if stove falls over • High non-PM toxic particle emissions
Electric  	• Electric cookstoves convert electrical energy into heat • Single-burner and double-burner models in use in urban Africa • Induction cookers generate heat via an oscillating magnetic field and are highly efficient	• Wide range of costs: \$15–50 for single burner; \$40–150 for double burner; >\$150 for electric induction cookers	• Tier 4 for efficiency, Tier 4 for indoor emissions	• Commercial stoves are highly durable, extremely efficient, easy to maintain	• Most expensive cooking solution in Africa, aside from 2–3 subsidized markets • Low grid penetration in SSA • Unreliable power services make regular cooking with electricity difficult
Alcohol  	• Fuel, such as plant oil, ethanol, methanol burned in liquid, solid, gel forms • Fuel needs to be produced from processing of sources, such as oil seeds, cassava • The fuel is collected in small tanks, and pressurized to be used on burner-style stoves	• CleanCook: \$50–80 • Lower-cost, lower-quality ethanol gel stoves available: \$25–50	• Tier 3–4 for efficiency, tier 3–4 for indoor emissions	• By-products of oil processing or ethanol making can be used as fertilizer or fodder • Stoves are durable—lasting for up to 10 years • Stoves are convenient and safe	• Needs a separate fuel-supply chain • Fuel usage will depend on local sources available for processing • Stoves are expensive, mostly catering to urban • May not burn as hot as LPG
Biogas  	• Stoves have to accompanied by a biogas plant, which produces methane from biomass • Pressured gas from tanks is burned on burner-style stoves • ABPP distribution program	• Traditional digesters: \$1,000–1,500 w/o subsidy, burner is \$10–30 • Small-scale digester (SimGas): \$500–800	• Tier 4 for efficiency, Tier 4 for indoor emissions • Cleaner than LPG	• The fuel used is renewable biomass/waste • The residue in the tanks can be used as fertilizer	• Need sufficient feedstock (dung) • High upfront costs • Ongoing maintenance requirements

Stove type	Description	Examples and illustrative prices	Performance indicators	Advantages	Disadvantages
Solar cookers 	• Direct solar thermal energy can be used to power solar cookstoves • A variety of designs available from global experience: foldable/ low-cost materials, box cookers, parabolic reflectors	• CookIt: $10–20 • Parabolic solar ovens: >$100 • Box cookers: $50–150	• Tier 4 for emissions; 100% fuel savings theoretically, though stove use limited to sunny days	• Absolutely the cleanest source of cooking energy • No ongoing costs once the solar oven/ cooker is purchased	• Slow cooking • Quality stoves are fairly expensive • Dependent on light availability and therefore a secondary solution

Note: All monetary values are in U.S. dollars.

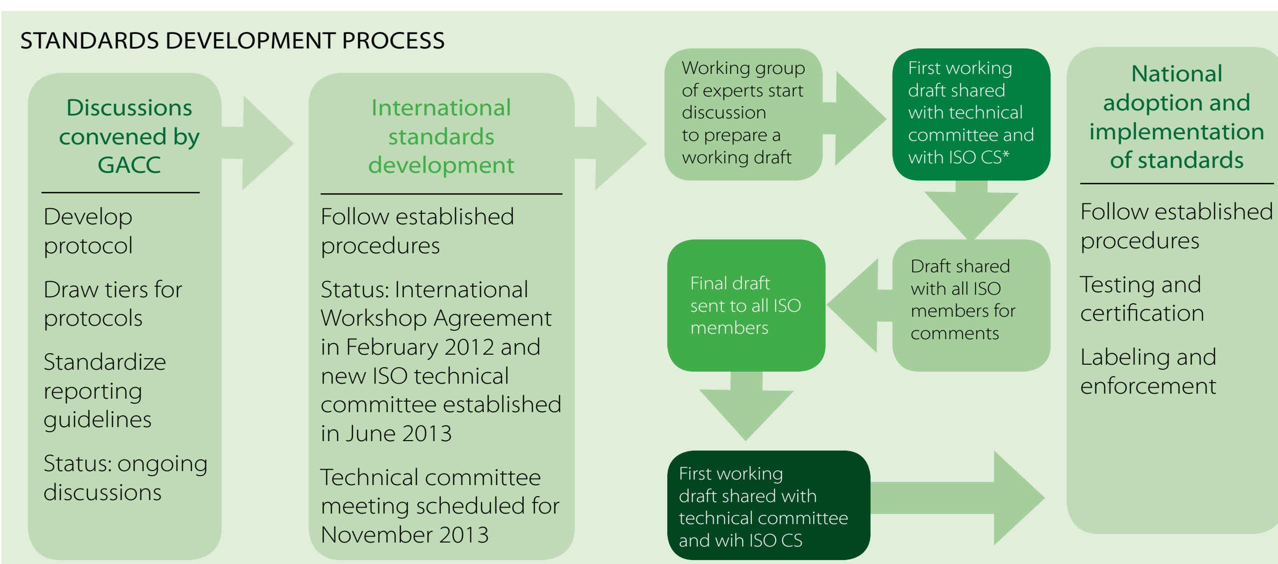
Sources: Press searches; interviews; desk review; GACC Stoves Catalog (http://catalog.cleancookstoves.org); Dalberg analysis.

APPENDIX 2: PROVISIONAL STANDARDS FOR IMPROVED AND CLEAN COOKSTOVES

Table 2.1: Provisional ISO/IWA tier classifications for clean and improved cooking technologies

Proposed ISO tier	Safety rating (Iowa State Univ. Rating System)	Fuel use (thermal efficiency) (%)	Emissions (CO + PM) (stove rating will be based on the lowest score from the four criteria)				Indoor emissions		Illustrative stove type
			CO (g/MJ)	CO (g/min/L)	PM (mg/MJ)	PM (µg/min/L)	CO (g/min)	PM (µg/min)	
Tier 0	<45	<15	>16	>0.2	>979	>8	>0.97	>40	3-stone fire
Tier 1	≥45	≥15	<16	<0.2	<979	<8	<0.97	<40	Improved efficient charcoal stove (KCJ type)
Tier 2	≥75	≥25	<11	<0.13	<386	<4	<0.62	<17	Rocket stove; natural-draft gasifier
Tier 3	≥88	≥35	<9	<0.1	<168	<2	<0.49	<8	Forced-draft "fan"-gasifier stove
Tier 4	≥95	≥45	<8	<0.09	<41	<1	<0.42	<2	LPG stove

Figure 2.1: Cookstove ISO standards development process



Source: Global Alliance for Clean Cookstoves (2012), available at http://www.cleancookstoves.org/resources_files/results-report-2012.pdf

APPENDIX 3: METHODOLOGY FOR SIZING SOLID-FUEL COOKING OPPORTUNITY COST

Our SSA impact model incorporates commonly attributed economic, health, and environmental impacts of solid-fuel cooking and represents the total economic value—or opportunity cost—foregone annually because of reliance on solid fuels. This is considered in relation to a best-case scenario of full adoption of higher-performing ICS by African households, intermediate Tier 2–3 rocket stoves at the bottom of the range, and Tier 3–4 gasifier biomass stoves at the top of the range.

Naturally, the precise numbers will vary based on the assumptions used and on the counterfactual baseline. For instance, in an alternate scenario where households that currently pay for solid fuels are shifted to LPG and biomass fuel collectors are shifted to high-performing ICS, the mid-range opportunity cost of solid-fuel cooking would be $27 billion, with higher health and environmental benefits and lower economic savings due to the relatively high costs of LPG fuel use. Independently of the precise scenario used, however, it is clear that the magnitude of the opportunity cost is in the high tens to the hundreds of billions of dollars.

For **economic impact**, key variables are avoidable economic values of solid-fuel spending, firewood collection time, and cooking time. For **health impacts**, the model includes the economic costs of the most recent *Lancet* HAP-related morbidity and mortality estimates, with the addition of burns linked to traditional solid-fuel stoves and minor eye conditions linked to indoor smoke exposure. For **environment and climate change** impacts, the model estimates the costs of deforestation (valued via potential afforestation costs) and the carbon credit value of avoidable GHG emissions. The opportunity costs of time and related values throughout the model (e.g., cost of death due to HAP) are based on average gross national income for the SSA region and agricultural value added using human-capital methodology. Cooking-fuel mix and fuel-use data draw on an up-to-date database of national fuel consumption surveys for all 47 SSA countries.

The core methodological framework is derived from Hutton et al. (2007) and Jeuland and Pattanayak (2012). Underlying assumptions are derived from the extensive existing literature on solid-fuel impacts, with strong weighting toward SSA examples.

Table 3.1: Economic losses and opportunity costs in SSA from dependence on solid fuel in 2010 (US$ billions)

Cost category	Low	Mid-range	High
Health	**$0.6**	**$5.0**	**$9.4**
Mortality for HAP	$0.3	$3.5	$6.8
Morbidity for HAP	$0.2	$0.7	$1.1
Other health conditions (burns and eye disease)	$0.1	$0.8	$1.5
Environment & climate change	**$0.6**	**$6.3**	**$11.9**
GHG emissions—fuel consumption	$0.2	$2.1	$3.9
GHG emissions—charcoal production	$0.2	$0.7	$1.2
Deforestation	$0.2	$3.5	$6.7
Economic effects	**$4.2**	**$20.6**	**$36.9**
Spending on solid fuels	$0.4	$3.8	$7.3
Time wastage (fuel collection)	$0.6	$6.5	$12.4
Time wastage (cooking time)	$3.3	$10.2	$17.2
Total	**$5.4**	**$31.8**	**$58.2**

Sources: Opportunity cost sizing model; Dalberg analysis.

APPENDIX 4: METHODOLOGY FOR CALCULATING SSA FUEL MIX AND FUEL MIX EVOLUTION

The regional fuel mix was calculated by aggregating household survey data for 45 SSA countries based on data maintained by the WHO Global Health Data Repository and/or from underlying country surveys from the Demographic and Health Surveys (DHS) Program, the Multiple Indicator Cluster Survey (MICS), the Living Standards Measurement Study (LSMS), or national census sources for the most recent year available. As a proxy for the year 2000, the analysis used household survey data from 1998 to 2002, depending on the country; for the year 2010, 2007–12 data were used. Only actual survey data were used—the aggregated results were triangulated with WHO parametric estimates for 2010, but WHO parametric data were not used. Survey data were cleaned to ensure that rural and urban mix data tallied to country totals, and absolute counts of fuel-user populations were computed by multiplying fuel mix with UN population estimates.

The regional fuel mix was projected to 2015 and 2020 by computing the historical annual changes in fuel share for each fuel (2000–10) for both rural and urban areas, assuming that the historical change will continue going forward in a linear fashion through 2020, and remixing the forecasted urban and rural fuel shares by UN forecasts for rural and urban population for each country. In effect, this analysis derives an "inertial case" fuel mix for each cooking fuel, adjusted for population growth and urbanization rates. At a country level, this approach may be inaccurate (it does not take into account differential GDP growth, for example), but at the regional level the data are likely robust and fit well with IEA/OECD 2010 projections for the overall African solid-fuel population (about 850 million in 2020).

Table 4.1: SSA population by primary cooking fuel (millions)

Fuel	2000	2010	2015 F	2020 F
Electricity	30	46	56	68
LPG	23	37	47	58
Natural gas	1	2	2	3
Kerosene	52	56	57	58
Coal	7	10	11	13
Charcoal	61	109	143	188
Wood	470	572	615	663
Dung/crop waste	12	15	16	20
Other	10	7	5	4
Total	**667**	**854**	**953**	**1,073**
Modern fuel	107	142	162	186
Solid fuel	550	705	786	883
Other	10	7	5	4
Total	**667**	**854**	**953**	**1,073**

Note: F = forecast.
Sources: SSA country fuel mix database; Dalberg analysis.

APPENDIX 5: SSA FUEL MIX

Table 5.1: Country fuel mix data

Country	Year	LPG/LNG/ biogas	Electricity	Kerosene	Coal	Charcoal	Wood	Ag. waste/ straw	Dung	Other	Solid-fuel share
Angola	2009	33%	1%	4%	0%	19%	42%	0%	0%	1%	62%
Benin	2012	6%	0%	0%	1%	26%	65%	1%	0%	1%	94%
Botswana	2006	46%	7%	3%	0%	0%	43%	0%	0%	0%	44%
Burkina Faso	2010	5%	0%	0%	0%	4%	88%	0%	0%	3%	95%
Burundi	2010	0%	0%	0%	0%	8%	85%	6%	0%	1%	100%
Cameroon	2011	18%	0%	4%	0%	2%	71%	1%	0%	3%	78%
Cape Verde	2006	64%	0%	0%	0%	0%	34%	0%	0%	2%	36%
Central African Republic	2010	0%	0%	0%	0%	3%	96%	0%	0%	1%	100%
Chad	2010	2%	0%	0%	0%	3%	93%	1%	1%	1%	98%
Comoros	2011	4%	1%	18%	0%	2%	73%	0%	0%	2%	77%
Congo (Brazzaville)	2012	15%	1%	11%	0%	33%	38%	0%	0%	1%	72%
Côte d'Ivoire	2012	15%	0%	0%	0%	18%	60%	0%	0%	7%	85%
Democratic Republic of the Congo	2007	0%	4%	0%	0%	25%	71%	0%	0%	0%	96%
Djibouti	2006	5%	1%	81%	0%	9%	4%	0%	0%	1%	14%
Equatorial Guinea	2012	18%	1%	35%	0%	1%	42%	0%	0%	3%	46%
Eritrea	2009	3%	0%	16%	0%	10%	60%	0%	10%	1%	81%
Ethiopia	2011	0%	1%	2%	0%	8%	78%	2%	7%	2%	97%
Gabon	2012	79%	0%	1%	0%	1%	13%	0%	0%	5%	20%
Gambia, The	2010	1%	0%	0%	0%	12%	85%	0%	0%	2%	99%
Ghana	2011	17%	0%	0%	0%	29%	50%	1%	0%	2%	82%
Guinea	2012	0%	0%	0%	0%	29%	69%	0%	0%	2%	100%
Guinea-Bissau	2010	1%	0%	0%	0%	31%	68%	1%	0%	0%	99%
Kenya	2009	5%	0%	5%	1%	16%	72%	2%	0%	0%	90%
Lesotho	2009	21%	6%	7%	0%	0%	49%	7%	8%	1%	66%
Liberia	2007	0%	0%	0%	0%	39%	59%	0%	0%	1%	100%
Madagascar	2011	1%	0%	0%	1%	21%	76%	0%	0%	1%	99%
Malawi	2010	0%	2%	0%	0%	10%	86%	2%	0%	0%	98%
Mali	2006	0%	0%	0%	0%	16%	80%	0%	2%	1%	100%
Mauritania	2011	38%	1%	0%	0%	20%	40%	0%	0%	1%	61%
Mozambique	2011	3%	1%	0%	1%	15%	80%	0%	0%	1%	97%
Namibia	2006	7%	34%	0%	0%	1%	55%	0%	0%	3%	58%
Niger	2012	1%	0%	0%	0%	2%	86%	7%	2%	2%	99%
Nigeria	2013	2%	0%	26%	0%	3%	64%	2%	0%	3%	72%
Rwanda	2010	0%	0%	0%	0%	10%	89%	0%	0%	1%	100%
Senegal	2011	32%	1%	0%	0%	12%	53%	0%	1%	1%	67%
Sierra Leone	2010	0%	0%	0%	0%	0%	14%	0%	83%	2%	100%
Somalia	2005	0%	0%	0%	0%	33%	66%	0%	0%	0%	100%
South Africa	2007	2%	66%	15%	1%	0%	15%	0%	0%	0%	17%
South Sudan	2010	8%	0%	0%	18%	2%	70%	1%	1%	0%	91%
Sudan	2006	0%	0%	0%	0%	14%	81%	3%	0%	1%	100%
Swaziland	2010	11%	17%	3%	0%	0%	69%	0%	0%	0%	70%
Tanzania	2010	0%	1%	3%	0%	21%	74%	0%	0%	1%	96%
Togo	2010	2%	0%	0%	0%	39%	59%	0%	0%	0%	98%
Uganda	2011	1%	0%	1%	0%	23%	73%	0%	0%	2%	98%
Zambia	2007	0%	15%	0%	0%	25%	60%	0%	0%	0%	85%
Zimbabwe	2011	0%	28%	2%	0%	0%	69%	0%	0%	1%	70%

Sources: WHO, DHS, MICS, National Census data, Dalberg analysis (rounded to nearest percentage point). Data are as of July 2014.

