BERKELEY AIR
MONITORING GROUP

Stove Performance Inventory Report

Prepared for the Global Alliance for Clean Cookstoves

United Nations Foundation

Berkeley Air Monitoring Group

October 2012

Contents

Acknowledgments

The stove performance inventory project was kicked off in February 2012 with generous support from the Canadian government. The initiative was led by Dr. Michael Johnson, Dr. David Pennise, and Dana Charron of Berkeley Air Monitoring Group, and involved researchers at several institutions. The inventory database was largely compiled by Dr. Sunny Karnani at the University of California, Irvine, with assistance from Professor Rufus Edwards, and University of California, Berkeley students Erin Milner, Anna Zimmerman, Anoop Muniyappa, and Lizi Feng. Translation of the database into a web-based platform was led by Michael Benedict of Carbon Keeper. Key staff at UNF including Dr. Ranyee Chiang and Dr. Sumi Mehta also provided guidance. Several experts from academia, government, and the non-profit sector graciously provided input into the design and populating of the inventory database.

1) Executive Summary

The inventory currently contains data from over 600 unique sets of performance tests, which represent more than 3500 individual samples collected using a range of laboratory and field methods. It was compiled through a systematic review of published and gray literature using search terms related to cookstove testing and performance. The inventory has also been designed to facilitate continual updating, so that additional sources, including new studies and foreign-language publications, may be included.

The purpose of this report is to present key information about the current inventory, breaking down the numbers by type of test, data source, region, and stove and fuel type. The bulk of the current inventory data is from laboratory tests, especially from North America and Asia, where a handful of large testing programs have been the main contributors. Although there is much less field data to present, the largest contribution of field data comes from Africa. Traditional and simple non-traditional stoves have been the most commonly tested stove types, with more testing now being done on newer stove technologies and fuels. Finally, the inventory substantiates the expectation that liquid and gas fuels burn more cleanly than solid fuels, whereas unprocessed crop residues and dung are generally the least clean household energy sources.

The stove performance inventory also provides an opportunity to map and compare stove performance against standards or benchmarks, the most relevant of which is the recently approved ISO International Workshop Agreement on Clean and Efficient Cookstoves (February 2012). The IWA, which is a preliminary step towards a formal ISO standard, uses “Tiers of Performance” to categorize stove performance levels for efficiency, safety, and emissions. The majority of non-traditional solid-fuel stove performance results place them in Tiers 1 and 2 for emissions and efficiency, with only liquid and gas stoves (e.g. ethanol and LPG) meeting the ambitious health and environmental-related targets associated with Tier 4. By and large, the best biomass stove performers – fan stoves and gasifiers – fit into Tier 3, although more data is needed to understand if these technologies can obtain similar levels of performance in the field.

Moreover, the comparison of laboratory and field data where both exist for specific stove/fuel combinations, which is generally for traditional (Tier 0) and Tier 1 stoves, indicates that laboratory testing overestimates the field performance for most stove types. The factors identified in the literature as having the greatest impact on the lab/field performance gap for biomass stoves are fuel quality and cooking and fire tending practices. This finding underscores the need for further field testing of advanced biomass stoves that fit into Tier 3 based on laboratory tests, to investigate whether this performance gap continues to exist in the higher tiers and if so, how it might be mitigated.

Although this first iteration of the inventory was compiled through the application of systematic search criteria and no doubt captures a great deal of the available work, there are some sources that are not represented and some topics that still need to be explored. Foreign language sources are missing, especially many Chinese papers, as are many proprietary data sets. Also missing are adoption-related metrics, as these are not yet well characterized. Finally, efforts still need to be done for mapping results from different water boiling-based protocols into a unified comparative framework, as well as the protocol development that would allow us to better include technologies not designed for typical water boiling testing, such as those for intended for cooking flatbreads (plancha) and indoor heating.

2) Introduction

The Global Alliance for Clean Cookstoves aims to catalyze 100 million households using clean cookstoves by 2020 in order to achieve improvements in human health, livelihoods, gender empowerment, and in the quality and stability of the global environment. The Alliance proposes three kinds of activities to achieve its goals: enhance demand, strengthen supply, and foster an enabling environment. The overarching purpose of the Stove Performance Inventory is to support the Global Alliance's phase one (2012-2014) priorities in the area of fostering an enabling environment, and especially developing international cookstove standards and creating systems to deliver robust monitoring and evaluation.

Across the sector, there has been widespread consensus around the need for a comprehensive, transparent and realistic understanding of stove performance, so that the current landscape can be aptly characterized and critical threats and opportunities identified. A stove performance inventory database was recognized as a key building block for this understanding by both the Global Alliance working groups on Standards and Testing and Monitoring and Evaluation (M&E) and was included in the M&E group's roadmap recommendations. A better understanding of the current stove performance landscape was also a need highlighted by the Climate and Carbon Finance working groups.

To fill this need, Berkeley Air was contracted by the Alliance to create the database framework for a detailed inventory and to populate it with the most relevant and accessible data. This report outlines the features of the database and the process used to create it and envisioned for updating its contents regularly. It also provides an analysis of the current inventory's strengths and gaps according to several key parameters, including geographic completeness, representativeness of stoves and fuels, comparability of metrics, and quality of the data sources. The later chapters seek to explore the implications of the strengths and gaps on several important ongoing efforts, including the ISO IWA, the WHO guidelines, the carbon finance market, and the Alliance's target and goals. The report also provides a discussion on comparing lab and field results. Finally, the document concludes with a set of recommendations for filling the gaps, including a review of parallel initiatives and how they fit into the overall landscape.

By documenting the range of current cookstove performance, the inventory will allow the sector to set standards that are relevant and credible. It will also allow the Alliance to set a realistic baseline for the growth target of 100 million households using clean cookstove technologies and inform what will be necessary to achieve gains in the four key mission areas of saving lives, improving livelihoods, protecting the global climate, and empowering women. The inventory will also serve the further purpose of allowing the sector to compare lab and field results and inform a discussion of how assessment methods could be improved to achieve better standardization, comparability, and efficiency.

3) Methods

Inventory Development and Composition

Identifying Resources

The review was conducted via a search of readily available information as well as unpublished data that may not be obtained through conventional web searches. Only sources with directly measured, primary data were included in the inventory. The data sources were saved and managed using Zotero, a free open-source resource management software (www.zotero.org). For the initial inventory, only sources presented in English from the previous 15 years were included (1997 to present). The inventory will be expanded to include additional sources. To suggest or share additional sources, please contact knowledge@cleancookstoves.org.

Peer-Reviewed Literature

Peer-reviewed literature was searched using the following terms and search engines/electronic databases:

- Google Scholar (http://scholar.google.com)
- Web of Science (http://apps.webofknowledge.com)
- Science Direct (http://www.sciencedirect.com)

Core search terms	**Additional search terms**		
stove	performance	water boiling test	WBT
cookstove	emissions	controlled cooking test	CCT
cooking stove	biomass	kitchen performance test	KPT
open fire stove	emission factor	efficiency	field
improved stove	fuel savings	adoption	laboratory
	usage	uptake	

Gray Literature

There is a substantial amount of stove performance data available in reports or other non-peer reviewed material. There are a variety of sources and no universal or simple method for searching the body of gray literature. We identified several initial sources (see below) and conducted as many manual searches for stove performance data as possible. Due to time constraints, we have include only major reports and data sources for the initial inventory, with the aim of including as much available data as possible over time.

The initial list of sources for gray literature is provided below:

- Aprovecho Research Center: www.aprovecho.org/lab/index.php
- Asian Development Bank: beta.adb.org/
- Beijing University of Chemical Technology: www.buct.edu.cn/
- Berkeley Air Monitoring Group: www.berkeleyair.com
- Bioenergylist.org: www.bioenergylists.org/stoves
- Center for Research in Energy and Energy Conservation, Makerere University: www.creec.or.ug
- Engines and Energy Conversion Laboratory, Colorado State University: www.eecl.colostate.edu/
- Food and Agricultural Organization: www.fao.org
- GERES Cambodia: www.cambodia.geres.eu/
- GIZ/Energypedia: www.energypedia.info/index.php/Portal:Improved_Cooking
- Global Alliance for Clean Cookstoves: cleancookstoves.org/
- Global Village Energy Partnership (GVEP): www.gvepinternational.org/en
- HEDON: www.hedon.org
- ITT Deli: www.iitd.ac.in/
- Partnership for Clean Indoor Air: www.pciaonline.org/

- Project Gaia: www.projectgaia.com/page.php?page=resources
- Sustainable energy Technology and Research (SeTAR) Centre: www.uj.ac.za/EN/Faculties/science/departments/geography/research/SeTAR/Pages/home.aspx
- UNDP: www.undp.org/
- UNEP: www.unep.org
- United States Environmental Protection Agency, National Risk Management Research Laboratory: www.epa.gov/nrmrl/
- USAID: www.usaid.gov/index.html
- World Bank Energy Sector Management Assistance Program: www.esmap.org/esmap/

Proprietary Data

Although the gray literature on cookstove performance is still a rich source of data, it does not provide comprehensive access, together with the published literature, to the results of stove testing activities. Whereas in earlier phases of the sector development, implementers were eager to share information on their programs and lessons learned through publications like *Boiling Point*, now a significant portion of information is kept under wraps in order to preserve competitive advantages in growing stove sales and accessing carbon financing. To access carbon finance, stove disseminators have had to start collecting quantitative data and conducting at least some stove performance testing. This development in tandem with a strong focus on developing clean cook stove markets has changed the nature of information sharing across the sector. This inventory includes only data which is available publicly.

Inventory Structure

The inventory database is organized such that each record, or row of data, represents a unique set of stove test results. For example, a set of five WBTs conducted under the same conditions on a specific rocket stove is represented by one row of data in the inventory. The number of replicates associated with each row of unique test set results (e.g. sample size) is included in the inventory along with the pertinent contextual information, including, but not limited to:

- Data source (citation)
- Stove as named in source
- Stove classification/characteristics (e.g. plancha, chimney, gasifier, fan, etc.)
- Fuel type used during testing
- Lead testing organization type
- Location (test region and country)
- Test type (lab, field, WBT, CCT, HTP, KPT, etc.)
- Unique test conditions (new/old stove, poorly tended fire, season, etc.)

A list of stove/fuel categories and output metrics is provided below. Note that the stove characteristics and fuels used are not exclusive, meaning that a stove can, for example, have a rocket-style combustion chamber and a chimney, as well as other characteristics.

Stove/fuel categories

Stoves/Fuels				
Stove characteristics			**Fuels**	
TSF	Fixed/Built-in	Biochar-producing	Wood	Gel
U-shaped traditional	Plancha	Multi-pot	Charcoal	Kerosene
Traditional metal	Sunken pot	Ceramic-lined	Dung	Plant oil
Other traditional	Fan	Heating	Crop residue	Ethanol
Simple non-traditional*	TEG#	Parabolic	Briquettes	LPG
Rocket	Pot skirt	Heat-trap box	Pellets	Biogas
Chimney	Pressure	Panel	Other biomass	Methanol
Gasifier	Wick	Batch-loaded	Solar	Coal

*Simple non-traditional are defined as stoves which have some type of design intended to increase combustion or fuel efficiency but do not fit into the other stove classes; for example, stoves constructed with simple, non-rocket style ceramic or mud combustion chambers.

#Thermoelectric generator

The output metrics, which correspond to each unique data row, are summarized below. Only those presented directly in the source, or which can be readily and clearly calculated from the presented data, are included in the inventory.

Inventory Metrics

Output metrics		
Fuel use	**Emissions**	**Time**
Thermal efficiency	Species: CO_2, CO, CH_4, NMHC, PM, BC, OC	Time per test phase
Specific energy consumption	Emissions per MJ delivered	Time per task
Specific energy consumption rate	Emissions per kg and MJ fuel	
Fuel use per capita	Emissions per minute	
	Emissions per task	
	Modified combustion efficiency	
	Combustion efficiency	

An illustrative example of the physical inventory is presented below. Note this is not the actual inventory, which has a far more comprehensive set of fields for specifying the exact stove model/characteristics, test type/conditions, and relevant system information, as well as output metrics encompassing those outlined in the previous table. The web-based version of the inventory will have filters and forms for searching and sorting. The entire database will be also be downloadable in text or comma-separated-variable for importing into statistical or database platforms.

source	lead_research _group_type	source_link	source_ type	stove as named in source	non- trad	Test Type	Mean time to boil (min)	Cold start thermal efficiency	Hot start thermal efficiency	Average Efficiency
Academy for Educa	NGO	http://www.usa	Report	6 Brick (N	1	MWBT:1	16.5	0.136	0.143	0.144
Academy for Educa	NGO	http://www.usa	Report	TSF	0	MWBT:1	21.5	0.137	0.125	0.139
Academy for Educa	NGO	http://www.usa	Report	Traditiona	0	MWBT:1	22	0.109	0.093	0.120
Academy for Educa	NGO	http://www.usa	Report	Trench S	0	MWBT:1	25.5	0.085	0.101	0.120
Academy for Educa	NGO	http://www.usa	Report	Lorena 2-	1	MWBT:1	42.5	0.088	0.075	0.090
Academy for Educa	NGO	http://www.usa	Report	Lorena 2-	1	MWBT:1	54	0.048	0.045	0.065