Table 5.2: Detailed country fuel mix data—latest available, as of July 2014

Country	Year	Source	Mix	LPG/LNG/ biogas	Electricity	Kerosene	Coal	Charcoal	Wood	Ag. waste/ straw	Dung	Other	Solid fuel	Modern fuel
Angola	2009	MICS/ IBEP (2011)	Total	33%	1%	4%	0%	19%	43%	0%	0%	0%	62%	38%
			Rural	3.5%	0.3%	3.5%	0.0%	11.8%	79.9%	0.3%	0.0%	0.7%	92.7%	7.3%
			Urban	59.5%	1.7%	4.1%	0.0%	25.2%	8.0%	0.2%	0.0%	1.3%	34.7%	65.3%
Benin	2012	DHS	Total	5.9%	0.0%	0.4%	1.0%	25.7%	65.3%	0.6%	0.0%	1.1%	93.7%	6.3%
			Rural	0.4%	0.0%	0.1%	0.1%	7.6%	90.0%	0.8%	0.0%	1.0%	99.5%	0.5%
			Urban	12.9%	0.1%	0.8%	2.1%	48.4%	34.1%	0.2%	0.0%	1.4%	86.2%	13.8%
Botswana	2006	WHO	Total	45.8%	7.2%	3.2%	0.1%	0.0%	43.4%	0.0%	0.1%	0.1%	43.8%	56.2%
			Rural	36.7%	4.5%	1.8%	0.1%	0.0%	56.6%	0.0%	0.2%	0.1%	57.0%	43.0%
			Urban	71.1%	14.8%	7.2%	0.1%	0.0%	6.6%	0.0%	0.0%	0.2%	6.9%	93.1%
Burkina Faso	2010	DHS	Total	5.3%	0.0%	0.0%	0.0%	4.3%	87.5%	0.0%	0.0%	2.9%	94.7%	5.3%
			Rural	0.8%	0.0%	0.0%	0.0%	1.3%	95.4%	0.0%	0.0%	2.5%	99.2%	0.8%
			Urban	19.0%	0.0%	0.0%	0.0%	13.2%	63.6%	0.0%	0.0%	4.2%	81.0%	19.0%
Burundi	2010	DHS	Total	0.2%	0.0%	0.0%	0.0%	8.3%	84.7%	5.5%	0.0%	1.3%	99.8%	0.2%
			Rural	0.0%	0.1%	0.0%	0.0%	2.2%	91.2%	5.9%	0.0%	0.6%	99.9%	0.1%
			Urban	0.5%	0.8%	0.0%	0.0%	70.0%	20.0%	1.1%	0.0%	7.6%	98.7%	1.3%
Cameroon	2011	DHS	Total	18.3%	0.1%	3.8%	0.3%	2.4%	70.5%	1.3%	0.0%	3.3%	77.8%	22.2%
			Rural	1.6%	0.0%	0.9%	0.0%	1.3%	92.5%	1.7%	0.0%	2.0%	97.5%	2.5%
			Urban	34.3%	0.2%	6.6%	0.6%	3.4%	49.3%	1.1%	0.0%	4.5%	58.9%	41.1%
Cape Verde	2006	WHO	Total	63.7%	0.0%	0.0%	0.0%	0.0%	33.8%	0.0%	0.0%	2.4%	36.3%	63.7%
			Rural	27.6%	0.0%	0.0%	0.0%	0.0%	70.7%	0.0%	0.0%	1.7%	72.4%	27.6%
			Urban	86.0%	0.0%	0.0%	0.0%	0.0%	11.1%	0.0%	0.0%	2.9%	14.0%	86.0%
Central African Republic	2010	MICS	Total	0.1%	0.1%	0.0%	0.2%	2.6%	96.3%	0.0%	0.0%	0.7%	99.8%	0.2%
			Rural	0.0%	0.0%	0.0%	0.2%	0.4%	98.8%	0.0%	0.0%	0.6%	100.0%	0.0%
			Urban	0.1%	0.2%	0.1%	0.3%	6.1%	92.5%	0.0%	0.0%	0.8%	99.7%	0.3%
Chad	2010	MICS	Total	1.6%	0.1%	0.3%	0.0%	2.9%	92.9%	0.6%	0.5%	1.1%	98.0%	2.0%
			Rural	0.0%	0.0%	0.0%	0.0%	1.1%	96.9%	0.6%	0.6%	0.8%	100.0%	0.0%
			Urban	7.0%	0.4%	1.3%	0.1%	8.7%	80.1%	0.5%	0.2%	1.7%	91.3%	8.7%
Comoros	2011	DHS	Total	4.0%	0.5%	18.3%	0.2%	1.6%	73.4%	0.2%	0.0%	1.8%	77.2%	22.8%
			Rural	1.6%	0.3%	5.5%	0.2%	1.2%	89.2%	0.2%	0.0%	1.8%	92.6%	7.4%
			Urban	8.7%	1.0%	43.8%	0.2%	2.3%	41.7%	0.3%	0.0%	2.0%	46.5%	53.5%
Congo (Brazzaville)	2012	DHS	Total	15.0%	1.2%	11.4%	0.0%	32.8%	37.8%	0.3%	0.0%	1.5%	72.4%	27.6%
			Rural	1.4%	1.1%	3.6%	0.0%	11.3%	81.7%	0.0%	0.0%	0.9%	93.9%	6.1%
			Urban	22.9%	1.3%	16.0%	0.0%	45.3%	12.2%	0.4%	0.0%	1.9%	59.8%	40.2%
Côte D'Ivoire	2012	DHS	Total	14.9%	0.0%	0.0%	0.0%	17.8%	60.0%	0.0%	0.0%	7.3%	85.1%	14.9%
			Rural	0.9%	0.0%	0.0%	0.0%	5.4%	86.9%	0.0%	0.0%	6.8%	99.1%	0.9%
			Urban	31.8%	0.0%	0.0%	0.0%	32.8%	27.6%	0.0%	0.0%	7.8%	68.2%	31.8%
Democratic Republic of the Congo	2007	DHS	Total	0.0%	3.7%	0.1%	0.0%	24.9%	71.2%	0.0%	0.0%	0.1%	96.2%	3.8%
			Rural	0.0%	0.0%	0.0%	0.0%	11.2%	88.8%	0.0%	0.0%	0.1%	100.0%	0.0%
			Urban	0.0%	10.9%	0.3%	0.0%	52.0%	36.2%	0.6%	0.0%	0.0%	88.8%	11.2%
Djibouti	2006	National Census / WHO	Total	4.9%	0.6%	80.6%	0.0%	8.7%	3.7%	0.0%	0.0%	1.5%	13.9%	86.1%
			Rural	4.2%	0.6%	70.7%	0.0%	14.6%	7.7%	0.0%	0.0%	2.2%	24.5%	75.5%
			Urban	5.1%	0.6%	83.6%	0.0%	6.9%	2.5%	0.0%	0.0%	1.3%	10.7%	89.3%
Equatorial Guinea	2012	DHS	Total	17.9%	1.3%	34.7%	0.3%	1.0%	42.2%	0.1%	0.0%	2.5%	46.1%	53.9%
			Rural	5.3%	0.9%	17.9%	0.3%	1.8%	72.2%	0.2%	0.2%	1.2%	75.9%	24.1%
			Urban	32.6%	1.8%	54.4%	0.2%	0.0%	7.3%	0.0%	0.1%	3.6%	11.2%	88.8%

Country	Year	Source	Mix	LPG/LNG/ biogas	Electricity	Kerosene	Coal	Charcoal	Wood	Ag. waste/ straw	Dung	Other	Solid fuel	Modern fuel
Eritrea	2009	EPHS (2010)	Total	3.0%	0.0%	16.0%	0.0%	10.0%	60.0%	0.0%	10.0%	1.0%	81.0%	19.0%
			Rural	0.5%	0.0%	7.0%	0.0%	10.0%	71.0%	0.0%	11.0%	0.5%	92.5%	7.5%
			Urban	13.7%	2.0%	54.4%	0.0%	10.0%	13.1%	0.0%	5.7%	1.1%	30.0%	70.0%
Ethiopia	2011	DHS	Total	0.3%	0.7%	2.4%	0.0%	7.7%	77.9%	2.0%	7.0%	2.0%	96.6%	3.4%
			Rural	0.0%	0.0%	0.1%	0.0%	1.2%	87.3%	2.2%	8.3%	0.9%	99.9%	0.1%
			Urban	1.1%	2.9%	10.1%	0.0%	29.9%	46.2%	1.3%	2.8%	5.7%	85.9%	14.1%
Gabon	2012	DHS	Total	79.0%	0.3%	0.9%	0.0%	1.4%	13.1%	0.0%	0.0%	5.3%	19.8%	80.2%
			Rural	35.3%	0.1%	0.7%	0.0%	4.6%	57.8%	0.0%	0.0%	1.5%	63.9%	36.1%
			Urban	87.7%	0.4%	0.9%	0.0%	0.8%	4.4%	0.0%	0.0%	5.8%	11.0%	89.0%
Gambia, The	2010	MICS	Total	0.7%	0.1%	0.0%	0.0%	12.0%	85.2%	0.4%	0.0%	1.6%	99.2%	0.8%
			Rural	0.0%	0.0%	0.0%	0.0%	0.6%	98.3%	0.3%	0.0%	0.8%	100.0%	0.0%
			Urban	1.7%	0.0%	0.1%	0.0%	25.2%	70.1%	0.4%	0.0%	2.5%	98.2%	1.8%
Ghana	2011	MICS	Total	17.4%	0.3%	0.1%	0.0%	29.4%	50.0%	1.0%	0.0%	1.8%	82.2%	17.8%
			Rural	3.6%	0.0%	0.0%	0.0%	15.6%	77.0%	2.9%	0.0%	0.9%	96.4%	3.6%
			Urban	31.9%	0.6%	0.3%	0.0%	44.2%	21.2%	0.4%	0.0%	1.4%	67.2%	32.8%
Guinea	2012	DHS	Total	0.1%	0.2%	0.0%	0.0%	28.6%	68.6%	0.0%	0.0%	2.5%	99.7%	0.3%
			Rural	0.0%	0.0%	0.0%	0.0%	7.0%	91.7%	0.0%	0.0%	1.3%	100.0%	0.0%
			Urban	0.2%	0.6%	0.1%	0.0%	72.9%	21.1%	0.0%	0.0%	5.1%	99.1%	0.9%
Guinea-Bissau	2010	MICS	Total	0.6%	0.0%	0.0%	0.0%	30.8%	67.7%	0.8%	0.1%	0.0%	99.4%	0.6%
			Rural	0.0%	0.0%	0.0%	0.0%	3.0%	96.7%	0.1%	0.1%	0.1%	100.0%	0.0%
			Urban	1.3%	0.0%	0.0%	0.0%	69.5%	27.4%	1.7%	0.0%	0.1%	98.7%	1.3%
Kenya	2009	DHS	Total	4.8%	0.3%	4.5%	0.9%	15.8%	71.9%	1.5%	0.0%	0.3%	90.4%	9.6%
			Rural	0.9%	0.0%	0.6%	1.1%	8.7%	87.0%	1.6%	0.0%	0.1%	98.5%	1.5%
			Urban	21.2%	1.4%	20.9%	0.0%	45.2%	9.4%	1.0%	0.0%	0.9%	56.5%	43.5%
Lesotho	2009	DHS	Total	20.5%	6.1%	7.4%	0.2%	0.0%	49.4%	7.4%	7.9%	1.1%	66.0%	34.0%
			Rural	10.2%	1.7%	4.1%	0.2%	0.0%	71.8%	1.0%	10.1%	0.9%	84.0%	16.0%
			Urban	53.1%	20.1%	17.7%	0.1%	0.0%	7.0%	0.0%	1.1%	0.9%	9.1%	90.9%
Liberia	2007	DHS	Total	0.1%	0.0%	0.1%	0.0%	39.4%	59.3%	0.0%	0.0%	1.2%	99.9%	0.1%
			Rural	0.0%	0.0%	0.0%	0.0%	13.1%	86.2%	0.0%	0.0%	0.8%	100.0%	0.0%
			Urban	0.2%	0.0%	0.1%	0.0%	85.3%	12.6%	0.0%	0.0%	1.8%	99.7%	0.3%
Madagascar	2011	EIPMD / MICS	Total	0.6%	0.1%	0.0%	1.0%	21.4%	75.9%	0.0%	0.0%	1.1%	99.4%	0.7%
			Rural	0.1%	0.1%	0.0%	0.0%	12.7%	84.9%	0.0%	2.0%	0.2%	99.8%	0.2%
			Urban	2.6%	0.7%	0.1%	0.3%	74.5%	20.4%	0.0%	1.4%	0.0%	96.6%	3.4%
Malawi	2010	DHS	Total	0.0%	1.6%	0.0%	0.0%	10.4%	86.4%	1.5%	0.0%	0.1%	98.4%	1.6%
			Rural	0.0%	0.2%	0.0%	0.0%	3.0%	95.0%	1.7%	0.0%	0.1%	99.8%	0.2%
			Urban	0.0%	8.9%	0.1%	0.1%	49.4%	40.7%	0.5%	0.0%	0.3%	91.0%	9.0%
Mali	2006	DHS	Total	0.4%	0.0%	0.0%	0.0%	15.9%	80.2%	0.0%	2.2%	1.3%	99.5%	0.5%
			Rural	0.0%	0.0%	0.0%	0.0%	5.3%	91.2%	0.0%	2.6%	0.9%	99.9%	0.1%
			Urban	1.4%	0.1%	0.0%	0.0%	40.0%	55.2%	0.0%	1.1%	2.3%	98.6%	1.4%
Mauritania	2011	MICS	Total	38.2%	1.1%	0.0%	0.0%	19.5%	40.3%	0.0%	0.0%	0.9%	60.7%	39.3%
			Rural	18.1%	0.2%	0.0%	0.0%	15.0%	65.6%	0.0%	0.0%	1.1%	81.7%	18.3%
			Urban	65.5%	2.3%	0.0%	0.0%	25.7%	5.8%	0.0%	0.0%	0.7%	32.2%	67.8%
Mozambique	2011	DHS	Total	2.6%	0.8%	0.0%	1.0%	15.0%	80.0%	0.0%	0.0%	0.6%	96.6%	3.4%
			Rural	0.3%	0.1%	0.0%	0.2%	3.4%	95.4%	0.0%	0.0%	0.6%	99.6%	0.4%
			Urban	8.0%	2.5%	0.1%	2.8%	42.2%	44.2%	0.0%	0.0%	0.2%	89.4%	10.6%
Namibia	2006	DHS	Total	7.2%	34.2%	0.3%	0.1%	0.6%	54.9%	0.0%	0.2%	2.6%	58.3%	41.7%
			Rural	3.5%	5.9%	0.1%	0.1%	0.9%	88.8%	0.1%	0.4%	0.2%	90.5%	9.5%
			Urban	11.5%	67.1%	5.4%	0.0%	0.1%	15.5%	0.0%	0.0%	0.4%	16.0%	84.0%

Country	Year	Source	Mix	LPG/LNG/ biogas	Electricity	Kerosene	Coal	Charcoal	Wood	Ag. waste/ straw	Dung	Other	Solid fuel	Modern fuel
Niger	2012	DHS	**Total**	**0.8%**	**0.1%**	**0.0%**	**0.1%**	**1.5%**	**86.2%**	**7.3%**	**1.9%**	**2.1%**	**99.1%**	**0.9%**
			Rural	0.0%	0.0%	0.0%	0.0%	0.4%	86.9%	8.5%	2.3%	1.9%	100.0%	0.0%
			Urban	5.0%	0.5%	0.0%	0.5%	7.1%	82.7%	1.2%	0.0%	3.0%	94.5%	5.5%
Nigeria	2013	DHS	**Total**	**2.3%**	**0.4%**	**25.5%**	**0.3%**	**3.2%**	**63.7%**	**1.8%**	**0.1%**	**2.7%**	**71.8%**	**28.2%**
			Rural	0.5%	0.2%	8.7%	0.0%	1.6%	83.3%	3.1%	0.1%	2.5%	90.6%	9.4%
			Urban	4.6%	0.7%	47.6%	0.7%	5.3%	37.9%	0.2%	0.0%	3.0%	47.1%	52.9%
Rwanda	2010	DHS	**Total**	**0.1%**	**0.1%**	**0.1%**	**0.3%**	**9.6%**	**88.7%**	**0.0%**	**0.1%**	**1.1%**	**99.7%**	**0.3%**
			Rural	0.0%	0.0%	0.1%	0.1%	3.0%	95.7%	0.0%	0.2%	1.0%	99.9%	0.1%
			Urban	0.3%	0.3%	0.5%	1.6%	50.1%	45.4%	0.0%	0.0%	1.8%	98.9%	1.1%
Senegal	2011	DHS	**Total**	**31.6%**	**1.2%**	**0.0%**	**0.0%**	**11.8%**	**52.5%**	**0.0%**	**1.4%**	**1.5%**	**67.2%**	**32.8%**
			Rural	5.1%	0.5%	0.0%	0.0%	8.2%	82.8%	0.0%	2.7%	0.7%	94.4%	5.6%
			Urban	59.3%	2.0%	0.0%	0.0%	15.5%	20.8%	0.0%	0.1%	2.3%	38.7%	61.3%
Sierra Leone	2010	MICS	**Total**	**0.1%**	**0.0%**	**0.0%**	**0.3%**	**0.1%**	**14.0%**	**0.0%**	**83.3%**	**2.3%**	**99.9%**	**0.1%**
			Rural	0.0%	0.0%	0.0%	0.0%	0.0%	2.5%	0.0%	97.1%	0.4%	100.0%	0.0%
			Urban	0.1%	0.0%	0.0%	0.0%	0.0%	38.7%	0.0%	59.9%	1.3%	99.9%	0.1%
Somalia	2005	MICS	**Total**	**0.0%**	**0.1%**	**0.2%**	**0.0%**	**33.1%**	**66.4%**	**0.1%**	**0.0%**	**0.1%**	**99.7%**	**0.3%**
			Rural	0.0%	0.0%	0.1%	0.0%	8.0%	91.7%	0.1%	0.0%	0.1%	99.9%	0.1%
			Urban	0.1%	0.2%	0.3%	0.0%	79.1%	20.2%	0.0%	0.0%	0.1%	99.4%	0.6%
South Africa	2007	National Census / WHO	**Total**	**2.0%**	**66.4%**	**14.8%**	**1.2%**	**0.0%**	**15.2%**	**0.0%**	**0.2%**	**0.2%**	**16.8%**	**83.2%**
			Rural	1.5%	35.0%	30.0%	0.0%	0.0%	28.0%	0.0%	5.0%	0.5%	33.5%	66.5%
			Urban	2.5%	85.0%	5.0%	2.0%	0.0%	5.6%	0.0%	0.0%	0.0%	7.5%	92.5%
South Sudan	2010	MICS	**Total**	**0.3%**	**0.0%**	**0.1%**	**0.0%**	**14.0%**	**81.4%**	**3.4%**	**0.2%**	**0.6%**	**99.6%**	**0.4%**
			Rural	0.1%	0.0%	0.1%	0.0%	7.2%	88.0%	3.9%	0.3%	0.4%	99.8%	0.2%
			Urban	1.1%	0.0%	0.2%	0.0%	34.4%	61.6%	2.1%	0.1%	0.5%	98.7%	1.3%
Sudan	2006	SHHS/ MICS	**Total**	**8.1%**	**0.1%**	**0.5%**	**18.0%**	**2.0%**	**70.0%**	**0.7%**	**0.7%**	**0.0%**	**91.3%**	**8.7%**
			Rural	3.0%	0.0%	0.0%	15.0%	1.0%	79.0%	1.0%	1.0%	0.0%	97.0%	3.0%
			Urban	18.5%	0.2%	1.5%	24.0%	4.0%	51.8%	0.0%	0.0%	0.0%	79.8%	20.2%
Swaziland	2010	MICS	**Total**	**10.6%**	**16.8%**	**2.5%**	**0.2%**	**0.3%**	**68.7%**	**0.3%**	**0.1%**	**0.5%**	**70.1%**	**29.9%**
			Rural	5.9%	6.9%	0.7%	0.1%	0.2%	85.9%	0.0%	0.2%	0.1%	86.5%	13.5%
			Urban	26.4%	49.6%	8.8%	0.3%	0.6%	13.8%	0.0%	0.0%	0.5%	15.2%	84.8%
Tanzania	2010	DHS	**Total**	**0.3%**	**1.1%**	**2.7%**	**0.0%**	**20.8%**	**73.9%**	**0.3%**	**0.0%**	**0.9%**	**95.9%**	**4.1%**
			Rural	0.0%	0.2%	0.4%	0.0%	6.3%	92.4%	0.3%	0.0%	0.4%	99.4%	0.6%
			Urban	0.9%	3.8%	9.4%	0.0%	62.2%	20.7%	0.3%	0.0%	2.7%	85.9%	14.1%
Togo	2010	MICS	**Total**	**2.0%**	**0.1%**	**0.3%**	**0.0%**	**38.5%**	**58.6%**	**0.1%**	**0.0%**	**0.4%**	**97.6%**	**2.4%**
			Rural	0.1%	0.0%	0.1%	0.0%	14.5%	84.7%	0.6%	0.0%	0.1%	99.9%	0.1%
			Urban	5.3%	0.3%	0.5%	0.0%	78.3%	15.3%	0.1%	0.0%	0.2%	93.9%	6.1%
Uganda	2011	DHS	**Total**	**0.7%**	**0.3%**	**1.1%**	**0.0%**	**22.8%**	**72.5%**	**0.2%**	**0.0%**	**2.4%**	**97.9%**	**2.1%**
			Rural	0.0%	0.1%	0.3%	0.0%	12.4%	85.3%	0.2%	0.0%	1.7%	99.6%	0.4%
			Urban	4.3%	1.3%	4.3%	0.0%	67.8%	16.9%	0.0%	0.0%	5.4%	90.1%	9.9%
Zambia	2007	DHS	**Total**	**0.0%**	**14.5%**	**0.0%**	**0.2%**	**25.0%**	**60.0%**	**0.0%**	**0.0%**	**0.3%**	**85.5%**	**14.5%**
			Rural	0.0%	1.8%	0.0%	0.0%	10.2%	87.9%	0.0%	0.0%	0.1%	98.2%	1.8%
			Urban	0.0%	38.5%	0.0%	0.6%	53.1%	7.6%	0.0%	0.0%	0.2%	61.4%	38.6%
Zimbabwe	2011	DHS	**Total**	**0.2%**	**28.4%**	**1.9%**	**0.0%**	**0.1%**	**68.9%**	**0.0%**	**0.0%**	**0.5%**	**69.5%**	**30.5%**
			Rural	0.0%	5.6%	0.2%	0.1%	0.1%	93.9%	0.0%	0.0%	0.1%	94.2%	5.8%
			Urban	0.4%	73.2%	5.2%	0.0%	0.2%	19.8%	0.0%	0.0%	1.2%	21.2%	78.8%