4) Summary of Inventory Results

Overview

To date, the inventory includes data from over 75 sources, which constitute more than 600 unique test sets and over 3500 individual test samples, half of which come from sources published within the past five years. The inventory continues to be updated, so these numbers will grow over time. Figure 1 breaks down the number of unique test sets for major geographies and if the test was a laboratory or field test[1]. This high level illustration of the available data shows that laboratory testing in Asia and USA/Canada provide the bulk of stove performance data in the inventory. The test sets for Asia include the first large stove performance inventory produced for India and China by (Smith et al., 2000) and (Zhang et al., 2000), which constitute approximately one third of the test sets for Asia currently in the inventory. The laboratory data from USA/Canada consist largely of work by Aprovecho Research Center (MacCarty et al., 2010; Aprovecho Research Center, 2011) and the US EPA (Jetter and Kariher, 2009; Jetter et al., 2012). Although there is substantially more performance data available from laboratory testing than field testing, there has been a considerable amount of field data reported from Africa, which comes from a variety of papers and reports. We also are aware that there is considerable data that can be added for Africa and Latin America from carbon finance reports and regional laboratories (see the section on Carbon Finance [pg. 19] for a detailed discussion on this data).

---

[1] A laboratory test is defined as any test conducted in a laboratory or controlled environment with a technician or non-local user operating the stove. Field tests are defined as being in homes or target communities' facilities (e.g. community centers) with a local operator using the technology.

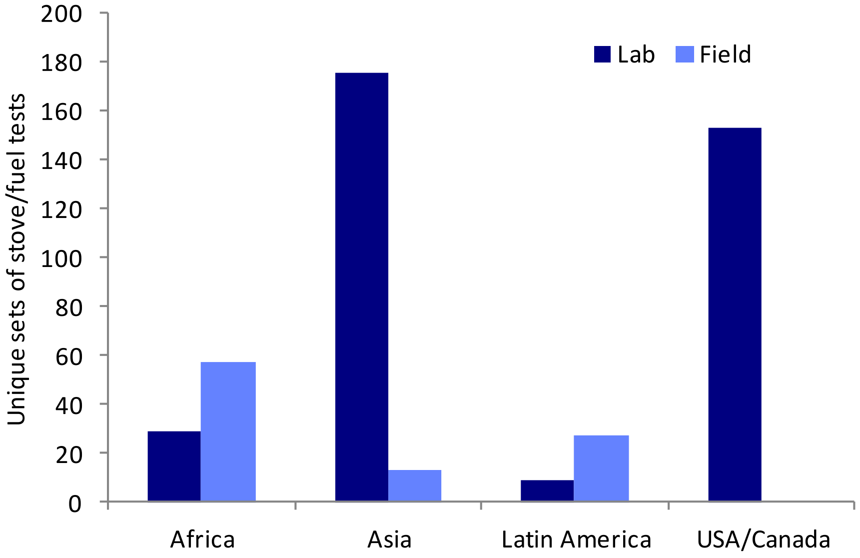

Figure 1. Number of unique test sets for laboratory and field testing across major regions.

Stove type

Figure 2 shows the number of test sets for major stove and fuel type classes. The bulk of testing has been done on traditional stoves, the results of which are generally used as a baseline for comparative purposes. Simple non-traditional stoves (e.g. clay pot-style or simple ceramic liners), chimney, rocket, and charcoal stoves were the next most commonly tested stove/fuel classes. Very little testing data is available on gasifier or forced draft (i.e. fan) stoves, nor is much performance data available on stoves that use liquid or gas fuels. The lack of data on these stoves/fuels is partly a reflection of the number of stoves available for testing, but it also indicates that more performance data is needed on these stoves and fuels. The gap is especially evident for field studies of these technologies, which are a critical step towards understanding their potential as viable clean solutions in the household energy sector.

The information on heating stoves comes primarily from a study funded by the Asian Development Bank and carried out by Crispin Pemberton-Pigott, who did a series of laboratory tests on heating stoves for potential use in Mongolia (Pemberton-Pigott, 2011). This study presented emission factors across a variety of conditions using the Heterogeneous Test Protocol (SeTAR, 2012) and included a measure of thermal efficiency considering energy delivered to the room. There is also limited field performance information on fuel consumption impacts for heating stoves presented in (Cowlin, Shannon et al., 2005) and (Khudadad et al., 2012). Given the numbers of people at high altitudes in Asia and Latin America where heating is critical and constitutes a major household energy demand, the lack of information on heating stove performance is an important gap in our knowledge base.

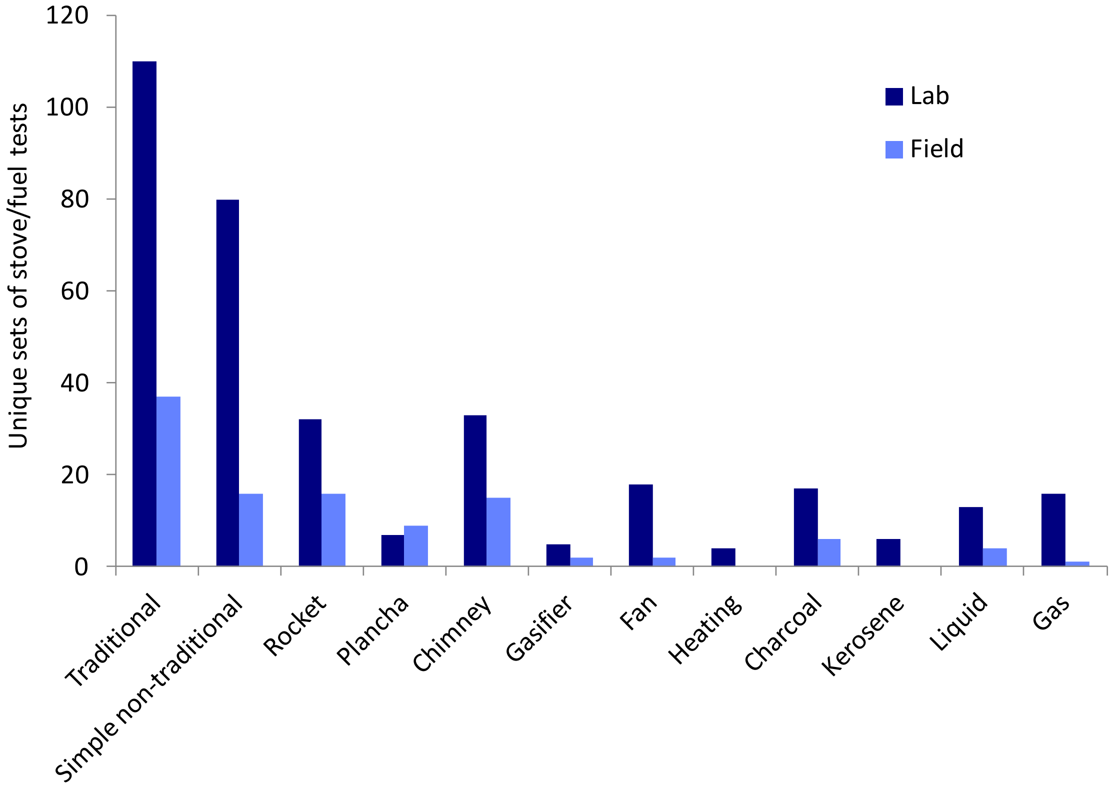

Figure 2. Number of test sets for different stove and fuel characteristics.