APPENDIX 6: METHODOLOGY FOR FUEL MARKET SIZING AND FORECAST

The value of the fuel market in 2010 is based on the estimated fuel mix, average SSA fuel prices, and average annual per-household fuel consumption for users of "primary" fuels. The logic of the model is that households using "primary" fuels (as reflected in fuel mix data) purchase a standard amount of fuel and pay the prevailing average retail market price.

Data Sources and Methodology for 2010 Market Sizing

Fuel mix: The SSA regional fuel mix is derived from the regional fuel mix analysis and draws on surveys for all 45 SSA countries (see Appendixes 4 and 5).

Fuel prices: Average 2010 fuel unit prices draw on a proprietary database of LPG, charcoal, kerosene, and electricity for the SSA region derived from press searches and pre-existing databases, such as the 2000–9 kerosene price database from Lighting Africa (2012), the UPDEA (2009) survey of electricity prices across the continent, and Data Monitor Statistical Review of LPG and WLPGA for LPG retail prices. Where possible, the prices are weighted by country fuel volumes (e.g., for charcoal, LPG, and electricity), to get the true average regional price. For those fuels that may be freely collected (e.g., dung, crop waste, firewood), the fuel collector vs. purchaser share is estimated based on country-level surveys (e.g., 12 country data points on the share of firewood-using households purchasing wood).

Fuel-use volumes: The average annual per-household fuel consumption data from Schlag and Zuzarte (2008) and the World Bank (2011b) assumes a standard household cooking "diet" of 320 MJ per month per household using a fuel as its primary cooking source, which equates to 2.5 meals per day for a household of 5. The average fuel consumption is computed for each major stove type (e.g., traditional, basic, intermediate, advanced for wood), using the average fuel savings rate for each fuel. Total fuel consumption volume calculations take into account the baseline penetration of each stove type. The size of the "secondary" cooking fuel market is estimated separately — i.e., fuel use by households who use a different fuel as their primary cooking energy (e.g., LPG use by households who primarily cook with biomass). The secondary market is estimated based on a few country proxies (e.g., Kojima et al. 2011 data on multifuel use for Kenya). Total cooking fuel consumption volumes for the region have been validated by triangulating the results with other aggregate regional fuel consumption databases (e.g., FAO 2010 data for wood and charcoal, WLPGA for LPG volumes, South Africa Coal Association for SSA coal volumes).

Methodology for 2020 Fuel Market Forecast

The 2020 fuel market forecast utilizes 2020 fuel mix data from the regional fuel mix analysis (Appendix 5), projects stove penetration rates and associated changes in average fuel volumes per household from the ICS penetration forecast model (Appendix 9), and projects fuel prices using historical price trends from SSA fuel data series data for 2000–10. All fuel prices are discounted by the global Consumer Price Index inflation rate (about 2.4%) to ensure comparability with 2010 data.

Tables 6.1 and 6.2 show key fuel volume, price, and price growth rate assumptions.

Table 6.1: 2010 Fuel market sizing

Fuel type	Share of SSA households (100% = 854 mil)	Average per HH annual fuel use	Cooking fuel annual volume (primary—total)	Cost (US$ per unit)	Market size (US$ billions)
Wood	67%	1745 kg	200–207 mn tons (32% purchased)[1]	0.10	6.2
Charcoal	13%	819 kg	18–22 mn tons	0.27	5.8
Dung	2%	2200 kg	6.7–8.3 mn tons (10% purchased)[2]	0.07	0.06
Coal	1%	824 kg	1.6–1.8 mn tons	0.10	0.18
LPG	5%	150 kg	1.1–1.2 mn tons	1.57	2.0
Kerosene	7%	200 liter	2.2–2.5 mn liters	1.00	2.5
Electricity	5%	3232 kWh	30–33 tWh	0.10	3.3
Natural gas	0.22%	6.6 mmBTU	2.5–2.7 mmBTU	4.50	0.01

[1] 12 SSA country data points on firewood purchasing behavior; includes both exclusive and partial firewood purchasers.
[2] Data based on interview estimates for Ethiopia.

Table 6.2: Key assumptions for fuel prices and household consumption

Fuel	Fuel use per household (2010)	Fuel prices (2010)
Wood	Traditional stove = 1800 kg (WB 2010) based on 14.5–16 MJ/kg and a 320-MJ diet; legacy stove = 10% fuel savings, basic KCJ-type ICS = 30% fuel savings, rocket ICS and ACS = 50% savings	US$0.1 price, assuming 30% of charcoal costs based on average charcoal-to-wood relationship in 8 SSA countries and average charcoal price of 0.30
Charcoal	Traditional stove = 880 kg (FAO 2011 = 700 kg, WB 2010 = 888 kg, Sullivan and Barnes 2006 = 830 kg); basic charcoal ICS like KCJ = 25% savings, advanced charcoal ICS = 50% savings	US$0.27/kg average charcoal price for a standard charcoal bag; average prices weighted for charcoal consumption volumes for 22 countries in SSA; rural area prices 50% of urban; poor purchasing small bags (1–2 kg) pay 45% premium on average
Dung	Traditional stove = 1000 kg; 1200 kg in Ethiopia Tigray region (Mekonnen & Kohlin 2008)	US$0.07/kg (price in Ethiopia, key SSA dung market, based on press reports)
Coal	Traditional stove = 880 kg, equivalent to 5 GJ of energy (reported use in S. Africa closer to 2,000 per HH but includes water and room heating)	US$0.1/kg based on global ~US$100/ton bituminous coal prices
LPG	154 kg per HH for 320 MJ (SEI 2008), WB 2010 has 156 kg per HH; equal to 13-kg cylinder per month	US$1.57/kg average retail price based on volume-based weighting of LPG prices in 20 SSA countries
Kerosene	204 kg per HH for 320 MJ (SEI 2008); WB (2010) assumes 180 kg per month, Sullivan and Barnes (2006) assumes 210 kg per month for 5 MJ	US$1/liter on average across SSA (Lighting Africa 2012)
Electricity	3232 kWh per year (assumes 3.6 MJ per kW according to FAO)	US$0.1/kWh on average across SSA, weighed for the 5–6 countries with 90% of all electric stove use
Natural gas	6.6 mmBTU = 3.6 mmBTU required annually divided by 55% fuel efficiency divided by 1 mmBTU stove output at 100% efficiency	

APPENDIX 7: METHODOLOGY FOR ANALYZING EMISSIONS FROM SOLID-FUEL COOKING

To assess the environmental and climate change impacts of solid-fuel reliance in Africa, the report authors developed a bottom-up inventory of the GHG and black carbon (BC) emissions resulting from charcoal production as well as solid-fuel cooking, using all common solid-fuel stove types. The analysis does not include emissions from kerosene stoves.

The analysis has involved (1) identifying common emission ranges (grams per unit of fuel used) for key gases and particles released from incomplete fuel combustion for all common types of SSA stoves, (2) converting emissions to CO_2 equivalents using a 100-year global warming potential (GWP-100) conversion factor, (3) applying emissions to the volume of fuel burned by each type of stove in Africa, and (4) cross-checking the aggregated GHG Kyoto emission and BC accounting with existing inventories of global emissions. Key stove types considered include traditional wood stoves, basic efficient wood ICS (e.g., ceramic wood stoves), intermediate wood ICS/rocket stoves, traditional charcoal stoves, basic efficient charcoal stoves (e.g., KCJ), and unvented coal stoves. The report also assesses the emissions of LPG stoves, advanced wood ICS (fan gasifier), and advanced charcoal ICS (e.g., Envirofit 4400), to develop a baseline for emissions abatement in the case that households switch to clean (or cleaner) technologies. For CO_2 emissions, the report assumes 50–90% fNRB (nonrenewability ratio) for charcoal, 10–90% fNRB for wood, 0% fNRB for dung and crop waste, and 100% fNRB for such fossil fuels as LPG and coal.

Detailed calculations are available upon request from the authors. Key assumptions and the results of the analysis are shown in Tables 7.1 and 7.2.

Table 7.1: GWP-100 weighting for calculating CO_2 equivalents of greenhouse gas emissions

PIC	GHG CO_2 multipliers	Source
CO_2	1	
CH_4	25	UNDP 2000/Smith (25)x; Bond et al. 2013 (21x); IPCC 2007 (25x)
CO	2	UNDP 2000
NMHC	11	UNDP 2000 = 11; Bond et al. 2013 (12x); IPCC 2007 (3.4x)
N_20	285	UNDP 2000/Smith = 261; Bond et al. 2013 = 296; Solomon et al. 2007 = 298
PM	67	Computed
- BC (EC)	460	Reynolds and Kandlikar (2008) = 455; 460–2020 range (Berkeley Air Monitoring Group 2010); 1500–2220 range in Jacobson 2010 using GWP-100
- OC	–30	50 to –30 range (Berkeley Air Monitoring Group 2010)

Sources: Multiple emission inventories; Dalberg analysis.

Table 7.2: Emission factors for common SSA stove/kiln types (grams of emissions per kg of fuel burned)

Particles of internal combustion	Traditional wood[1,2,3,4,5]	Basic wood ICS[1,3,4]	Wood rocket1	Wood fan gasifier[1]	Dung/crop waste[2,3,4,5]	Traditional charcoal stove[2,3,4]	Basic charcoal ICS7	Coal[2]	LPG stove[2]	Charcoal kiln[6]
CO_2 total	1370–1688	1370–1688	1519	1500	1045–1302	2260–2410	2394–2543	685	841	1800
CO_2 non-renewable	137–169	137–169	152	150	0	1140	1200	685	841	900
CO	39–70	74–79	70	5–6	39.9–65.6	110–275	270–350	30.3	16	225
CH_4	3.8–8.0	2.5–4.0	3.9	n/a	4.5–10.5	2.4–18	14–15	7.7	1	44.6
N_20	0.018	n/a	n/a	n/a	0.05–0.3	n/a	n/a	n/a	n/a	0.15
NMHC	2.4–9.4	1.6–12.6	5.1	n/a	8.5–24.2	0.4–10.5	30–53	2.4	154	92.6
$PM_{2.5}$	3.2–9.5	n/a	12.4	0.3	3–6.3	0.4–2.4	14–16	8.7	89	30.4
EC/BC	1.5	n/a	1.9	n/a	0.2–0.6	0.07	n/a	4.4	92	5.47
OC	–4	n/a	–12.5	n/a	n/a	–0.03	n/a	3.1	–3	16.0

(1) USAID (2011, 2012); (2) Grieshop et al. (2011); (3) UNDP (2000); (4) WHO (2006); (5) Venkataraman (2010); Pennise et al. (2001); Berkeley Air Monitoring Group 2010.
Source: Dalberg analysis.

APPENDIX 8: CUSTOMER SEGMENTATION METHODOLOGY

To facilitate market analysis, this report relies on a rough segmentation of fuel users across the regions of SSA (East, West, Southern, Central) for all major fuel types (wood, charcoal, kerosene, electricity, LPG, and others) by three income levels (low = under BoP 500, medium = BoP 500–1,500, high = BoP 1,500+) and fuel procurement approach (purchasing vs. collecting). The raw data generated by this analysis are used to further subdivide the SSA consumer into 7 distinct segments, which are then profiled in the report.

The methodology and data sources for the analysis are presented in Tables 8.1 through 8.4.:

Table 8.1: Fuel mix from fuel-use database (45 SSA countries)

Market segmentation		East Africa	West Africa	Central Africa	Southern Africa	Total
Urban	Electricity	1,399,005	927,485	4,610,259	32,950,497	39,887,247
	LPG	4,554,059	15,220,581	3,278,450	11,343,607	34,396,697
	Natural gas	1,110,372	42,027	1,026	423,315	1,576,740
	Biogas	335,434	8,383	61,585	35,000	440,402
	Kerosene	5,952,275	35,086,337	1,252,018	2,049,654	44,340,284
	Coal	3,530,923	673,184	69,034	651,771	4,924,912
	Charcoal	29,855,718	28,276,351	22,629,158	8,598,156	89,359,383
	Wood	21,237,696	55,747,318	22,309,760	7,917,674	107,212,448
	Dung	544,789	77,891	544,166	6,411	1,173,258
	Crop waste	276,192	625,051	2,019	11,580	914,842
	Other	1,252,991	2,062,523	116,742	202,023	3,634,278
Rural	Electricity	140,009	208,427	13,428	7,570,528	7,932,391
	LPG	1,903,597	1,713,190	158,819	1,403,208	5,178,814
	Natural gas	7,490	28,222	0	21,152	56,864
	Biogas	0	2,143	1,901	67,801	71,844
	Kerosene	902,575	6,515,378	203,473	5,870,571	13,491,997
	Coal	4,716,402	363,648	10,718	15,596	5,106,364
	Charcoal	11,814,954	14,118,161	3,174,326	3,580,420	32,687,861
	Wood	201,848,054	152,737,537	35,515,242	55,979,166	446,079,999
	Dung	6,807,348	984,798	16,155	1,198,213	9,006,515
	Crop waste	2,421,688	1,261,853	9,091	232,912	3,925,544
	Other	1,183,113	1,048,964	34,432	280,512	2,547,021
	Total	**301,794,684**	**317,729,452**	**94,011,801**	**140,409,767**	**853,945,705**

Figure 8.1: Average income mix by fuel type (10 SSA countries)

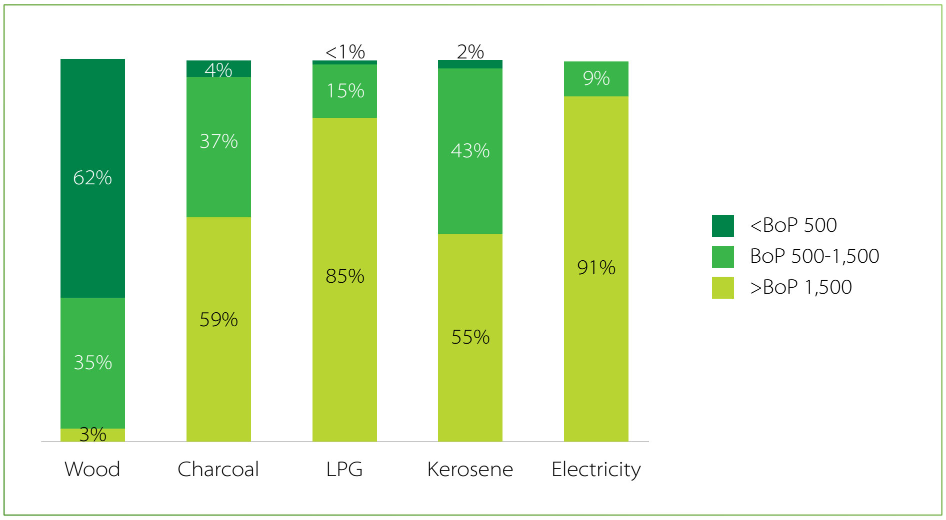


Table 8.2: Subregional population by BoP tier (10 countries)

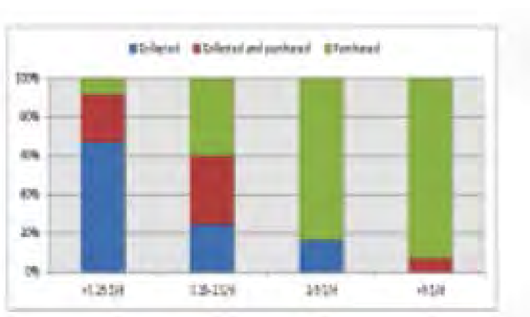
Subregion	Urban			Rural		
	Low	Middle	High	Low	Middle	High
East Africa	2.0%	5.7%	9.8%	20.8%	47.6%	14.1%
West Africa	24.5%	28.2%	5.1%	25.0%	16.1%	1.1%
Southern Africa	2.5%	12.0%	23.2%	32.5%	25.7%	4.1%
Central Africa	18.1%	21.0%	3.4%	38.0%	18.8%	0.7%

Figure 8.2: Wood purchaser vs. collector segmentation (12 countries)

Purchasing (~30%) vs. collecting: (~70%)

Purchasing rural (20% vs. urban 75%)

Purchasing low (19%), middle (45%), high (85%)



Sources: Fuel-purchasing behavior data across 12 countries globally (different data sources); analysis by Dalberg.

1. **Regional fuel segmentation:** Regional fuel mix data for 2010 (see Appendix 5).
2. **Regional income segmentation:** A consistent (absolute) income segmentation for each African region is derived from Hammond et al. (2007) income segmentation survey data, which allows us to segment the rural and urban population in each region into BoP income bands (<BoP 500, BoP 500–1,000, BoP 1,000–1,500, 1,500–3,000, 3,000+). WRI BoP survey data are available for only 11 African countries.
3. **Fuel use to income-tier mapping:** DHS/MICS surveys for select geographies have examined fuel use/penetration by income quintile. The report uses data from the available sample of Ghana, Sierra Leone,

Sudan, Swaziland, and Togo to extrapolate a general SSA-wide fuel penetration rate by income quintile. DHS income quintiles are remixed into High (top quintile), Medium (next two quintiles), and Low (bottom two quintiles).

4. **Wood purchaser vs. collector:** The wood-using population is segmented further into wood purchasers and collectors. On average, survey data from 12 SSA countries suggest that roughly 30% of wood primary fuel users purchase their fuel. Using this benchmark for the SSA average and survey data from half a dozen SSA countries where fuel-purchasing rates are available by income level, the report estimates fuel-purchasing rates per income tier.

The data from these four analyses were cross-tabulated into an overall SSA consumer matrix, from which the report extracts seven consumer subsegments with common hypothesized behavioral or purchasing characteristics. These segments were then profiled in detail on the basis of desk research and interview insights.

APPENDIX 9: METHODOLOGY FOR ANALYZING ICS PENETRATION

The ICS penetration analysis draws on a country-level database for improved cookstove and modern-fuel penetration; based on well over 100 sources, it contains data points for each country in SSA. The penetration numbers are a conservative estimate, and ranges are used wherever possible.

Key aspects of the methodology and data sources include the following three databases.

ICS country-level database: The country-level penetration database tallies total ICS penetration using bottom-up data sources ranging from WHO data for chimney stoves, to donor databases (ProBEC, EnDev), national surveys (e.g., ProBEC country baselines, USAID country baselines, Shell Foundation), Global Alliance for Clean Cookstoves market assessments, press searches, national program data, and stakeholder interviews. The data are ranged where possible, and all numbers are adjusted to reflect current penetration. For example, cumulative sales over long time series are converted into annual sales data and multiplied by average stove life, to ensure that only the current stove-using HH number is used. Household survey data indicating ICS penetration are prioritized in all cases where they are available.

Chimney stove penetration (WHO data): Chimney stove data, including information on both "legacy" chimney stoves and vented intermediate improved solutions (e.g., chimney rocket stoves), are, based on a WHO country database that draws on the most recent year known of DHS/MICS survey data. Countries where no DHS/MICS survey data are available (a dozen across Africa) are conservatively rated at 0% chimney stove penetration, unless other data on chimney stoves are available. While the chimney stove number has been used in earlier analyses to defined the universe of "improved biomass stoves" (e.g., UNDP/WHO 2009), it is not used in this fashion in this analysis, as the data are both over- and under-inclusive. First, chimney stoves include many stoves that are not truly improved—i.e., self-constructed chimney stoves or legacy stoves with low fuel efficiency. Second, the WHO chimney stove number does not include portable nonchimney ICS, which are a large and important segment in the SSA region that ranges from portable basic wood and charcoal stoves to intermediate portable rocket and charcoal stoves, and a rising number of advanced natural- and fan-draft gasifiers.

Industrial/semi-industrial manufacturer database: Using interview insights, publicly available manufacturer data, and sanitized surveys from the Partnership for Clean Indoor Air and the Global Alliance for Clean Cookstoves, the report team collated a database of sales for the top-30 global or domestic manufacturers focused on the SSA region. The data are self-reported, are at times dated, and have been interpreted conservatively.

Across all of these data sources, ICS penetration information has been captured at the country level and, where possible, categorized by (1) urban vs. rural customer share for each stove, (2) fuel type (wood, charcoal, hybrid), (3) domestic production vs. import, (4) portable vs. semi-fixed, and (5) government vs. private sector vs. donor program channel. The data have then been aggregated to enable the region-wide segmentation of common stove types.

APPENDIX 10: ICS MARKET FORECAST

The ICS forecast creates a baseline forecast scenario on the basis of historical cumulative penetration growth rates of various cookstove segments. The data are relatively robust at the first level of the hierarchy (i.e., legacy chimney vs. built-in vs. portable artisanal vs. portable industrial vs. portable semi-industrial). There is far less certainty about the relative growth rates of different subsegments (e.g., portable wood stoves industrial versus portable charcoal stoves industrial), so the subsegment forecast data are not used in the report.

Historical segment growth rates are based on market-penetration time series, cumulative sales, and annual sales growth data for 3–20 years for a dozen stove types, drawing on press reports and confidential data shared with the report team by manufacturers and stove program managers.

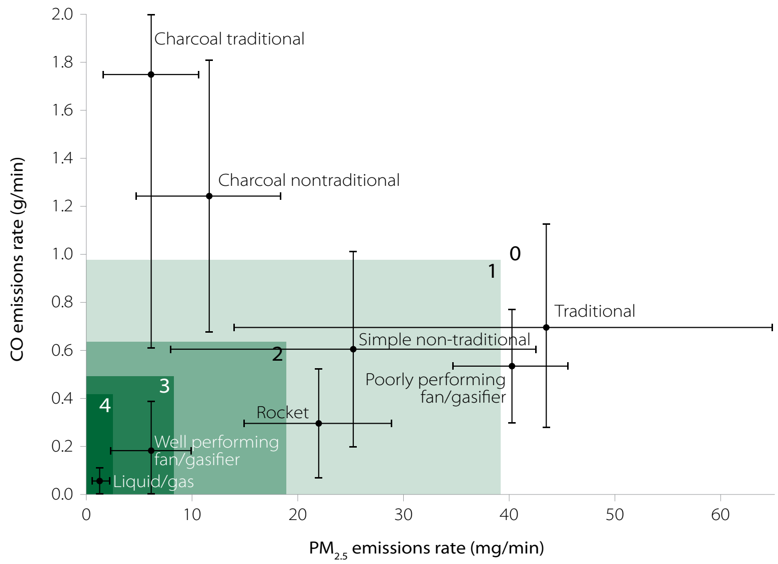
Table 10.1: ICS market forecast: overview of assumptions

Cookstove segment	Stove type	2010–2020 sales forecast (CAGR)	Assumptions/rationale
Legacy	• Variety of fixed-stove technologies and form factors featuring a chimney/hood or enclosed stoves	–5%	• Legacy chimney stove penetrations not growing or shrinking (e.g., Malawi, Uganda data)
ICS	• Built-in rocket	15%	• Low end of historical growth data for reported Uganda Rocket, Lorena, Kenya brick rocket, and Mirt *injera* stoves
	• Artisanal (wood /charcoal)	10–15%	• Long-term growth trend on Lakech charcoal stove in Ethiopia
	• Semi-industrial/local manufacture	25%	• Lowest end of historical 25–60% annual sales growth
	• Industrial/imported	35%	• 35–100% + CAGR seeb tiday for key players off low base; projection based on below-average outcome (current avg. 50–60%)
Modern-fuel stoves	• LPG	4.5%	• Historical growth range in HHs using as primary fuel
	• Electrictiy	4%	• Historical growth range in HHs using as primary fuel
	• Kerosene	0%	• No increase in use on average, with many countries showing declining use in the past 1–2 decades
Alternative fuels/ renewable cooking	• Biogas digesters	10%	• Historical rate for China and Nepal programs (15–25-year trends)
	• Liquid biofuel (e.g., ethanol)	20%	• Industry reviews for moderate case
	• Solar	5%	• 5–10% CAGR historical sales growth rate, even with donor support

Sources: Sector interviews; desk research; Dalberg analysis.

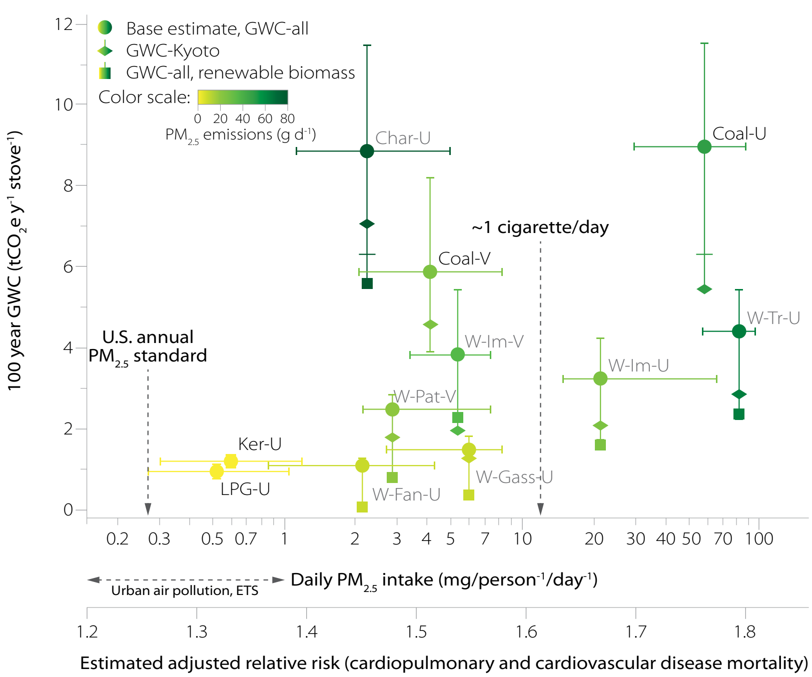
APPENDIX 11: RANGE OF PERFORMANCE, BY TECHNOLOGY

Figure 11.1: Range of CO and PM emissions, by stove type



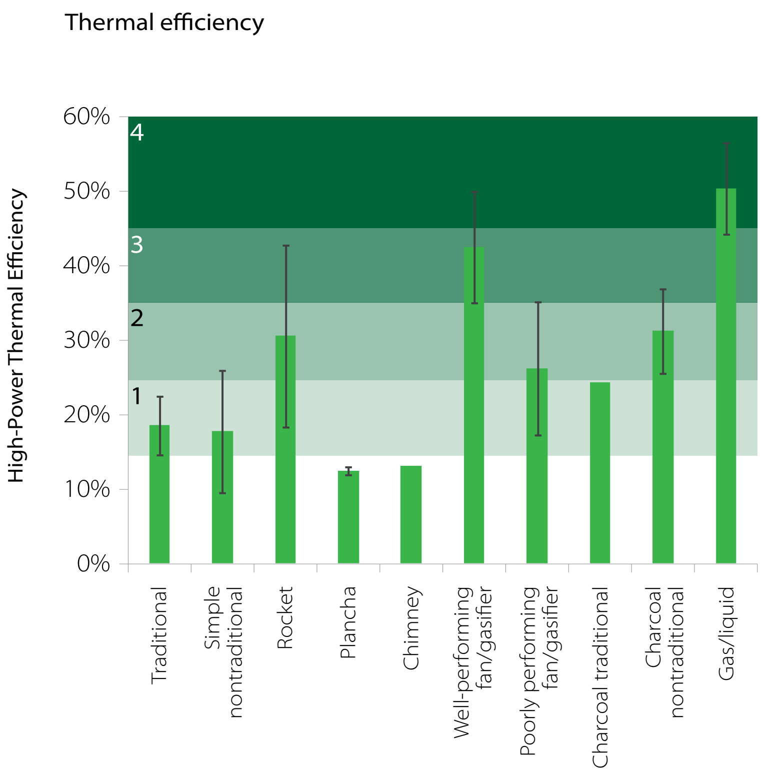
Note: Indoor emissions performance for key stoves/fuel classes across the IWA tiers for the water-boiling test. Error bars represent one standard deviation of the available tests set. Stove/fuel classes with no error bars consist of two or less data points.

Source: Berkeley Air Monitoring Group (2012).



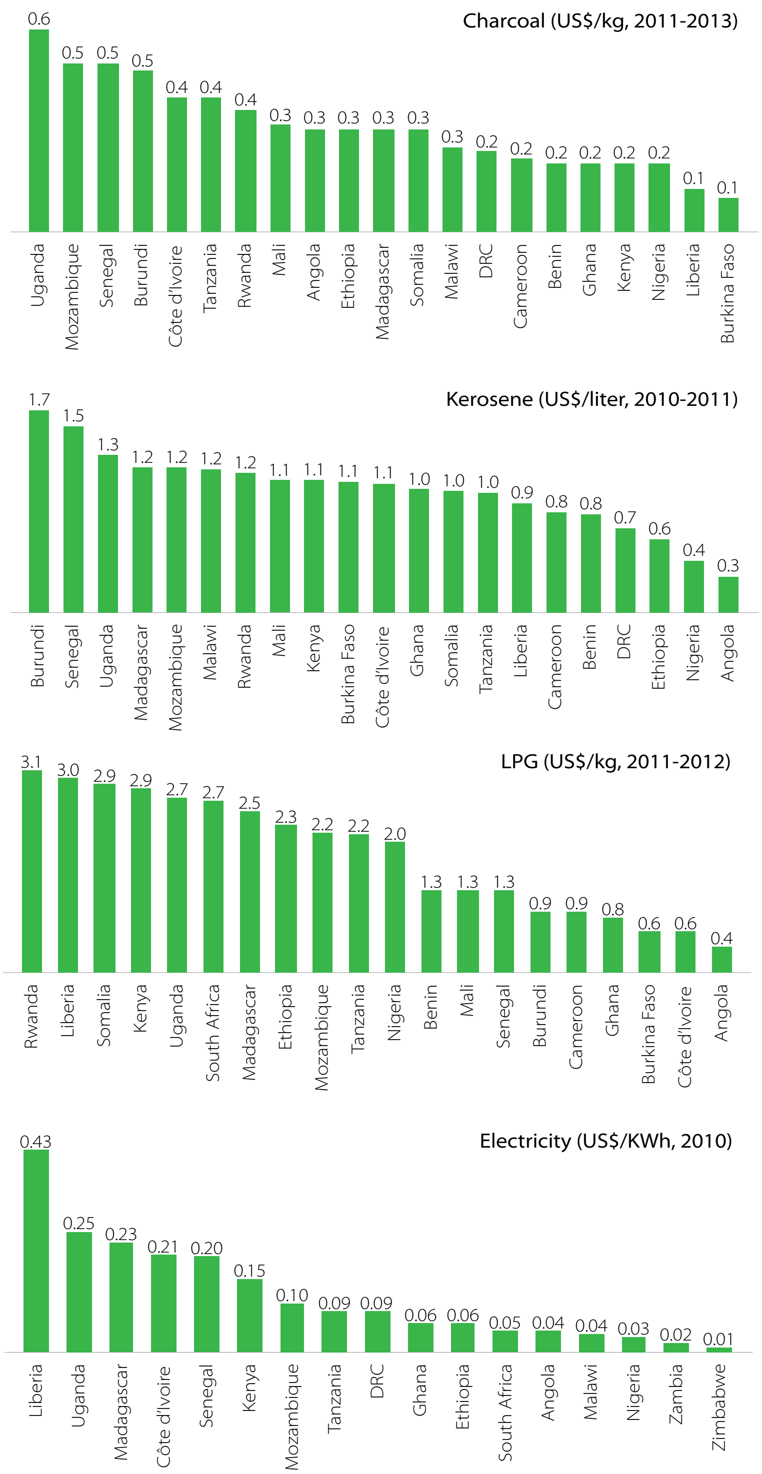
Source: Grieshop et al. (2011).

Figure 11.2: Technology comparison by thermal efficiency (water-boiling test)



Source: Berkeley Air Monitoring Group (2012).

APPENDIX 12: FUEL PRICES BY GEOGRAPHY



Sources: IMF data (kerosene), Africa electricity (UPDEA 2010), press searches for woodfuels, WLPG Alliance /press for LPG; Dalberg analysis.

APPENDIX 13: CONSUMER PREFERENCES, BY SEGMENT

Consumer preferences	Poor rural wood collectors	Mid-income rural wood collectors	Poor wood purchasers	Mid-income wood purchasers	Poor charcoal users	Mid–high-income charcoal	Modern fuel users
	53 mil (32%)	25 mil (15%)	17 mil (10%)	16 mil (10%)	6 mil (4%)	18 mil (11%)	29 mil (18%)
Cost of stove/fuel	●	●	●	◕	◕	◑	◔
Fuel savings (time spent collecting or cost)	◑	◑	◕	◕	●	◕	◑
Convenience of use	◑	◕	◕	◕	◕	◕	●
Cooking time savings	◔	◑	◑	◕	◑	◕	◕
Aesthetic attractiveness, aspirational value	◔	◑	◑	◕	◑	◕	●
Reduced smoke/improved health effects	○	◔	◔	◑	◔	◑	◕
Quality	◔	◑	◑	◕	◑	◕	◕
Improved safety while cooking	◔	◑	◔	◑	◑	◕	●
Environmental benefits	○	○	○	○	○	◔	◔

Sources: Various end-user surveys; Shell Foundation; GACC market assessments; Dalberg analysis.