Energy Ladder

Figure 3 shows the combustion efficiency and particulate emissions across the energy ladder, from what are considered the least clean energy sources (dung and crop residues) to those considered the cleanest (gas/liquid fuels). The performance inventory data indicates that dung and crop residues generally combust inefficiently and have high PM emissions relative to the energy content of the fuel, whereas liquid and gas fuels burn relatively cleanly with low PM emissions. Charcoal has a different emissions profile as its combustion efficiency[2] is generally low due to high CO emissions, but with relatively low PM emissions per unit energy of fuel content. Clearly the stove technology and quality/processing of the fuel also impact the quality of combustion, although for simplicity these factors are not taken into account for this graph. For example, the Oorja fan stove uses pellets processed from sugar cane residues and was one of the cleanest burning stoves in both the latest round of EPA laboratory testing and a field study in India (MCE's of 97% and 96%, respectively) (Johnson et al., 2011; Jetter et al., 2012). There has also been recent concern regarding kerosene, which although it can burn relatively completely in the right technologies, may still produce emissions linked to substantial health impacts (Pokhrel et al., 2010; Lam et al., 2012). Simple kerosene wick lamps commonly used in developing

---

[2] Combustion efficiency is a measure of how completely the carbon in a fuel is converted into carbon dioxide. Here we use a commonly used proxy, modified combustion efficiency (MCE), which is defined as $CO_2/[CO_2+CO]$, as an indicator of combustion efficiency.

countries are also known to have extremely high PM emissions (Schare and Smith, 1995; Apple et al., 2010). It should also be noted that biogas and ethanol, which are not represented directly in this figure, both have combustion efficiencies and particle emissions comparable to LPG (Smith et al., 2000; Zhang et al., 2000; MacCarty et al., 2010).

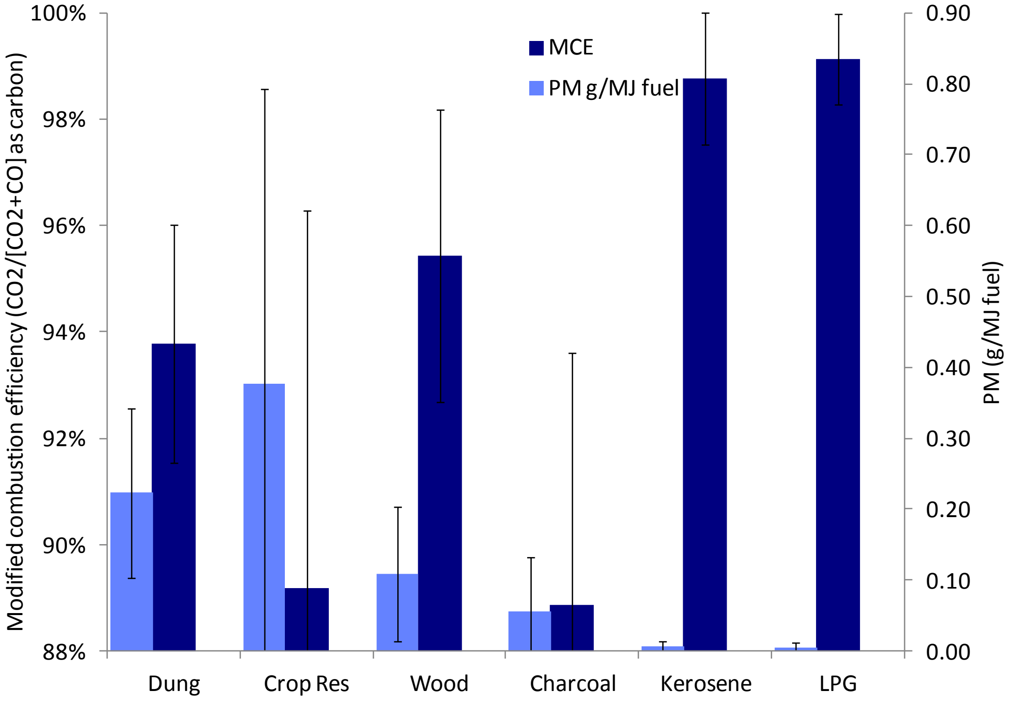

Figure 3. Combustion efficiency and PM emission factors across the energy ladder.

Two other energy sources have not been included in this energy ladder, which are important to note. First, solar powered cookers, which have zero household emissions, are not included. While solar based cooking technologies clearly represent clean solutions when feasible, they require relatively unique consideration as part of household energy systems, since other energy sources are required to supplement their use at night, on cloudy days, and when not suited for cooking specific food types. To avoid the implication that coal may be a relatively clean fuel, it has not been included in the energy ladder above as serious health impacts are associated with high levels of contaminants in coal, such as arsenic and fluoride (Zhang and Smith, 2007), which are emitted regardless of how completely coal combusts in a stove.

Test Protocols and Performance Metrics

Protocols

The stove performance test results were categorized by protocol type. These categories include: Water Boiling Test (WBT), Heterogeneous Testing Protocol (HTP), Controlled Cooking Test (CCT), Kitchen Performance Test (KPT), and Uncontrolled Field Test (UFT).

The WBT category includes any and all stove tests involving the boiling of water in a laboratory (i.e. WBT 4.1.2, WBT 3.0, Chinese Water Boiling Test, Indian Water Boiling Test, etc.). The specific information about the specific type of test is also in the inventory, but the larger WBT category is used for broad characterization of the test type. Thus, the category of WBT includes various slightly different test protocols. The variations in the protocols create data comparability issues, but variations between WBT protocols are likely small compared to the large differences in the various, broad test type categories.