NOTES

[1] See GACC (2012), Ekouevi and Tountivate (2012), and World Bank (2011a). At the country level, the Global Alliance Market Assessment reports are an important resource on the cooking landscape in such countries as Ethiopia, Ghana, Kenya, Nigeria, Rwanda, Tanzania, and Uganda (www.cleancookstoves.org).

[2] For a detailed overview of SSA cookstoves, see Appendix 1.

[3] That the ISO/IWA standards promoted by the Global Alliance for Clean Cookstoves cannot be neatly mapped to stove technologies is due to the range of stove performance in the field within each technology category. Indicative ISO tier ranges are provided in Appendix 2 to suggest the relative performance levels of average stoves within each technology category, excluding outlier products. The World Bank, in coordination with SE4All, is currently developing integrated performance ratings across multiple performance dimensions (such as efficiency, emissions, safety, and stove life) that will incorporate and build on the new ISO/IWA standards.

[4] Kenya's Bureau of Standards (KEBS) and the United States' American National Standards Institute (ANSI) serve as co-secretariats of the ISO Technical Committee 285, which is comprised of other participating national committees, including more than 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. A subsequent meeting to further detail these standards with the aid of four sectoral working groups was recently held in Antigua, Guatemala, in October 2014.

[5] Project evaluations and recent randomized controlled trials in India (Hanna et al. 2012) and Ghana (Burwen and Levine 2012) suggest that many "legacy" chimney stoves likely do meet Tier 1 standards for fuel efficiency and emission reductions, but they are included here under the ICS definition due to their prevalence in the field.

[6] There is a wide range of performance in pilot-fan and natural-draft gasifier models tested over the years by reputable testing centers and researchers (see, e.g., Berkeley Air Monitoring Group 2010, Jetter et al. 2012), with some of these appliances falling into the Tier 2 or even Tier 1 particulate emissions range. The best-performing fan-gasifier stoves, including several of the solutions that are currently being commercialized in Africa, do reach Tier 3 emissions performance and, based on self-reported results, may approach Tier 4 performance under some circumstances. Natural-draft gasifiers tend to have higher emissions than fan gasifiers, with higher variability of field performance. The best natural-draft gasifiers, however, can approach average fan-gasifier performance under controlled cooking conditions.

[7] For emerging evidence on the HAP risks of kerosene cooking, particularly with poor-quality kerosene wick stoves that are so common in Africa, see Berkeley Air Monitoring Group 2010, Lam et al. (2012), and Pokhrel et al. (2010). It is also important to note that poorly made kerosene stoves in particular pose safety concerns, including the potential for severe burns and injury associated with accidental fires (Peck et al. 2008).

[8] This is based on the latest solid-fuel penetration data for all SSA countries from DHS, MIS, LSMS, and national census surveys; data have been triangulated with WHO Global Health Database parametric estimates for 2010. Data on penetration of advanced gasifier stoves are based on self-reported manufacturer and program data across Africa.

[9] For the opportunity-cost analysis methodology, see Appendix 3. The analysis incorporates economic, health, and environmental/climate change effects and is informed by previous cost-benefit analysis reviews of the sector, including Jeuland and Pattanayak (2012), Garcia Frapolli et al. (2010), and Hutton et al. (2007).

[10] For an overview of evidence on these conditions, see acute lower respiratory infections in Dherani et al. (2008), Smith et al. (2000, 2004), and Ezzati and Kammen (2001); chronic pulmonary disease in Bruce et al. (2000) and Kurmi et al. (2010); lung cancer in Hosgood et al. (2014) and Bruce et al. 2015; cataracts in Siddiqui et al. (2005) and Pokhrel et al. (2005); and low birth weights and perinatal mortality in Misra et al. (2012) and Sreeramareddy et al. (2011).

[11] DALYs are 2010 figures from the Global Burden of Disease analysis in Lim et al. (2012); the mortality burden of 581,000 is sourced from the latest WHO data (http://www.who.int/phe/health_topics/outdoorair/databases/en/), up from an earlier Global Burden of Disease 2010 estimate of 464,000 deaths.

[12] 2010 Lancet Global Burden of Disease, available at (www.healthmetricsandevaluation.org); for analysis see Lim et al. (2012).

[13] Conditions linked to HAP, but not quantified in current Global Burden of Disease data, include tuberculosis (Sumpter and Chandramohan 2013); childhood nutritional deficiencies, including anemia and stunted growth (Mishra and Retherford 2007); blindness (Siddiqui et al. 2005 and 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, Franco Suglia et al. 2008, and Perera et al. 2012); upper respiratory, digestive, and cervical cancers (Reid et al. 2012 and 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).

[14] See note 7.

[15] Household expenditure data are based on WB energy expenditure surveys in Bacon et al. (2010), national census sources, and other energy surveys; cooking and lighting are typically not disaggregated, but calculations are based on average fuel volumes and prices suggest that cooking constitutes 40–80% of total household expenditure, depending on country fuel mix. Daurella and Foster (2009) report 7% of total household expenditure going toward LPG, kerosene, and charcoal cooking fuels across a large sample of African countries; WRI surveys in 30 developing countries globally point to 7% average energy expenditures, including both lighting and cooking (Hammond et al. 2007).

[16] See methodology in Appendix 3. The estimate is based on aggregate estimated fuel consumption volumes and average market prices across Africa; the forecast is based on a linear extrapolation of historical fuel-mix trends, adjusted for urbanization/population growth and historical fuel-price growth trends. It is consistent with the WB estimate of US$7 billion in annual spending in Africa on charcoal alone (World Bank 2011b).

[17] The systemic review of 50 country-survey data points for this report indicates that the average SSA firewood-collecting household spends two hours a day on firewood collection and three hours on cooking. To estimate time wastage, the report assumes potential 100% time savings for firewood collection and 50% reduction in cooking time from switching to LPG from baseline cooking technologies.

[18] This figure, which includes 200 million tons (MT) of firewood and 22 MT of charcoal for cooking, is based on SSA country fuel-mix surveys and average-per-HH consumption data. It assumes six kilograms of wood per kilogram of charcoal and compares with FAO's 2010 estimate (which included nonhousehold and noncooking woodfuel uses) of 25 MT of charcoal and 280 MT of firewood.

[19] See World Bank (2011b).

[20] See methodology in Appendix 4. The estimate is based on a bottom-up inventory of emissions for common fuel-stove combinations across Africa applied to aggregate fuel-consumption volumes. The range reflects uncertainty regarding the share of SSA woodfuel that is sourced nonrenewably (fNRB), since CO_2 emissions from renewably sourced wood are sequestered during wood regrowth and have no global warming impact. The report uses an fNRB range of 10% (Solomon et al. 2007) to 90% (UNFCCC Clean Development Mechanism) for firewood and 50% to 90% for charcoal.

[21] For the latest on impacts for stove emissions of black carbon, see Bond et al. (2013) and Ekouevi and Tountivate (2012). Local BC climate impacts in Africa likely include contributions to Kilimanjaro and Rwenzori Range glacial melting and related downstream effects.

[22] See World Bank (2011b); see also Figure 19 and related discussion in text.

[23] Rough estimate based on assumption of 2 tons of GHG (including non-Kyoto particles and PM) per ton of firewood consumed and 8 tons of GHG per ton of charcoal produced and consumed. The top-10 countries, in order, are Nigeria, Ethiopia, DRC, Tanzania, Kenya, Uganda, Ghana, Mozambique, Madagascar, and Côte d'Ivoire.

[24] 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 question the data quality of FRAs.

[25] See gender impact overviews in Köhlin et al. (2011) and Clancy et al. (2011).

[26] See Lim et al. (2012) and HAP-specific analysis from Dr. Kirk Smith at http://www.cleancookstoves.org/media-and-events/news/household-air-pollution-findings-from-the-global-burden-of-disease-2010-study.html.

[27] See 2010 Lancet Global Burden of Disease at www.healthmetricsandevaluation.org (accessed February 13, 2013).

[28] For impact on educational outcomes, see research from Kenya (Ndiritu and Nyangena 2010), Malawi (Nankhuni and Findeis 2004), and Ethiopia (Kiros 2011). Data on nutritional impacts are more tentative; see Cecelski (2004).

[29] For the disappointing data on legacy ICS, see the widely cited India RCT analysis by the Abdul Lateef Jamil Poverty Action Lab (Hanna et al. 2012); similar results were replicated in a Ghana legacy stove RCT (Burwen and Levine 2012).

[30] For data on basic ICS fuel savings; see, e.g., GIZ ProBEC charcoal and wood stove interventions (provided by authors); Senegal charcoal *jiko* RCT (Bensch and Peters 2013) showing 25% savings; and Burkina Faso Roumde ICS (wood ICS stove) showing 27% savings (Bensch et al. 2013).

[31] Portable rocket ICS evaluations in Africa have shown significant savings; see, e.g., EcoZoom Dura wood rocket stove data showing 65% wood savings (Barstow et al. 2014); and Envirofit and StoveTec/EcoZoom evaluation in Tanzania, Uganda, and Malawi showing 38–50% fuel savings under real-world conditions (Adkins et. al. 2010);

[32] Semi-industrial and artisanal built-in rocket ICS, such as the Uganda Rocket Lorena (Malinski 2006) and the Ethiopia Mirt stove (MeGen Power 2008), have demonstrated household-level savings of 40–66% in field trials.

[33] Independent RCTs are ongoing in Africa. Self-reported data from companies manufacturing fan-gasifier stoves, such as BioLite and Philips/ACE, or Africa distributors working with such products, suggest that household-level fuel savings of 50–65% are achievable with traditional biomass fuels (e.g., straw, crop waste, wood) and, while the result is not directly comparable, could exceed 80% for stoves calibrated for pellet use. Self-reported fuel-saving results for some African natural-draft stoves are comparable or even higher—for example, 70% for the Vesto stove in Swaziland, 75% for the Aron stove in Nigeria, and 80% for the "mlc" rice husk gasifier stove in Chad and Cameroon (Roth 2014). Comparable results have been demonstrated in international field trials of ACS technologies; see Ternes et al. (2008) pilot data for Costa Rica natural-draft ACS reaching 40–70% fuel savings, and Kar et al. (2011) for India gasifier trial data.

[34] For biogas, there are no robust field data from Africa pilots. The international experience in Lao PDR (Synesis 2011), Indonesia (JRI Research 2011), and Bangladesh (iDE 2011) suggests that woodfuel savings can be significant (66–80%), even when traditional stove persistence is factored into the analysis. For solar, Szulczewski (2006) reports household fuel savings of 25–40% in a field trial of a cookstove in Kenya and Ethiopia, but a more recent RCT in Ghana showed no statistically significant impact on fuel savings once fuel stacking was taken into account (Levine and Beltramo 2012). For LPG, Malla et al. (2011) showed only woodfuel-consumption impacts in Sudan and Kenya from LPG pilots (50–70%) due to the lack of displacement of baseline technologies.

[35] See MacCarty et al. (2008) for technology overview. For biogas, evaluations show very notable reductions in HAP exposures and end-user reports of improved health outcomes, though impacts on lung function are not conclusive (Dooho et al. 2012; Apsleya et al. 2014). Under normal use conditions, when stacking is taken into account, actual impacts on health are likely to be substantially lower than the potential for the technology (see, e.g., Semple et al. 2014), showing only 25–30% decreases in daily particulate emissions in biogas-using households in Uganda.

[36] Madagascar ethanol pilot data in Practical Action (2011).

[37] Simon et al. (2014) argue that only the very cleanest cooking solutions—a group that, pending further evidence, may include the best-performing biomass gasifier stoves—can generate health effects. See also Hawley and Volckens (2014), the first in-vitro study showing that improved cookstoves have the potential to reduce respiratory inflammation; it does this by comparing the effects of a traditional, a rocket, and a gasifier stove.

[38] Currently, of all technologies actually commercialized in the Africa market, the Philips HD4012 fan-gasifier stove likely comes closest to an IWA Tier 4 standard, but even with well-calibrated pellet fuels, is still a Tier 3 emissions stove (Jetter et al. 2012). Anecdotal evidence from Asia suggests that multipot chimney gasifiers can reach into the Tier 4 emissions range, but independent evidence for such stoves is not yet available.

[39] Burn Design Lab, for instance, is working on developing a prototype of a natural-draft gasifier that can approach IWA Tier 4 standards by 2016. It is doing so with financial support from the U.S. Department of Energy and in collaboration with players, such as Berkeley Air Monitoring Group 2010 (see www.burndesignlab.org). Designers who would prefer to remain anonymous at this stage are also beginning to work on the development of a next-generation, multipot, IWA-Tier-4-emissions fan-gasifier stove with advanced functionality (e.g., spark ignition).

[40] Patsari data from RESPIRE evaluations (Smith-Sivertsen et al. 2009).

[41] See, e.g., the evaluation of the jambar stove in Senegal in Bensch and Peters (2012).

[42] Regional data and specific-country trends are based on (1) the most recent available fuel-use survey data for all SSA countries from MICS, DHS, and LSMS and (2) national census and energy surveys.

[43] WHO's Global Disease Burden 2010 analysis, which is based on more than 600 survey data points, shows a decline in global solid-fuel dependence from 53% in 1990 to about 50% in 2000 and to 41% in 2010 (Bonjour et al. 2013). WHO's analysis of Africa over the same time period, using parametric country estimates for 2010, shows a decline from about 80% in 2000 to 77% in 2010. This report's analysis of actual (nonparametric) survey data for years most closely approximating 1995, 2000, and 2010 suggests no noticeable decline for the SSA region (i.e., solid-fuel use remains in the 80–82% range).

[44] The most common drivers for such "backsliding" down the energy ladder are modern-fuel supply chain interruptions and the discontinuation of subsidies. Nigeria is a notable example of both, with the high prices of kerosene and LPG leading to large spikes in woodfuel demand. Between 2000 and 2008, for instance, tracking the overall countrywide trend, the percentage of households using firewood as the primary source of domestic energy rose from 10% to 45% for low-income groups and from 4% to 25% for medium-income consumers (Abd'razack et al. 2012). In Zimbabwe, the rapid recent increase in urban firewood consumption has been triggered by electricity outages (Chazovachii et al. 2013). In Senegal and Tanzania, rising charcoal use can be traced to LPG shortages.

[45] See the discussion of fuel stacking in Hiemstra-van der Horst and Hovorka (2008) and Masera et al. (2000).

[46] Hiemstra-van der Horst and Hovorka (2008).

[47] Desalu et al. (2012).

[48] For Kenya, see Ruiz-Mercado et al. (2011); for Senegal, see Practical Action (2014); and for Burkina Faso, see Bensch et al. (2013).

[49] The 20–50% estimate range is based on sector stakeholder interviews in such countries as Ethiopia, Ghana, Kenya, and Senegal. Interview perspectives were triangulated with data from a large-scale Kenya household survey that related primary and secondary fuel-user numbers for a range of modern-fuel types; the resulting data in Kenya showed a 52% (maximum) overlap between primary (16.9% of total HH) and secondary (9% of HH) modern-fuel users. For individual modern fuels, the secondary-to-primary user ratio was 36% for LPG users, 80% for electricity (albeit with a very small sample), and 56% for kerosene (raw data sourced from Kojima et al. 2011). A similar World Bank survey in Senegal (Practical Action 2014) showed a ratio of 20–50% for LPG in urban and peri-urban Dakar and 30% in urban Sant-Louis.

[50] This report's forecast methodology uses a linear extrapolation of 2000–10 fuel-use trends, adjusted by overall population growth and urbanization, and suggests that the SSA region may reach up to 900 million solid-fuel households by 2020. IEA/OECD conducted a similar analysis that suggests an SSA solid-fuel population that is closer to 850 million in 2020, continuing to grow to 918 million in 2030 (IEA 2010).

[51] A minimum solid-fuel population of 850 million, minus 70–80 million of incremental LPG and biogas users (based on the most optimistic industry and program forecasts), still leads to a solid-fuel population of more than 750 million.

[52] Fuel-price trends are based on 2000–12 time-series data for key cooking fuels for 15–45 countries in Africa (depending on the fuel). The data were collected from multiple sources, including pre-existing databases (e.g., the IFC/Lighting Africa kerosene database), official price bulletins (e.g., electricity and LPG prices published by regulatory agencies), and press reports on retail fuel prices (typically in the capital city market). Note: Due to complex structure of retail LPG and kerosene cooking fuel markets, the last mile fuel prices tends to lag considerably behind global fossil fuel indices with a 50% decline in oil prices in 2014-2015 leading to only a 5-15% decline in LPG prices at the last mile based on our fuel tracker.

[53] The poverty premium for charcoal purchases is based on data points for 10 SSA countries comparing the costs of 1–2-kg charcoal sacks/buckets against the costs of standard 40–60-kg bags.

[54] See Appendix 4 for methodology.

[55] This analysis is based on estimated sales by cooking technology in 2010, including replacements and new penetration of all variants of charcoal and wood ICS, ethanol stoves, LPG stoves, electric stoves, and Africa biogas plants. Drawing on historical penetration rates, average stove life, and typical costs for key stove types, the market for clean and improved stove technologies is estimated at less than US$250 million annually, not including the US$50–100 million annual SSA carbon finance revenue streams that are not paid by consumers. It was more difficult to estimate the annual sales of unimproved wood and charcoal stoves. Data on the number of such stoves that are purchased commercially (e.g., traditional charcoal bucket stoves, ceramic wood stoves), as opposed to self-manufactured by households (e.g., mud stoves, three-stone fires) are scarce. Even at the high end of estimates, however, annual purchases of traditional stoves in SSA are unlikely to exceed US$50 million annually (assuming 50% of all traditional stoves are purchased, purchase price of less than US$2, and a lifetime of 1–2 years).

[56] Potential customer segments can be defined in innumerable ways; the report team has chosen the present segmentation in consultation with sector stakeholders to reflect distinct fuel- and stove-purchasing characteristics of large swaths of the African population. It is also important to note that African households using renewable solutions, such as solar, biogas digesters, and briquette/pellet fuels, and biofuels like ethanol are too few for meaningful segmentation (at maximum, in the tens of thousands for each of these technologies), and are therefore excluded from the analysis. While the methodology differs, for a dozen SSA markets and some market niches (e.g., LPG use in Kenya), more detailed country-level segmentations are available in market assessment reports developed by the Global Alliance for Clean Cookstoves. See the growing list of market assessments at www.cleancookstoves.org.

[57] Hard longitudinal survey data in Africa on the share of firewood-dependent households purchasing fuel rather than collecting it are limited, but there is extensive anecdotal evidence from interviews with stove program managers that wood-purchasing behavior is increasing as incomes rise and firewood collection becomes more difficult (i.e., progressively longer collection time due to wood scarcity in the vicinity of urban areas).

[58] Urban firewood-purchasing poor are most common in large West African urban markets, such as Cameroon, Burkina Faso, Gambia, Mali, Niger, and Nigeria, where firewood use in urban areas exceeds half of the urban population.

[59] Dalberg's database on SSA wood use, with data points on more than 20 countries, shows, for instance, that 30% of Kenya wood-purchasing households also collected fuel; the ratio was comparable in Malawi and stands at 20% in Mozambique.

[60] Press reports of spikes in firewood purchasing during the rainy season abound in countries as diverse as Nigeria, Uganda, Cameroon, Rwanda, and Kenya, but no quantitative survey data on this phenomenon can be found.

[61] As with modern fuels (see note 50), the number of primary fuel users for charcoal is deceptive, given the prevalence of multifuel and multistove households. Data from Kenya (Kojima et al. 2011) and Senegal (Practical Action 2014) suggest that the actual number of charcoal users may be anywhere between 1.5 and 2.5 times larger than the number of primary charcoal-using households. Applying an average multiplier of two yields a total charcoal-using population of about 50 million African charcoal users.

[62] Old FAO models suggest 30–50% growth in the number of charcoal users by 2020; the market forecast model in this report suggests the market could grow even more quickly (50–70%), based on current charcoal demand trends.

[63] The city list is informed both by Africa-wide household survey evidence for charcoal cooking dependence, as well as by the sanitized proprietary database developed by a cookstove manufacturer that focuses on African urban charcoal cooking markets.

[64] Author interviews in Kibera, Kenya, in 2011.

[65] Although modern fuels serve as the primary fuel for 17% of Africans, in absolute terms the number of SSA modern-fuel users is substantially larger. Applying a 1.2–1.5x multiplier to modern-fuel users to reflect fuel stacking, there may be as many as 45 million households in Africa who use one of these fuels at least occasionally, and are therefore owners of a kerosene, LPG, or electric stove (see note 50 and associated text).

[66] McKinsey (2010) projects that the African population with disposable incomes, defined as households with purchasing power parity (PPP) incomes of above US$5,000 annually, will grow from 85 million to 128 million in 2020.

[67] See note 7.

[68] A good starting point for the literature on (largely demand-side) factors for improved stove uptake is the in-depth systemic review recently conducted by a team of researchers with Department for International Development support (Rehfuess et al. 2014 and Puzzolo et al. 2013) and an earlier multicountry review focused on stove-adoption factors (Lewis and Pattanayak 2012). Building on such global systemic reviews, the demand driver discussion in this report is also informed by end-user preference data from 20 SSA stove program evaluations across eight countries and extensive report team interviews with SSA stove program managers, stove designers, and entrepreneurs.

Key country end-user survey data sets reviewed for this analysis included, by country: Mozambique ICS end-user survey (Risseeuw 2012); Kenya evaluation of a basic ICS (jiko upesi) program (Person et al. 2012) and household survey of urban intermediate charcoal ICS (Burn Design *Jiko* Poa) users (Sharma 2012); Burkina Faso FAFASO rocket and basic ICS stove program evaluation (Bensch et al. 2013); Malawi basic ICS evaluation for ProBEC (Malinski 2006); Ethiopia Mirt stove evaluations (Gebreegziabher et al. 2014 and MeGen Power 2008); Uganda efficient ProBEC stove user survey (AED 2008), Rocket Lorena impact evaluation (Malinski 2006), ICS pilot evaluation for the Uganda Millenium Village Program (Adkins et al. 2010), formative research on peri-urban stove users near Kampala (Martin et al. 2013), and Acholi district stove consumer survey (Nicholson and Beevers 2013); Ghana household energy survey in Axim region (Manyo-Plange 2011); Senegal household energy survey in multiple locations around the country (Practical Action 2014); and Tanzania *Jiko* Bora charcoal ICS program evaluation for ProBEC (Evodius 2010) and an assessment of an ICS pilot for the Millenium Village Program (Adkins et al. 2010).

[69] Generally, ICS and clean fuel adoption is positively correlated with greater household income and wealth (Rehfuess et al. 2014; Lewis and Pattanayak 2012; Miller and Mobarak 2011; and Levine et al. 2010). Educational attainment is a positive proxy for demand, as it reflects greater household awareness of stove benefits, including a better ability to assess the economic pay-off of switching to new technologies and a greater appreciation for such noneconomic benefits as health (Rehfuess et al. 2014). The household status of women, including their level of autonomy and decision-making power, is an important determinant of demand in patriarchal developing-world societies, as it correlates with women's ability to actualize their preferences for improved cooking solutions (Miller and Mobarak 2013). These factors are often context-specific. For instance, household size is positively correlated to demand in markets where households have no choice but to purchase their fuel (Levine et al. 2010); however, in rural and very poor urban environments, there is some evidence that large biomass-dependent households may actually have less demand for improved stoves than smaller ones, since they have more spare labor, and therefore lower implicit opportunity costs, to collect firewood for cooking (van der Kroon et al. 2014; Mekonnen and Kohlin 2008).

[70] See in-depth discussion under "African End-user Preferences for Stove Design and Performance" later in this chapter.

[71] Consumer awareness is consistently rated as an important demand driver, and overall levels of ICS awareness and knowledge of the harms of traditional cooking are low across the SSA region (Rehfuess et al. 2014; Puzzolo et al. 2013. Even where there is awareness of basic ICS, there are very few places in Africa with extensive awareness of more efficient and cleaner cooking solutions and their benefits. For example, in a recent large-scale Uganda survey, 58–60% of consumers were not sure that an ICS saves either time or money (TNS 2013). In a survey conducted in Maputo, Mozambique, 28% of consumers were not aware of potential ICS impacts on fuel expenditures, and a full 55% did not know about the long-term

health harms of traditional charcoal cooking (Risseouw 2012). In a survey of women in the Gondar region of Ethiopia, the results showed that only 20% of women realized that traditional stove emissions are harmful for children, and only 13% believed that inhaling indoor emissions is a "cause for concern" (Edelstein et al. 2008).

[72] There is a growing body of cognitive economics research on the issue of "present bias" in the context of distributing health- or wealth-generating products to the base of the pyramid (see, e.g., Banerjee and Mullainathan 2010). Levine et al. (2012) explore this issue for cookstoves in the context of a Uganda ICS pilot. The issue is, of course, not unique to African stove consumers; it is a challenge marketers have successfully tackled in developed markets for such products as life insurance that require trading near-term costs for long-term benefits. The particular challenge in the Africa cooking market case is to develop the kind of refined awareness-building and marketing techniques that acknowledge and then work around the present bias issue.

[73] See the discussions on consumer trust and its importance for stove adoption in Beltramo et al. (2014a and 2014b), Levine et al. (2012), O'Dell et al. (2013), and Miller and Mobarak (2011).

[74] Bryan et al. (2014).

[75] Levine et al. (2012b).

[76] See discussions of access and supply-chain reach in Rehfuess et al. (2014) and Lewis and Pattanayak (2012).

[77] *Affordability* issues are often discussed interchangeably, with *adoption* factors affecting consumers' willingness to use a new solution. For terminological clarity, we deal with affordability separately from other stove-adoption factors later in the report.

[78] The literature on clean and improved cooking solutions has no universally accepted definition of willingness to adopt. We define "willingness to adopt" as the household's openness to partly or fully displace its existing cookstove with a new cooking solution on a sustained basis. The features and performance of the cooking technology, consumer awareness, trust in quality, and easy access to the stove, its replacement parts, and associated fuel are directly linked to the initial willingness to adopt a technology. Sustained use, as distinct from the initial adoption decision, is largely determined by only the first of these factors—i.e., stove design and performance. For the distinction between factors of initial adoption and sustained use, see Puzzolo et al. (2013).

[79] The household's willingness to pay, defined as the maximum amount a person would be willing to pay, sacrifice, or exchange in order to receive a new cookstove, is related to willingness to adopt but is a distinct concept. A high willingness to adopt a new product may not translate into willingness to pay for it when households believe that the product may be obtained elsewhere at lower or no cost (e.g., via government subsidy schemes, through NGO efforts) or when lower-cost alternatives are available. Unlike willingness to adopt, which is independent from considerations of cost and affordability, willingness to pay a specific amount for a new stove is contingent on consumers' disposable incomes. All else being equal, a household that is wealthier or has less liquidity constraints will be willing to pay more for a desirable stove than a household that faces more rigid income and savings constraints.

[80] Since the goal of this section is to focus on consumer preferences, the key features of stove design in the discussion are described from an end-user perspective. A number of these stove features are linked to a small set of technical characteristics, such as combustion efficiency, heat transfer efficiency, and particulate emissions.

[81] The rating of design features in this figure is specific to SSA ICS and ACS biomass stove users. Global systemic reviews of stove-adoption factors suggest that, while there will be many commonalities, the ranking order will vary for other cooking technologies. For instance, cooking time and safety will be more important adoption factors for LPG, electricity, and biofuel stove users than fuel savings; aesthetic and status considerations will also be more important for such households (see Rehfuess et al. 2014).

[82] Fuel savings are consistently ranked as the primary motivator for SSA stove purchases in household surveys conducted for stove program evaluations and baseline studies. Viewing, more generally, global systemic review evidence highlighting the primacy of fuel savings as a driver for improved cooking solution adoption, fuel savings were the top-rated adoption factor among hundreds reviewed (Rehfuess et al. 2014).

[83] Time savings is the second-highest rated factor in the recent systemic review of stove- and fuel-adoption factors (Rehfuess et al. 2014) and across the dozen ICS program evaluations reviewed for this report (see note 68). It is important to note that women's appetite for time saving does not always directly translate into demand for stoves, since their time may be undervalued by male household heads, where men have the dominant voice on household cash outlays. Furthermore, the time benefit may be not be fully appreciated in rural African settings, which are often characterized by polychronic traditional cultures in which time awareness is poor and tasks are not strictly bound by time pressures (see, e.g., Concern Universal 2012).

[84] Smoke abatement is consistently rated among the top 3–5 adoption factors in the dozen SSA stove program evaluations and household surveys referenced in note 69.

[85] This factor is expressed differently in various SSA household surveys and is typically expressed via such terms as *convenience, fit with specific cooking preferences*, and *suitability to local cooking conditions* (see surveys referenced in note 68 and Rehfuess et al. 2014).

[86] For instance, several common foods in Uganda require strong stirring, called "mingling." Three-stone fires can nestle a round-bottomed pot, permitting the cook to stir with both hands. This has implications for any ICS design in Uganda and other East African countries with similar cooking practices (Harrell et al. 2013).

[87] Lack of stove design fit to cooking behavior is a common factor for recent evaluations of stove-adoption factors—see Rehfuess et al. (2014), Puzzolo et al. (2013), and Lewis and Pattanayk (2012)—and goes back to the earliest comprehensive reviews of stove programs and technologies in the early 1990s (Barnes et al. 1994).

[88] See note 68.

[89] See Puzzolo et al. (2013).

[90] Attractive stove appearance has rated as a top decision factor for only 0–5% of households in SSA end-user surveys referenced in note 68—as compared with 50–90% ratings for such variables as fuel savings, time savings, and smoke reduction. Many older surveys entirely exclude stove appearance from the list of ratable attributes, impairing the comparability of findings.

[91] See, e.g., O'Dell et al. (2010). Aspirational marketing focused on the stove's appearance for both urban and rural consumers is a feature of nearly all SSA industrial stoves reviewed by the report team and is a common theme for other consumer durables, such as solar lanterns, targeting comparable consumer segments (Lighting Africa 2013). Research on this demand driver is ongoing, and many questions remain on the gender implications (e.g., some research suggests that men are more motivated by status aspects of "modern" stoves than women) and on the value of aesthetic considerations relative to more fundamental dimensions of stove performance.

[92] See Rehfuess et al. (2014), where cleanliness and home improved ranks 6th among 30 stove-adoption factors by number of literature mentions cleaner floors, pots, and food from ICS and clean fuel cooking are important themes of most ICS end-user surveys.

[93] A growing volume of theoretical research and survey evidence suggests that poor stove users do not highly value long-term health impacts. The research of Mushfiq Mobarak, using Bangladesh data, has demonstrated low willingness to pay for incremental health benefits, even when households are aware of the harms of traditional fuel cooking (Mobarak et al. 2012). The low value consumers place on health benefits has been discussed and corroborated in numerous country reports for Africa. See, for instance, the general discussion in Thurber et al. 2014 and stove-specific research from Rwanda showing that perceived health benefits were not a major driver for EcoZoom stove adoption in Rwanda, despite the heavy health orientation of the stove's marketing (Barstow et al. 2014). Health benefits do become more important as a demand driver for stoves for higher-income consumers, based on revealed preference surveys in various African countries (Takama et al. 2011). Furthermore, there is evidence that women place more value on health effects than men, but due to their generally lower decision-making power in households, this preference does not translate into improved uptake or willingness to pay (Miller and Mobarak 2013; Beltramo et al. 2014).

[94] The lack of developing-world consumer interest in the public-good dimension of improved cooking technologies in general, and of their environmental impacts in particular, is a common refrain in the literature. See, e.g., O'Dell et al. (2013).

[95] For instance, interviews and public statements suggest that human-centered design is at the core of the efforts of Africa-focused industrial ICS manufacturers, such as EcoZoom, Envirofit, BURN Manufacturing, and Prakti Design; ACS players, such as Biolite and Philips; and alternative fuel stove manufacturers, such as Dometic.

[96] Human-centered design, based on ethnographic research and rapid prototyping, was at the core of large-scale African cookstove programs. Low-cost customized design was the hallmark of GIZ/ProBEC's work in Africa in the past decade. The current wave of EnDev initiatives across the continent likewise use rapid iteration of stove design as a cornerstone of their approach. End-user-focused design thinking is likewise the hallmark of large Africa-focused NGOs that design or manage artisanal stove programs; these include Practical Action, Relief International/EnterpriseWorks, and GERES. "Design thinking" is likewise viewed as a core capability by such Africa players as the International Lifeline Fund and Potential Energy, which focus on stove delivery to end users from the most disadvantaged environments, including the poorest of the rural poor and residents of humanitarian relief camps.

[97] The volume of end-user research in the public sphere is growing, as witnessed by a new series of consumer-segmentation reports from the Global Alliance for Clean Cookstoves. See, e.g., http://www.cleancookstoves.org/resources_files/ghana-consumer-segmentation-exec-summary.pdf and IDEO.org's research on Tanzania stove consumers at https://s3.amazonaws.com/ideo-org-images-production/documents/9/original/20120323_Final_Small-1.pdf.

[98] Long cooking times, while not a necessary feature of improved cookstoves, are a major theme across many basic and intermediate ICS evaluations. See, e.g., Adkins et al. (2010) highlighting the longer cooking times of several common rocket stove models tested in Tanzania and Uganda relative to three-stone fires, with one stove taking 60% longer to cook

typical dishes. Cooking time is likewise a major challenge for many rocket and natural-draft stove models tested outside of Africa (e.g., 75% of consumers in Bangladesh reported longer cooking times relative to traditional stoves for a range of six industrial ICS models manufactured by leading global and regional manufacturers (USAID WashPlus 2013). Alternative cooking technologies, such as solar and retained-heat cooking, are also famously slow—50–100% longer cooking times than traditional biomass cookstoves (see, e.g., ProBEC SunStove evaluation in Zimbabwe in 2007). In contrast, for modern-fuel (LPG, electricity), biofuel (ethanol), and ACS stoves (natural-draft TLUD, fan-gasifier stoves), cooking times tend to be significantly faster than baseline technologies.

[99] Fit with pot size comes up as an issue in many ICS evaluations, though for well-designed stoves the issue is addressable with adjustable pot skirts. For instance, 40–70% of frequently used pots had a diameter above that of the common models of ICS rocket stoves tested in Tanzania and Uganda (Adkins et al. 2010). Fuel preparation time and difficulty of refueling have been common themes in reviews of natural-draft stoves; see, e.g., the recent Uganda TLUD stove evaluation in Martin et al. (2013). The need for increased stove monitoring and fire tending is also a major theme in rocket stove program evaluations; see, e.g., the EcoZoom experience in Rwanda (Barstow et al. 2014). Other common usability issues include stove size, the ability to accommodate multiple stoves, and the need for constant monitoring to feed the stove small pieces of firewood; see, e.g., Harrell et al. (2013).

[100] Durability has in particular been a challenge for basic ICS. This was a major nonadoption or stove abandonment factor in large-scale basic ICS programs in Africa, as is reflected in GIZ ProBEC program evaluations (e.g., GIZ 2008) and is often highlighted as the key challenge of Kenya Ceramic *Jiko*-style ICS around Africa (see, e.g., Njogu and Kuung'u 2013).

[101] Safety and stability issues affect the full range of ICS, including basic ICS stoves (see, e.g., GIZ ProBEC evaluations) and many rocket stove technologies (see, e.g., USAID WashPlus 2013 and Harrell et al. 2013).

[102] A review of basic and intermediate ICS pilot and program evaluations reveals that 5–30% of consumers have failed to adopt new technologies, even when they are provided at no cost. Rural consumers unwilling to use a stove free of charge represented 30% in an Ethiopia Mirt stove survey (MeGen Power 2008), 20–30% in Uganda and Kenya for modern wood rocket stoves (Shell Foundation, Breathing Space Survey 2007–08), 15–20% in Uganda and Tanzania for wood rocket stoves (Adkins 2010), and 5–20% in most GIZ market baseline surveys conducted as part of the GiZ ProBEC program. Evidence from other countries shows comparable results—e.g., 30% of rural Bangladeshis were unwilling to use an improved chulha, even when it was distributed free of charge (Miller and Mobarak 2011). The level of nonadoption should and does differ by technology, so further evidence is needed to appropriately set expectations for adoption levels for less common types of highly improved and clean cooking technologies, such as natural-draft gasifiers, fan gasifiers, ethanol cookstoves.