The HTP category involves laboratory testing where stoves are systematically operated across a range of fuel loadings/powers and pot sizes. It should be noted that the CCT or KPT categorization was applied to some stove test results where the test protocol matched the general principles of these test types, even though the source authors did not refer to their protocols as a CCT or KPT. The UFT category includes any and all types of uncontrolled field testing and includes the Uncontrolled Cooking Test (UCT), for which performance is measured for single events (meals, boiling water, etc.) and longer tests of daily operational stove use. Figure 4 shows the distribution of test sets for the different protocol classes. WBT versions are by far the most commonly used protocols, with field CCTs, KPTs, and UFTs providing the remainder of the test sets.

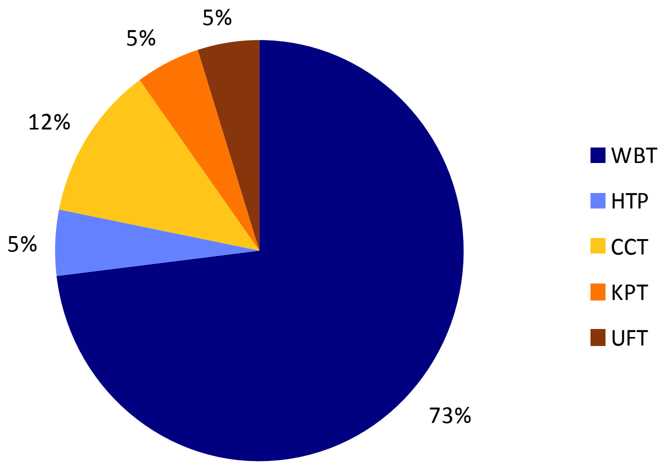

Figure 4. Percentage of test sets by protocol.

Performance Metrics

The use of universal output metrics for stove performance testing results allows comparison of performance across protocol types within one test type category. Different output metrics from different WBT protocols can often be inter-converted, and the same goes for the different variations of the HTP, CCT, KPT, and UFT protocols. Many output metrics, however, are protocol specific and cannot be compared or translated across the major protocol classes. For example, the primary WBT output metrics such as thermal efficiency or grams pollutant per MJ-delivered cannot be directly compared to CCT, KPT, or UFT output metrics. There are still many metrics that can be measured across protocols, such as combustion efficiency, emission factors and rates, and relative fuel savings (when comparing the relative stove performance of two or more stoves).

Output metrics from one publication and/or protocol type can often only be translated to another metric (i.e. a universal metric) if the publication provides enough details on the stove testing method/protocol. Another challenge in the development of the inventory is that sources are sometimes unclear about the exact units of their output metrics, which can make the translation difficult. For example, while grams of pollutant emitted per kilogram of wood combusted (g/kg) is a common and widely applicable emissions output metric, the data sources do not always specify whether the emission factor is gram per kg wet wood, dry wood, or dry wood equivalent, resulting in a significant lack of clarity and comparability. In general, our knowledge base and capacity to fairly and accurately compare stove performance data could be aided by more standardized metrics and presentation of those metrics.

Data sources and quality

The type of the lead research group who produced each test set was also tracked in the inventory, which was defined as affiliation of the lead author, or the group that produced the respective presentation or report. We classified these groups as universities, NGOs, private consultants or research groups, and government agencies, which accounted for the following relative contributions to the test sets.

- 55% from universities
- 22% from NGOs
- 12% from consultants or private research groups
- 10% from government agencies

There has not been any assessment of the independence of each research group in the inventory. Universities can typically be considered independent evaluators, although not always. Also, research on stove performance is often collaborative, involving many partners. So, identifying exactly who performed which part of the research can be difficult in many cases.

At this point there has not been formal evaluation or rating of the quality of the data included in the inventory. The publication source type itself is tracked in the inventory, yielding the following breakdown of test sets:

- 66% from peer-reviewed literature
- 21% from reports
- 13% from conference proceedings/presentations

The peer-review process ensures some level of rigor in the overall quality of the publication, as peer reviewers judge the entire article submission against the general norms of scientific rigor, methodology, and quality for their field of expertise. The peer review process, however, is not standardized and certainly does not involve the evaluation of the published data against specific, fixed criteria. For example, the ISO IWA specifies that PM measurements must be performed using the gravimetric method for comparison against the tiers of performance for PM emissions. Future efforts could focus on the application of specific methodological criteria for filtering stove performance data within the inventory.

5) Implications and linkages

Standards and Testing

As a repository for stove performance data, this inventory provides the means for easily comparing and mapping stove performance against standards or benchmarks. The cookstove sector recently made a substantial step towards more formal standards with the recently approved ISO International Workshop

Agreement (http://www.pciaonline.org/files/ISO-IWA-Cookstoves.pdf). The IWA standards provide, for the first time, an internationally agreed upon framework for comparing stove performance. The standards are based on “Tiers of Performance”, which provide a map towards increasing performance, from traditional open fire stoves (Tier 0) to aspirational goals for meeting ambitious health and/or environmental targets (Tier 4). The IWA only includes emissions and fuel use Tiers of Performance for the WBT 4.1.2[3], although the document also includes recommendations for incorporating data from other test protocols through a “Rosetta Stone” approach and developing protocols better suited for different stove types (e.g. batch-fed, solar, plancha, heating), as well as developing approaches informed by, or inclusive of, field performance. The IWA also recommends that performance tiers related to durability and climate be developed as protocols and more data become available for these indicators.

The available data for mapping stoves to the IWA Tiers of Performance would be severely limited had we only included inventory data that strictly adhered to the requirements outlined by the IWA. We therefore have included data that we determined to be valuable for the purposes of broadly understanding the range of stove performance with respect to the IWA tiers. Specifically, we have included all available PM measurements, not just those collected gravimetrically for $PM_{2.5}$[4]. We have also included results from different versions of the WBT (e.g. 4.1.2, 3.0), and in many cases the WBT protocols were slightly modified for various reasons. Therefore, the performance ranges mapped here should be interpreted as a broad understanding of where the current stove/fuel classes fall within the Tiers.

Figure 5 and Figure 6 show the emissions performance for major stove/fuel classes against the IWA Tiers. The data points represent the means with error bars of one standard deviation for technologies that fit the respective stove/fuel classes. Each point may represent multiple stoves/fuels of that class, with a caveat that fan/gasifiers were split into “well performing” and “poorly performing” categories as there was a clear and wide performance difference that resulted into two distinct clusters. The graphs show a general trend of increasing emissions performance from traditional wood stoves, to simple traditional and plancha stoves, then rocket stoves, and finally well performing fan/gasifier stoves approaching the emissions performance of gas/liquid fuelled stoves. Charcoal stoves are characterized by high CO emissions, which is evident by their poor performance on the CO emission metrics. Only gas and liquid fuel stoves have performance levels for the highest tier. Aside from charcoal stoves, better performance against the CO standards is observed than for $PM_{2.5}$, although the overall emissions rating is determined as the lowest across all PM and CO metrics. This difference implies that the greatest challenge for achieving the highest levels of performance will be reducing PM emissions, especially to approach those achieved by liquid and gas fuels.