[103] Report author interviews with key African market stakeholders for LPG (WLPGA, GLPGP), biogas (SNV), ethanol (Project Gaia and CleanStar Mozambique), and solar (Solar Cookers International).

[104] Declining use of improved technologies over time has been particularly notable for legacy mud stoves. For example, a ProBEC baselining study found that mud stoves distributed under a national program in Malawi in the 1990s were completely abandoned a decade later. Anecdotal evidence from interviews and press reports suggests a similar fate for chimney mud stoves in Madagascar, Uganda, Rwanda, Zimbabwe, Tanzania, and Ghana. See e.g., Ghana legacy stove evaluation in Burwen and Levine (2012). For basic ICS, see GIZ ProBEC program reports, showing 50–90% use of distributed stoves 6–18 months after distribution. For intermediate ICS, see, e.g., EcoZoom Rwanda distribution data showing 10–20% abandonment 5 months after the intervention (Barstow et al. 2014). For advanced biomass fan-gasifier cookstoves, see, e.g., Oorja experience of more than 90% of end-user households abandoning the stove over time (Thurber et al. 2014). The ratio of nonfunctional or abandoned household biogas plants has ranged from 20% to 75% for countries, such as Kenya, Ethiopia, Bangladesh, Sri Lanka, and India (Bond et al. 2013), though information from new biogas digester programs, such as those supported by SNV (www.snv.org), shows significantly lower abandonment rates. RCT findings on the ongoing household utilization of basic solar cookers have shown high rates of stove abandonment and disuse (Levine and Beltramo 2012). A similar fate has been reported for ethanol gel-fuel stoves and ethanol stoves (Practical Action 2011).

[105] 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), Khonje (2010), Evodius (2010), Chidamba (2010), MeGen Power (2008), and Malinski (2006).

[106] See, e.g., 89% persistence in LPG use in a program for low-income households in South Africa who received subsidized LPG stoves and fuel (Mohlakoana and Annecke 2008).

[107] See note 28 and associated text.

[108] Surveys conducted by GIZ and EnDev ICS promotion programs in Ethiopia, Ghana, Malawi, Tanzania, and Uganda suggest a village-level penetration of 70–90% for US$4–10 ICS products. In the urban setting, Kenya surveys show a >80% penetration of Kenya Ceramic *Jiko* (US$4–8) stoves in such cities as Nairobi. In contrast, the very poorest in such low-income markets as Ethiopia are unable to afford even very-low-cost stoves. For example, an in-depth 2011 market feasibility study of a US$4–7 Mirt *injera* improved stove in southern Ethiopia suggested that such a product would be absolutely unaffordable to 5–10%

of the urban and 20–30% of the rural population, even in the presence of consumer credit, installment purchase options, or partial subsidies (GIZ/MeGen Power 2011).

[109] Africa research by the Global LPG Partnership (e.g., see 2013 Kenya LPG market assessment at www.cleancookstoves.org) and interviews with modern-fuel experts across the region conducted for this report all point to the primary importance of improved affordability for unlocking clean fuel market growth.

[110] While it is impossible to draw a precise demand curve for the SSA market for every cooking technology, the basic premise is that clean cookstoves will be prohibitively expensive for the 50% of SSA households who currently earn less than US$1.25 per person per day, especially since many of these households currently pay nothing or nearly nothing for their stoves and fuels. See more detail in the affordability discussion later in the report.

[111] Broadcasting Board of Governors/Gallup surveys suggest that 57% of the SSA adult population in 2010 owned a mobile phone handset; more recent data from the GSM Association suggest that penetration will exceed 70% by the end of 2014.

[112] National energy survey data from DHS, LSMS, and MICS and national census data show modern-fuel stove (US$15–100) penetration of 17–18% for SSA; this report's estimates for ICS uptake across the region show a penetration of up to 2% for intermediate ICS (US$15–30). These data suggest that at least 20% of households have paid more than US$15–20 in the past; adding basic ICS (6%), at least 25% of HH have paid for some form of improved or clean cooking appliance that they use as their primary stove. While there are no good data on secondary stove ownership, the best-guess estimates that are available (see note 32), suggest that secondary modern-fuel stove owners may be at maximum another 6–9% of the SSA population, for a grand total of up to a third (34%) of all SSA households owning a purchased (as opposed to home-built or three-stone fire) cookstove.

[113] Shell Foundation, Room to Breathe Program (2007–09). Since the survey results are somewhat dated, projecting these numbers into 2013 with 5–7% inflation and income growth suggests that the share of consumers who can afford a US$30+ product could now be a good deal higher. On the other hand, income levels in many parts of the continent are much lower than in these three countries, so the evidence is still telling.

[114] Although average SSA handset costs are unknown and likely vary greatly by country, the literature and interviews suggest that the average trends low (US$30–50) due to the introduction of low-cost (US$15–20) handsets over the past five years, the high share of very-low-cost "counterfeit" phones from low-quality providers, and extensive use of old and second-hand handsets across the region (see, e.g., Chabossou et al. 2009).

[115] Applying average SSA prices with typical unimproved stoves, the annual cost of cooking all meals with LPG for a household of five (about US$260) is 40–50% higher than the cost of cooking all meals with purchased wood (US$180). The premium of ethanol fuel use (US$200–300) over purchased firewood cooking is comparable. The cost of charcoal cooking is roughly on a par with LPG on average, though the relationship varies dramatically by country and the lower costs of charcoal stoves and easier access to charcoal constrain fuelswitching from charcoal to LPG.

[116] This estimate assumes that high-cost clean cookstoves are analogous to the average consumer durable in Africa and, therefore, are unlikely to see more uptake than the historical share of consumers who annually buy US$30+ consumer durables in countries, such as Kenya, Tanzania, and Uganda. This consumer segment roughly corresponds to the high-income (>BoP 1,500) consumer in this report's segmentation model, which corresponds to 16% of the SSA population.

[117] As one point of triangulation, the <BoP 500 consumer (<$1.25 per day) corresponds to roughly 40% of the SSA population and would be highly unlikely to easily afford a cash purchase of a US$15–30 product that would require spending 10–20% of monthly income—a significantly higher portion of income than is likely available for discretionary purchases of energy appliances. This suggests that less than half of the SSA population would be able to afford such products.

[118] The concept of experience goods (Nelson 1970) has been widely explored in the development literature on health economics for such products as malaria bednets and is increasingly being applied to research on off-grid energy products for the BoP, such as solar lanterns (Lighting Africa 2013) and cookstoves. See, e.g., Levine et al. (2012) and Burwen (2011).

[119] Doubling in price was extrapolated by plotting a demand curve based on the experimental result of adoption increasing from 4% in the control group (i.e., upfront cash purchase) to 29% in the treatment group (i.e., one week free trial) (Levine et al. 2012).

[120] For instance, a Bangladesh trial of several stove models that are also marketed in Africa (e.g., EcoZoom, Envirofit, Grameen Infra, Prakti) showed that, for the 100 households involved, 55% preferred the new stove to traditional solutions after 3 days of use, whereas only 40% preferred them after 3 weeks of use (USAID WashPlus 2013).

[121] The amount consumers were willing to pay for an Envirofit 3300 stove increased from a mean of US$4.86 to US$6.83 with the move to four weekly payments; this still represented only 30–40% of the stove's actual retail price, but was a significant result (Beltramo et al. 2014).

[122] Risseeuw (2012).

[123] Net of product returns, the baseline cash purchase offer led to 4% adoption, free trial to 29% adoption, weekly payment offer to 26% adoption, and a cumulative "novel" offer with all of these features to 46% adoption—a 12-fold increase from traditional cash sales (Levine et al. 2012).

[124] Research sponsored by the USAID TRAction Project in 2012 replicated a similar experiment for an Envirofit 3300 wood rocket stove (US$16 cost) in rural Uganda, showing a 12-fold increase in stove demand when it was marketed with a 1-week free trial and four-installment-plan payment option (Harrell et. al. 2013).

[125] While there is limited research on this topic, the literature estimates the optimal payback period to be within the 1–6-month range, with payback of less than 2 months being seen as critical for poorer segments of consumers. See., e.g., an assessment suggesting that a payback period of 1 to 3 months is needed for improved cookstove acceptability (IFC 2012), an estimate suggesting that a 2–4 month payback period is optimal (USAID 2009), and a World Bank review of 1980s and 1990s cookstove programs suggesting an optimal payback period of 1 to 6 months for basic ICS technologies (Barnes et al. 1994). This rule of thumb also applies to other consumer durables for the BoP; for instance, the Lighting Africa market review for solar lanterns concluded that liquidity constraints are minimized and willingness to pay increased significantly when solutions can achieve a payback period of less than 2 months (Lighting Africa 2013).

[126] There is ample evidence that doing this is difficult due to the relatively high transaction costs of traditional consumer finance (e.g., via MFI lending) relative to the small value and margins of the stoves; see, e.g., the Lighting Africa (2013) discussion of transaction cost obstacles to consumer finance for small consumer durables.

[127] See, for example, the discussion of the Inyenyeri Rwanda model in the supply section of this report. Inyenyeri leases stoves to consumers at low or no cost and recoups its costs through pellet fuel sales. Other models of this sort include the earlier phases of First Energy's distribution strategy in India for the Oorja gasifier stove and the CleanStar ethanol stove effort in Mozambique.

[128] Several of the SSA market stakeholders consulted for this report were considering trialing this model for high-cost cooking solutions on the basis of existing technologies and models being applied for lighting (e.g., IndiGo, http://www.azuri-technologies.com/indigo), but thus far no projects of the sort have been launched.

[129] Surveys in urban Kenya show that two-thirds of charcoal-using households are willing to pay US$30 for a highly improved charcoal stove (2-month payback with fuel savings); this is likely a major demand driver for BURN Manufacturing's *Jiko*Koa (US$33) and Envirofit CH6600 (US$37) stoves (Sharma 2012).

[130] The heavily subsidized US$30 price of the CleanCook ethanol stove in Mozambique for the CleanStar/Novozyme program has seen reasonable uptake, but is overly expensive for the majority of consumers. In major charcoal markets, such as Madagascar, there is likewise good evidence that willingness to pay will be low. The average urban charcoal users in Antananarivo spend on charcoal is US$6–7 per month; so even at a 50% fuel savings rate, a US$30-dollar stove would have a 10-month payback period.

[131] Adkins et al. (2010).

[132] In Adkins et al. (2010) wood rocket stove trials in Malawi, Tanzania, and Uganda, for instance, the average WTP was US$10–12, compared with a US$20–35 fair-market value of the stove in these geographies (i.e., WTP was 30–50% of actual cost). Nigeria research by Project Gaia showed that the WTP for the CleanCook methanol stove (US$30) was 50% of the lowest-cost CleanCook stove model (Obueh 2008). An evaluation of a TLUD stove in Uganda showed that that WTP after a few days of use was US$5 on average (US$2–8 range), vis-à-vis the TLUD's costs of US$14 (i.e., WTP of 35% against stove cost) (Martin et al. 2013).

[133] The data in this section rely on a roll-up of country-level stove sales, use, and penetration data points for 45 SSA countries and involve the triangulation of (1) self-reported Africa-wide stove sales data from industrial and semi-industrial stove entrepreneurs (more than 50 companies) sourced in interviews, reported in the press, or estimated by competitors; (2) self-reported Africa-wide cumulative sales, annual stove sales, and "stoves in use" estimates for all major regional (e.g., PROBEC, EnDev) and country-specific (e.g., Ethiopia) stove programs; (3) GACC member survey sales data, including raw data for 2011 and aggregated information from the GACC 2012–13 results report; (4) individual market assessment estimates for "stoves in use"; and (5) country-level consumer survey data on primary fuel use and legacy stove ownership ("stoves with chimneys") aggregated in a proprietary fuel use database.

Where possible, the resulting numbers were assigned to individual countries. To get to an apples-to-apples comparison of stove penetration by technology, the numbers were converted to a common "number of households owning stove" metric using simplifying assumptions to derive household stove ownership estimates where the reported figures provide stove sales or use, rather than number of unique households utilizing the solution.

The resulting data must be interpreted with caution due to inevitable imprecision, but should offer a directionally accurate picture of the relative stove mix across the region. The report provides clarifications and caveats in footnotes where the methodological certainty of the estimates is particularly low. See also the ICS penetration survey methodology in Appendix 9 for further detail.

[134] See note 7 and associated text on kerosene's categorization as a clean fuel.

[135] This estimate is based on a roll-up of country-level survey data from DHS, LSMS, MICS, and national census surveys for all SSA countries using 2008–13 data points; this should provide a reasonable average for aggregate modern-fuel primary-user households in 2010–11, equating to 8.2 million LPG/LNG households, 9.6 million electric stove households, and 11.6 million kerosene households. Assuming one modern-fuel stove of each type per household, these data also equate to the number of primary household stoves of each type. In most cases the market is highly concentrated: 73% of SSA electric-cooking households are in South Africa, 63% of kerosene-cooking households are in Nigeria, and 50% of LPG households are in just five countries, including Angola, Cameroon, Ghana, and Senegal.

[136] This assumes one modern-fuel stove of each type per household. See note 50 for more details on converting primary-fuel households into the total number of stove-using households and stoves. It is difficult to aggregate these numbers into the total number of modern-fuel stoves in use in the market, since there is significant overlap between electric, LPG, and kerosene stove users in markets where two or more of these technologies are present. At maximum, assuming zero overlap between modern-fuel-using populations, the total number of modern-fuel users can be in the 48–56 million range. Given the phenomenon of fuel stacking, the actual number is likely in the 40–45 million range (i.e., at the midpoint between the estimate of 30–32 million primary modern-fuel users and the estimated 48–56 million modern-fuel stoves owned by SSA households.

[137] The penetration numbers for 2010 include 10,000–50,000 ACS, 5,000–10,000 biogas stoves, 150,000–200,000 biofuel stoves, 50,000 solar cookers, 150,000 retained-heat cookers—a grand total of >450,000 renewable cooking fuel households. The source data for this information are listed in the notes and text that follow.

[138] This figure includes roughly 20,000 fan-gasifier stoves utilized in market pilots or RCTs by Q1 2014; the balance of stoves are a variety of natural-draft gasifier stove models. Data on stove distribution are sourced by aggregating self-reported project/manufacturer data and then triangulated with interviews with peer/competitor firms and the limited publications available on the ACS sector; see, e.g., Roth et al. (2013). The estimate covers 15 ACS manufacturers, including Philips/ACE, BioLite, New Dawn Engineering, Peko Pe, ARTI Sampada, WorldStove, Awamu/ABE (Uganda); GreenTech (Gambia); and Aaron (Niger); 5 Star Stoves (South Africa); Wisdom Innovation, Kiwia, and Laustsen (Tanzania); mlc (Gambia); Arti Sampada. With the exception of a few demonstration models, very few of these stoves (<15,000) have been sold; the vast majority are models distributed as part of a range of commercial and noncommercial market pilots. The wide range on the estimated stove count is explained by uncertainty about the validity of stove sales reported by several of the ACS market participants.

[139] These late 2013 data are from the Africa Biogas Partnership Programme, which is responsible for most of the biogas stoves installed in Africa today; additional self-reported data come from unaffiliated biogas project developers in Burundi, Lesotho, Rwanda, and Tanzania (e.g., SimGas).

[140] Includes less than 50,000 Domestic CleanCook stoves distributed in a range of market pilots, primarily the now liquidated CleanStar Mozambique business in Mozambique (33,000 stoves); Project Gaia initiatives in Ethiopia, Madagascar, and Nigeria; an estimated 160,000–200,000 Green Energy and Biofuel "KIKE Green Cook" ethanol-gel fuel stoves in Nigeria, Ghana, Togo, and Cameroon; 45,000 ThermoSafe Energy ethanol-gel stoves in Nigeria; and an additional estimated 50,000–100,000 units in Malawi (SuperBlu), Kenya (Consumer's Choice Ltd. "Moto Safi" and "Moto Poa" stoves), and South Africa (BioHeat/BioCorp, Greenheat, and ProtoEnergy ethanol stoves). All data are self-reported via manufacturer interviews and public statements.

[141] This estimate is based on self-reported data on pellet production volumes (focused at retail market) from mid-sized to large producers in Kenya, Tanzania, Senegal, Rwanda, and Ethiopia, triangulated with recent African reports on the pellet/briquette sector; see, e.g., Ferguson (2012) and EEP (2013). Data on SME briquette/pellet producers and social-sector artisanal pellet manufacturing projects come from the Legacy Foundation.

[142] Self-reported data sourced from Solar Cookers International (SCI) and a range of other solar project promoters throughout Africa.

[143] Self-reported data from Natural Balance (manufacturer of WonderBag retained-heat cooker) suggest that >600,000+ stoves were sold or distributed in South Africa, Kenya, and Rwanda by early 2013.

[144] See note 7.

[145] See the ICS penetration survey methodology in Appendix 9.

[146] See methodological note 136 and Appendix 9 for more details on how these numbers were derived.

[147] For most biomass stove technologies, the number of households owning a given stove type and the total number of stoves in use are identical. This is not so for portable basic ICS in Africa, where top-down survey data often only indicate the number of ICS households without tracking the number of stoves. Using rough estimates based on known ratios of basic ICS stoves disseminated to stoves owned per ICS-using household (e.g., 1.25–1.5 in Kenya), it is likely that the total number of basic ICS stoves, such as charcoal and wood *jiko*s, is 30–50% higher than the number of households—i.e., bringing the basic ICS count up to a maximum of 8–9 million stoves in 2010–11.

[148] See the forthcoming report titled *The State of the Global Clean and Improved Cooking Sector*, jointly published by ESMAP/WB and the Global Alliance for Clean Cookstoves. The estimate is based on bottom-up country analyses for more than 75 countries globally, accounting for more than 90% of solid-fuel users.

[149] The precise number and proportion of three-stone fires in use in Africa are unknown, as such data are typically not captured in national surveys. Interviews with stove program managers across the region suggest that three-stone fire stoves constitute the absolute majority (70–85%) of all traditional stoves used as a primary household stove. The only traditional segment where commercially produced stoves are common is the unimproved metal charcoal stove market, with an estimated 10–15 million unimproved metal stoves used as a primary cookstove in Africa out of the 20 million African households that rely on charcoal as their main fuel (i.e., this is net of the estimated 5–7.5 million improved charcoal stoves in the market). Once secondary charcoal users are counted (50–100% of primary charcoal users based on the SSA fuel database), the real number of unimproved metal stoves in the market could be twice as large—i.e., a total directional estimate of 15–30 million traditional metal charcoal stoves.