Also evident in the figures is the large range of emissions performance for many of the stove classes. This variability is likely due to differences in operation, design differences, and testing conditions. For example, Jetter (2012) found that a minimally attended three stone fire emitted approximately one third more CO and almost twice the PM per MJ-delivered compared to a well-tended three stone fire. The variability in “traditional” stove performance also demonstrates the impracticality of establishing a

---

[3] There are also Tiers of Performance in the IWA for safety as measured by the Biomass Stove Safety Protocol developed at Iowa State University -- http://www.pciaonline.org/files/Stove-Testing-Safety-Guidelines.pdf.

[4] There can be error and bias associated with measurement of PM with non-gravimetric techniques such as light scattering, as well as with the assumption that PM mass is similar to $PM_{2.5}$.

universal baseline for comparing stove performance. For example, some "traditional" stoves are high thermal mass stoves, such as many of the chulhas in India and Nepal, whereas others can be as simple as a depression in the ground. These design differences have impacts on emissions and fuel performance, which means that the relevant baseline for comparison will vary by location and corresponding technologies targeted for replacement.

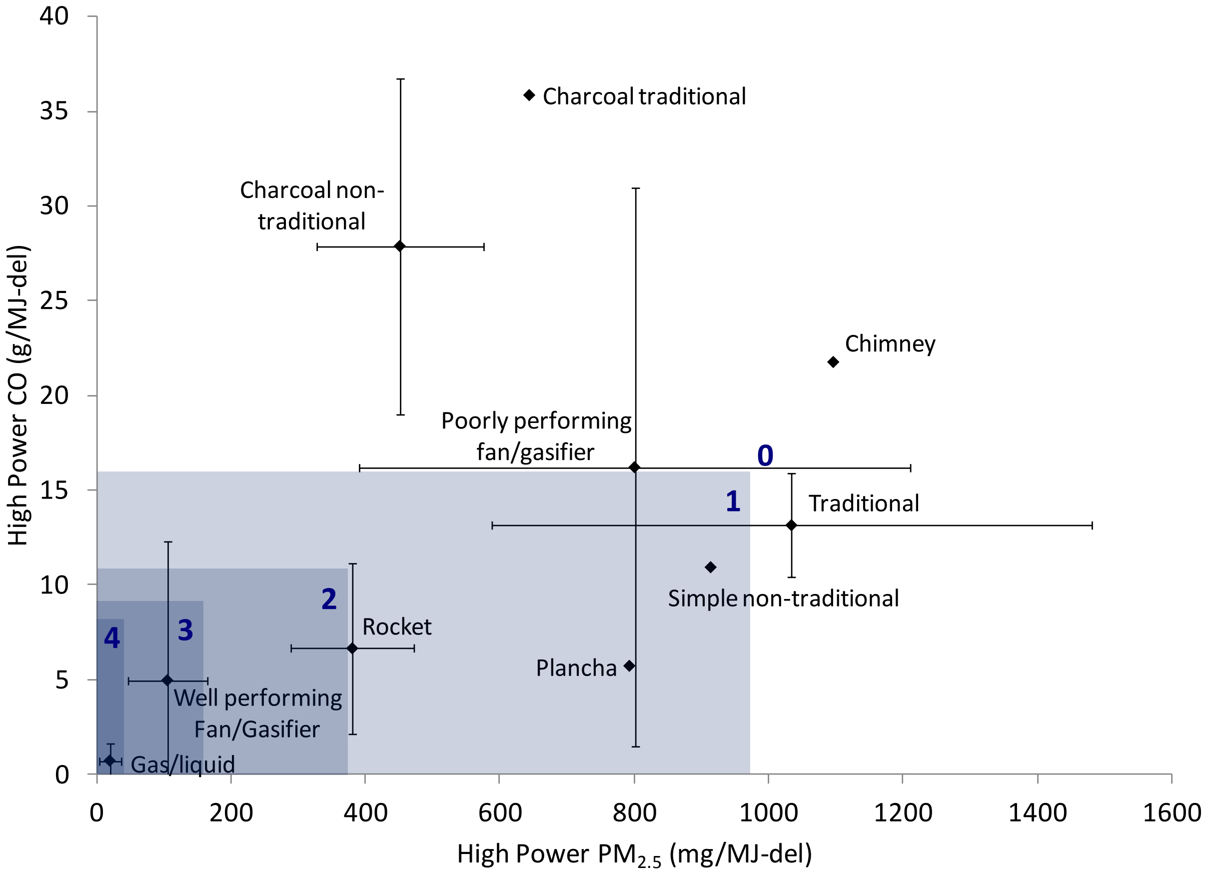

Figure 5. High power emissions performance for key stove/fuel classes across the IWA Tiers for the WBT. Error bars represent ± one standard deviation of the available tests sets. Stove/fuel classes with no error bars consist of two or less data points. Tiers are indicated by blue numbers.