[150] See note 4; most "legacy" improved stoves in the ground in Africa are either unimproved stoves with chimneys or very basic home-built stoves that likely fall into ISO Tier 0–1 for fuel efficiency and Tier 0 for emissions.

[151] While an aggregate figure for market growth is difficult to derive from fragmentary self-reported data, survey evidence from the Global Alliance for Clean Cookstoves (more than 700 members answering survey) suggests that cumulative clean and improved cooking market sales growth is likely very rapid. For instance, there was 74% annual growth in the number of stoves produced and tracked by the Alliance and its predecessors globally from 2003 to 2012, half of them in Africa, and more than 80% sales growth year-on-year for many individual producers reporting figures in both 2011 and 2012 (GACC 2013).

[152] Historical (2000–10) growth trends for primary-fuel use across SSA, based on an aggregation of national surveys for 45 SSA countries, are 5% annual increase for LPG, 3.5% for LNG, 4.3% for electric cooking, and 0.7% for kerosene (reflecting a negative growth rate for kerosene use in the past 3–5 years).

[153] See, for instance, detailed data showing the retrenchment of LPG fuel use in Senegal in recent years (Practical Action 2014)—a trend that was likely attended by a corresponding softening in the LPG appliance market.

[154] See http://www.snvworld.org/en/regions/africa/news/fuelling-the-biogas-future-in-africa-abpp-secures-new-funding. For general ABPP project background, see www.africabiogas.org.

[155] Pellet and briquette fuel businesses that fall into this category include Inyenyeri in Rwanda (www.inyenyeri.org); Africa Briquet Factory in Ethiopia (www.afribiomass.com); Abellon Clean Energy in Ghana (www.abelloncleanenergy.com); Emerging Cooking Solutions in Zambia (www.emerging.se); Greentech in Gambia (www.greentechgambia.com/); Mota Bombo pellet fuels (www.treetanz.com) and renewable charcoal dust briquettes by the East Africa Briquette Company (www.mkaabora.com/) in Tanzania; Chardust charcoal briquettes and FireBalls in Kenya (chardust-kenya.blogspot.com); 5 Star Stoves in South Africa (http://5starstoves.com/); Tassouma Briquettes (www.tassouma-briquettes.com/) in Côte d'Ivoire; and businesses like Green Bio Energy (www.greenbioenergy.org) and Eco Fuel Africa (ecofuelafrica.co.ug) in Uganda.

[156] The estimate for chimney stoves draws on Africa-wide DHS/MICS national survey data aggregated by WHO; the data are problematic insofar as they are available only for 33 countries, are sometimes quite dated (2005–13), and may include what are effectively traditional stoves with chimneys attached. To develop a continent-wide estimate, "missing" data points were filled in through interviews with country stakeholders, subnational NGO surveys on stove prevalence, and in once instance (Rwanda) a national census survey (RBESS 2009). For enclosed mud/clay stoves, the estimate is partly drawn from data for 2009–11 for Ethiopia and anecdotal reports of hundreds of thousands of such stoves elsewhere in the continent. For conservatism, only the Ethiopia numbers have been used, but the total number of such stoves may be significantly higher.

[157] For the geographic spread of the KCJ technology and its analogues, see Figure 36. More than 25 million African households used the technology in 2011—a figure that has increased significantly in recent years to more than 30 million African households based on report penetration figures in countries, such as Kenya, Senegal, Ethiopia, and Ghana.

[158] The basic wood ICS segment covers a wide range of technologies, including fired-clay solutions (*upesi* in Kenya and Tanzania, *opesi* in Ethiopia, *chitetezo mbaula* in Malawi); ceramic or clay-lined metal wood stoves along the lines of the KCJ (e.g., *centrafricain* in Chad and Cameroon, *mandeleo* metal clad *upesi* in Kenya, *sewa/teliman* in Mali); cement/brick stoves (e.g., Ethiopia cement wood stoves, Malawi *esperanza*); and a range of all-metal wood stove designs in West Africa (e.g., *roumdé* in Burkina Faso, *sakkanal* in Senegal, *nansu* in Benin). This report's estimate for the basic wood ICS segment is likely an underestimate, since the dissemination of stoves of this type is fragmented over several government programs, 5–10 major international NGOs, and dozens of local NGOs throughout the continent. With notable exceptions, such as the GIZ and EnDev programs, the governments of Rwanda and Ethiopia, and a few large local and international NGOs, data tracking is extremely poor. The estimate in this report relies on self-reported data from reputable programs and triangulation from country-level estimates captured in the Global Alliance for Clean Cookstoves' market assessment reports and is likely an underestimate of the stoves currently in the market.

[159] Anecdotal reports of the decline of the legacy stove segment were universal in the interviews conducted with more than 100 stove market stakeholders across East and West Africa for this report. The (admittedly sparse) data on the segment from the WHO survey bears this out, with significant declines tracked for some countries (e.g., 8% chimney stove penetration in Malawi in the 2005–6 household survey and less than 2% penetration in 2010).

[160] The acceleration in basic charcoal ICS production is reflected in survey numbers for countries, such as Kenya (i.e., showing continued growth in urban ICS penetration, even as that market is beginning to reach saturation); the data of sizable semi-industrial KCJ stove manufacturers from Kenya, Uganda, Senegal, and Ethiopia made available to the report team showing 15–60% annual sales growth; and the data of large-scale NGO (e.g., Enterprise Works) and government (e.g., Ethiopia *Lakech* stove) efforts. The growth shown in Figure 32 is a conservative estimate based on known numbers of units (adjusted for replacements and obsolescence) sold by major programs and manufacturers annually.

[161] Data on the Burkina Fasa *roumde* adoption path are available in Bensch et al. (2013); anecdotal evidence from Kenya, Tanzania, and Uganda suggests that *upesi*-style stove sales are continuing to grow, but the extent to which these are replacement sales versus extension of the technology to new households is unclear in the absence of tracking, since major supporting programs, such as GIZ ProBEC, are no longer in place.

[162] This analysis is based on (1) an aggregation of self-reported rocket stove sales by the top-30 industrial and semi-industrial manufacturers in Africa (or their carbon project development partners), and (2) the self-reported dissemination volumes from major national and NGO chimney/built-in rocket stove initiatives. It is quite possible that this analysis underestimates this segment's rate of growth.

The *2012 Results Report* from the Global Alliance for Clean Cookstoves (GACC 20??), based on survey data from 744 Alliance members, showed that 1.6 million rocket stoves were sold and distributed in 2012 (about 37% of the 4.3 million stoves distributed to African consumers by survey respondents). Using a sales growth rate of roughly 50% annually, this corresponds to the more than 4 million stoves added to the market during 2012 and 2013, as captured by this report team's data. Higher growth rates for the rocket stove sector are possible, however, based on anecdotal evidence from manufacturers and distributors. For instance, applying the Global Alliance 74% year-on-year historical growth rate in stove sales for the entire cooking sector overall would mean that the actual rocket stove penetration by the end of 2013 was even higher—a total of more than 8.5 million. This report uses the more conservative figure of 8 million that can be traced back to individual manufacturers, pending the release of new Global Alliance member survey data at the end of 2014.

[163] Key developments of this sort include investments in production capacity in Kenya made by Envirofit, BURN Manufacturing, and EcoZoom, and exploratory measures by some of these companies and others to open manufacturing or subassembly facilities in other African countries to serve as potential subregional hubs.

[164] In Rwanda, DelAgua Health has partnered with the Ministry of Health since 2012 to distribute free-of-charge household water treatment and EcoZoom wood rocket cookstoves to approximately 600,000 poor households (about 3 million people) throughout the country's 30 districts. The pilot program was initiated in 2012, and mass-scale distribution was launched in mid-2014. For more details on the program and initial pilot results, see Barstow et al. (2014).

[165] Government of Kenya 2006 Energy Policy; USAID and Winrock 2011; Dalberg analysis.

[166] This result is based on the analysis of an Africa-wide database of DHS/MICS surveys (2005–13). The top-five markets for LPG are Angola, Cameroon, Côte d'Ivoire, Senegal, and South Africa. The six key markets for electric cooking, in rank order, are South Africa, Zimbabwe, the Democratic Republic of the Congo, Zambia, Namibia, and Ethiopia. Key markets for kerosene include Cameroon, Eritrea, Kenya, Nigeria, and South Africa.

[167] These themes came across strongly in 2012–13 regional Global Alliance and World Bank ACCES consultations and are also well documented in the literature on the artisanal sector; see, e.g., Clough (2012).

[168] While there are no robust quantitative data on stove quality, quality challenges—particularly for artisanally manufactured stoves—were a consistent theme in the report team's interviews across a dozen SSA countries. Stakeholders in the Kenya stove market, for instance, reported that the average quality of Kenya Ceramic *Jiko* stoves in the field is low; the average stove life has declined over time to 1–1.5 years, as many producers use low-quality metal casings and liner materials; and average fuel efficiency levels (15–20%) are significantly below the KCJ technology's potential (30–35%).

[169] See Lighting Africa's 2010 and 2012 solar portable industry reports at www.lightingafrica.org.

[170] The World Bank estimates that 7 million people are employed in the charcoal value chain alone across SSA today, with aggregate charcoal-sector employment expected to reach 12 million people by 2030 (World Bank 2011b). Recent individual country studies estimate the involvement of 700,000 in the charcoal sector in Kenya, around 200,000 in Uganda, more than 100,000 in Malawi, and several hundred thousand supplying the needs of Dar es Salaam in Tanzania. 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 urban firewood trade markets. Many of these jobs are part time and provide only low or moderate income, but a growing body of evidence points to the important livelihood benefits of woodfuel-sector employment for economically vulnerable segments of the SSA population. In aggregate, informal and formal woodfuel-sector employment, including part-time labor, could exceed 15 million individuals across the entire SSA region (Oksanen et al. 2003).

[171] See World Bank (2011b).

[172] For REDD+, see http://www.un-redd.org/aboutredd/tabid/102614/default.aspx; for FIP, see https://www.climateinvestmentfunds.org/cif/node/5.

[173] One successful example is the Community-Based Woodfuel Production (CBWP) project in Senegal; covering 380,000 hectares of forest, it is supported by the World Bank and promoted as part of the PROGEDE program. Other countries that have established plans for sustainable forest management include Benin, with a target of covering 600,000 hectares; Mali, where 1.4 million hectares will involve sustainably managed wood-based biomass approaches; and Burkina Faso, where 441,000 hectares are currently under sustainable forest management, and 270,000 are to be added. Ethiopia plans to bring 300,000 hectares of natural forest under participatory management schemes. In Madagascar, much of the charcoal consumed in the capital Antananarivo comes from sustainable eucalyptus plantations established around the capital since colonial times (World Bank 2011b). The last few years have also seen the launch of large-scale CBFM projects in Tanzania as part of the REDD+ initiative.

[174] See note 142 and related text. The report team believes that despite numerous challenges, such as a lack of financing, the renewable biomass fuel sector is on the verge of much broader experimentation and scale-up, as charcoal prices in many countries have approached or begun to exceed the costs of briquette/pellet production, making this market attractive for entry. The growing dynamism of this market is obvious in the launch of Inyenyeri and other companies in at least eight African countries focused on developing mid- to large-scale briquette fuel supply for households (targeting urban charcoal consumers in particular).

[175] See the GLPGP/Global Alliance for Clean Cookstoves recent report on the Kenya LPG market (Dalberg 2013); general information on the Global LPG Partnership is available at www.GLPGP.com.

[176] Manufacturing labor costs in key stove-manufacturing markets in Africa (e.g., Kenya), China, and India have risen 8–13%; steel prices, accounting for 70–90% of stove-material costs depending on product, have been highly volatile, vacillating from US$500 to US$1,100 per MT (U.S. hot-rolled-coil steel) in the past five years. LPG and electric stoves are, of course, very different technologically from industrial ICS, but are likewise not expected to come down significantly in cost since (1) these technologies are already manufactured at great scale globally, including lower-cost models available in the SSA market; and (2) some of the same labor and materials cost concerns apply.

[177] See Kojima et al. (2011). The most notable successful example of small-cylinder promotion is that of Indonesia, where the government subsidized the distribution of 3-kg cylinders and cookstoves as part of its kerosene elimination campaign.

[178] See www.projectgaia.com.

[179] Project Gaia, for instance, has worked on producing and commercializing methanol captured from flared gas in Nigeria in large-scale methanol stove pilots (see http://www.projectgaia.com/page.php?page=nigeria); the Protos BSH Bosh and Siemens jatropha oil stoves have been discontinued by the manufacturer, but entrepreneurs are continuing to promote an artisanally manufactured jatropha stove, the *Jiko* Safi, in Tanzania.

[180] See, for instance, Oketch (2013), showing that significant improvements are possible for baseline ethanol stove models, such as the Moto Safi. See, generally, the overview of ethanol cooking appliances in Puzzolo (2013).

[181] SimGas markets both urban digester models (e.g., the GesiSafi, which uses kitchen waste) and larger-scale rural digester models targeted at smallholder farmers (e.g., the GesiShamba, which uses animal manure). See www.simgas.com for details.

[182] See www.ecofys.com/en/project/ecofys-plastic-bag-digester.

[183] See www.biogaspro.com.

[184] See the latest information on the new ACE stove design, drawing on patented Philips technology, at http://www.africancleanenergy.com/the-solution/.

[185] In BioLite's case, stove-use monitoring data are logged by the stove-use monitor, and are then recorded onto an embedded microSD card, which is electronically tagged to the specific stove, and can be collected by an untrained field worker.

[186] For an overview of new PATS technologies, see Pillarisetti et al. (2014).

[187] BioLite holds significant IP globally and in Africa on the core heat-to-electricity TEG technology within cookstoves (see patents EP2342500A1, WO2010042574A1, US20130112187, US8297271).

[188] For pilots integrating TEG units into existing Africa ICS technologies, see O'Shaughnessy et al. (2014).

[190] Biomass is exchanged at the rate of 5 kg of wood branches for 1 kg of fuel pellets, which the company reports is more than sufficient to meet most rural household cooking requirements. Households report that this system reduces the amount of fuelwood collected, and the time required to collect it, by about half from before signing the contract. The company

reported that rural household adoption rates are in the 70–99% range in the pilot area, and that retention rates are likewise high.

[191] It is important to note that a number of the bigger Africa cooking-sector stakeholders—such as the Global Alliance, the World Bank, USAID, and GiZ—simultaneously play multiple roles across the landscape as coordination bodies, donors, research and learning providers, implementers (through local partners), and social impact investors.

[192] USAID research on Africa cookstoves is channeled through several different programs, including WashPlus and Translating Research into Action (TRAction).

[193] Major public health institutions with ongoing cookstove RCTs in Africa include the University of Liverpool, Columbia University Mailman School of Public Health, and the University of North Carolina at Chapel Hill.

[194] See update on ISO/IWA process status in GACC (2014) and the Alliance's Web site (http://cleancookstoves.org/).

[195] SUMs have been adopted in many quality cookstove program and project evaluations in the past 2–3 years; see, e.g., Ruiz-Mercado et al. (2011) and Bensch et al. (2013).

[196] See, e.g., the Biomass Energy Strategy for Rwanda (2009); a new biomass policy in progress in Tanzania in 2013–14; and new biomass and charcoal policies in Kenya 2012–13.

[197] One example is the recent zero rating of stove importation tariffs in Rwanda. Discussions are in progress for similar steps in other geographies, but aside from ad hoc exceptions, in most cases, tariffs and taxes on imported stoves and stove components are a major obstacle.

[198] See GACC (2012) for details on the volume of SSA cooking-sector research.

[199] Gifford (2011).

[200] See Muchiri (2008) for Kenya, Habermehl (2007) for Malawi, and Bensch and Peters (2011) for Senegal.

[201] Kojima et al. (2011).

[202] Schwebel et al. (2009).

[203] GACC (2013).

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

[205] See the Gold Standard VER registry at http://mer.markit.com/br-reg/public/index.jsp (accessed March 1, 2014). The "Gold Standard" is a standard used when creating emission reduction projects in the Clean Development Mechanism (CDM) Joint Implementation (JI) and Voluntary Carbon Market.

[206] As of early 2014, in alphabetical order, African countries with CDM-registered cookstove projects included Burkina Faso, Burundi, Cameroon, Côte d'Ivoire, Ethiopia, Ghana, Kenya, Malawi, Mali, Nigeria, Rwanda, Senegal, South Africa, Togo, Uganda, and Zambia. Registered and listed Gold Standard VER stoves projects are additionally present in Niger, Guinea, and Lesotho.

[207] See, e.g., https://www.gov.uk/result-based-financing-for-low-carbon-energy-access-rbf.

[208] IMC Worldwide (2014).

[209] See http://www.cquestcapital.com/wp-content/uploads/2013/05/Health_reductions_paper_4_19_2013.pdf and http://www.worldbank.org/content/dam/Worldbank/document/HDN/Health/021214CQCandLaosStovesNewcombe.pdf.

[210] See http://www.cardanodevelopment.com/initiatives/bix-fund-management-company.

[211] In 2010, IEA estimated total global spending of US$70 million annually on improved biomass stoves and up to US$1 billion annually on clean and improved cooking, once LPG, biogas, and other renewable and modern fuels were included. The proportion of these investments focused on Africa is unclear. Dalberg (2013) has separately assessed SSA investments into clean and improved cooking at US$100–200 million annually for SSA, using bottom-up reported program data from donors, such as GIZ, DFID, WB/IFC, and USAID; CDM data; and publicly available data on private-sector investments, including the latest data on carbon finance streams.

[i] See the latest information on the new ACE stove design, drawing on patented Philips technology, at http://www.africancleanenergy.com/the-solution/.

[ii] In BioLite's case, stove-use monitoring data are logged by the monitor and then recorded onto an embedded microSD card, which is electronically tagged to the specific stove, and can be collected by an untrained field worker.

[iii] For an overview of new PATS technologies, see Pillarisetti et al. (2014).

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