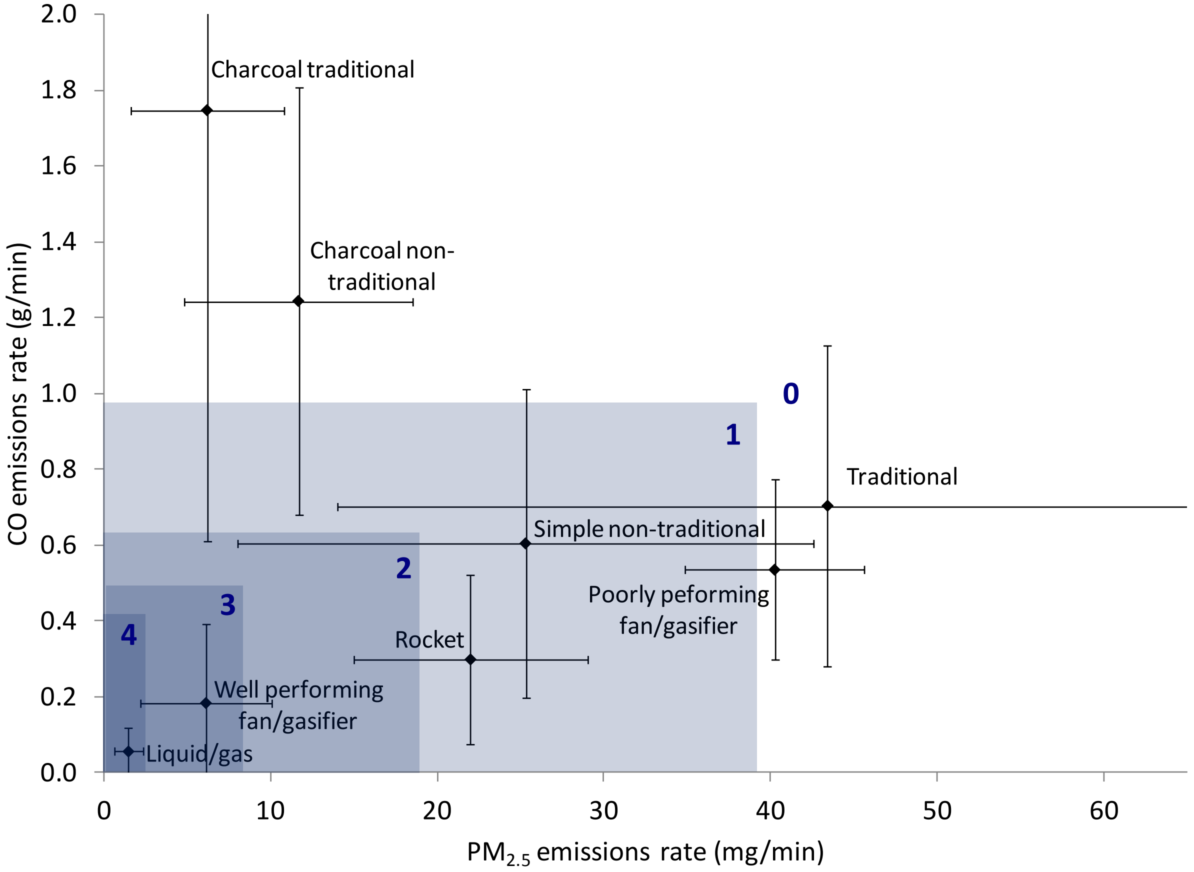

Figure 6. Indoor emissions performance for key stove/fuel classes across the IWA Tiers for the WBT. Error bars represent ± one standard deviation of the available tests sets. Stove/fuel classes with no error bars consist of two or less data points. Tiers are indicated by blue numbers.

Figure 7 shows the thermal efficiency performance against the IWA Tiers of Performance. The liquid and gas fuel stoves again show performance within Tier 4, with the well performing fan/gasifier stoves in Tier 3 and rocket stoves generally in Tiers 1 and 2. The lowest performing stoves for thermal efficiency as measured by the "WBT" were plancha and chimney stoves. The results for plancha stoves may be expected as these stoves are not designed to boil water as their primary task.

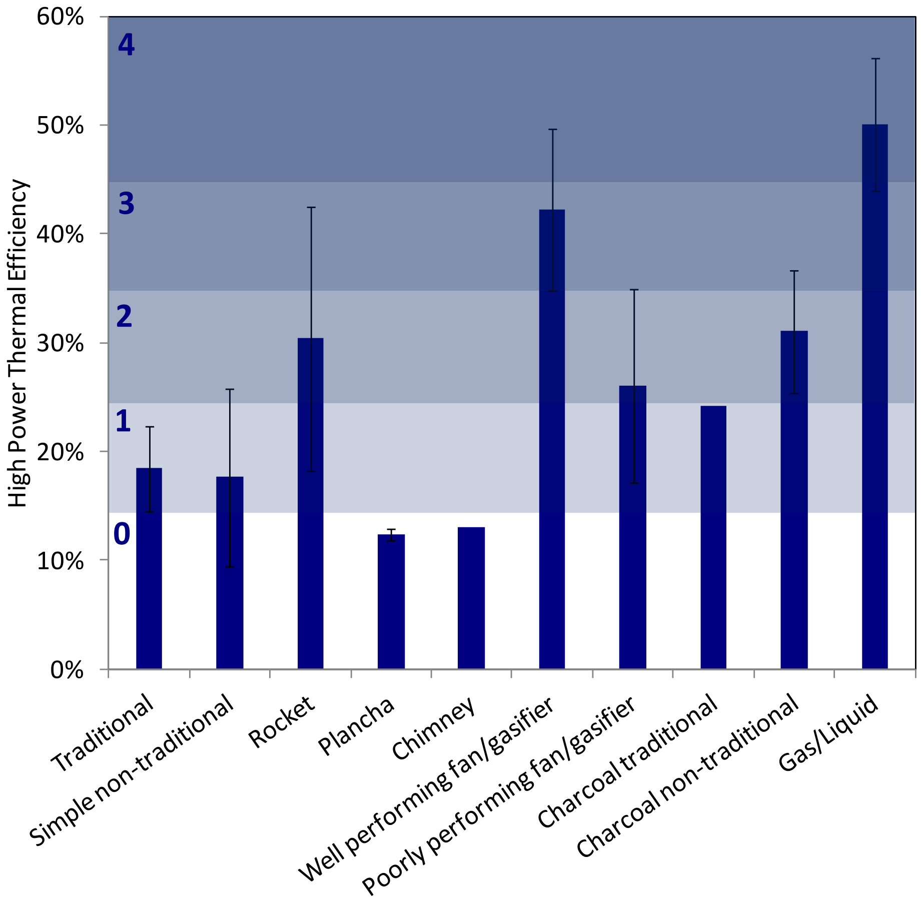

Figure 7. Thermal efficiency performance for key stove/fuel classes across the IWA Tiers for the VITA WBT. Error bars represent ± one standard deviation of the available tests sets. Tiers are indicated by blue numbers.

Overall, the performance data from the inventory, when mapped against the IWA Tiers of Performance indicates that gas and liquid fuels represent the cleanest current household energy solutions. They also show that there are biomass-fuelled solutions that can approach the performance of these fuels, which is critical for areas where LPG, ethanol, electricity, and other clean fuels are currently either not available or prohibitively expensive.

While this inventory is an important step towards organizing stove performance data such that comparisons against standards can be readily conducted, there are still challenges in reporting and interpreting data. Perhaps most important is that the IWA only directly provides Tiers of Performance for the WBT 4.1.2. There are current efforts to translate equivalent tiers of performance for other protocols such as those used by the Indian Bureau of Standards, Chinese certification agencies, and with the University of Johannesburg’s Heterogeneous Test Protocol. As these efforts progress and the inventory is populated by results from additional protocols, comparisons between stoves will be facilitated by a harmonized system for reporting common and/or comparable metrics.

Stove Usage and Durability

The inventory does not include any metrics related to adoption, despite widespread agreement that adoption is enormously important as a link between technical performance and impacts. How much and how well a household is able to integrate a new cooking technology/fuel into its daily activities will determine how close the technology comes to delivering its maximum long-term health, development, and environmental benefits. There is further consensus that a deficit exists in the literature around how to define adoption and the related concepts of acceptance, uptake, and usage, and what methods and metrics to use to measure it. Although studies of adoption factors and approaches are on the rise, the learnings do not yet provide an agreed upon set of quantitative measures that can be fairly and systematically integrated into the stove performance inventory. The forthcoming systematic review funded by DFID and expected to be available later this year is expected to help the sector streamline how to assess adoption and to inform on how best to summarize this key parameter across stove types and geographies (Puzzolo et al., 2011).

Stove usage is also closely related to, and in many cases a direct function of, stove durability and condition. Stove durability is an indicator that the ISO IWA recommended for protocol development and later inclusion in the standards framework, as a stove's condition and lifetime clearly impact its performance and ability to impart benefits. Although durability testing is conducted formally and informally at various testing laboratories, there are no commonly defined metrics or universally accepted indicators regarding stove durability and correspondingly very little available data to include in the inventory. Future efforts to assess stove durability with common protocols and indictors would provide a means to include durability related metrics in the inventory.

Monitoring and Evaluation

Stove performance testing is a logical precursor to monitoring and evaluation in the results chain. Almost all of the short and medium-term outcomes of cookstove projects, particularly energy efficiency and reduced concentrations of smoke in the home, as well as the desired long-term impacts, including reduced mortality and poverty alleviation, are all tied to the technical capabilities of the stove. It is also clear that the technical capabilities *alone* are not enough to deliver benefits. The inventory provides a tool that allows evaluators to make smart decisions about how to spend limited assessment resources to document likely impacts. The inventory helps highlight promising technologies that have performed well enough in lab tests to be categorized into Tiers 3 and 4, but about which there is still very little field testing or monitoring data. Currently, this is especially true of fan stoves, gasifier stoves, solar stoves, and liquid or gas fuel stoves. The implication is that if monitoring and evaluation resources were focused towards these stoves, it could be possible to document some best practices that would help advance the entire sector. Of course, in some instances there are significant barriers to disseminating these stoves at scale, which must first be overcome in order for extensive monitoring or evaluation to make sense.

Carbon finance

Household energy relevant data on carbon finance projects is contained in Project Design Documents (PDDs), which are generally publically available on the United Nation's Clean Development Mechanism (CDM) and Gold Standard (GS) websites (http://cdm.unfccc.int/, http://www.cdmgoldstandard.org/). Stove efficiency data that is collected and reported in PDDs includes in-field fuel use data from Kitchen

Performance Tests (GS), in-field specific consumption data from Controlled Cooking Tests (CDM), laboratory thermal efficiency data from Water Boiling Tests (CDM), and survey/questionnaire information on baseline fuel use (CDM). Very little new stove emissions data is generated from stove carbon finance projects, as CDM projects require use of the IPCC default fossil fuel emission factors and, while the GS methodology allows the project to measure and apply emission factors for the project and traditional stoves, almost all GS projects choose to apply the IPCC default emission factor for the relevant fuel type. Stove usage information is collected annually or every other year, generally via surveys, and typically reported as the fraction of project stoves still in use.

At this point stove performance data from carbon finance projects has not been included in this inventory for a number of reasons. For one, the detailed methods used to collect the stove monitoring data are not fully required or reported in PDDs. It is often not clear if the fuel use results are per household or per appliance, and some estimates are adjusted for the sake of conservativeness, which would cause bias in some of the reported data. Also, it is also sometimes not clear if PDD source material is meant to be publically available, even if acquired over seemingly public means. As time and resources allow, however, the clear, high quality stove performance information included in PDDs should be integrated into this inventory.

Nonetheless, the current inventory still has utility for the carbon finance sector by improving the quality and accuracy of data that is used to quantify carbon offsets. For example, the inventory can help provide better default values and appropriate, project-specific fuel use, efficiency, and emissions data. Table 1 summarizes some of the values for key parameters of interest to carbon projects for traditional wood stoves, the most common baseline scenario for carbon projects. Thermal efficiency of baseline biomass stoves, for example, has a default of 10% for CDM projects, which is well underestimated compared to the mean thermal efficiency measured during laboratory studies[5]. Field-based emission factors for GHGs and black carbon are presented as these provide a more realistic basis for estimating the key greenhouse pollutant emissions than laboratory or default estimates.

Table 1. Key carbon finance parameters for traditional wood burning cookstoves.

	Mean	SD	N (test sets)
Laboratory Thermal Efficiency	17%	6%	52
CO_2 (g/kg dry wood)	1560	80	5
CH_4 (g/kg dry wood)	5.0	1.8	5
Black carbon (g/kg wood)	1.0	0.5	5
CO (g/kg fuel dry wood)	78	30	4
TNMHC* (g/dry wood)	10	6	9

*TNMHC = Total non-methane hydrocarbons.

Also, the inventory may help project developers estimate expected emission reductions more accurately, thus increasing their confidence in making investments in the project. The inventory may

---

[5] Estimation of thermal efficiency requires careful measurement of energy delivered to a pot or food, which is impractical to measure during normal daily stove use.

also help project developers choose appropriate, high-performing stoves and target regions where need and expected emission reductions are greatest.

Laboratory and Field Performance

There has been much interest in understanding the differences between the laboratory and field performance of cookstoves. Controlled laboratory testing is critical for testing, designing, and comparing stoves, but it is not currently recommended for prediction of performance during normal operation in homes. During normal operation, stove and fuel use practices are generally more variable and less ideal than in the laboratory, which results in lower performance for many stove/fuel types. The reasons for performance differences likely stem from differences in fuel conditions and cooking/fire tending practices. For example, fuelwood used in homes is often more irregular, larger, and higher in moisture content than that used for laboratory tests. Pots used in for cooking in homes vary in size, shape, and material, and cooking demands encompass more than tasks based on boiling water. Stoves are also often left unattended while users conduct other tasks, which can result in suboptimal combustion conditions and long smoldering periods.

Figure 8 shows an example of laboratory-to-field performance differences for traditional and rocket-style stoves, which were the only stoves classes with enough data to make reasonably sound comparisons. The figure shows that for both stove types the quality of combustion is lower during normal use compared to laboratory testing, with lower combustion efficiency and higher PM emissions per unit fuel consumed. Relative fuel efficiency appears to be more robust for rocket stoves, with similar savings of approximately 50% and 40% in the laboratory and field[6], respectively. Although the quality of combustion appears to not be improved in the field for rocket stoves based on current inventory data, overall PM and CO emissions reductions are likely to be achieved through fuel savings. Despite the limited data for other stove types, the current data show that the pattern of laboratory-to-field performance differences can vary for other stove types. Plancha style stoves, for example, are not designed primarily to boil water, and the opposite trend has been observed, with better emissions and fuel performance in homes than during controlled testing (Berrueta et al., 2008; Johnson et al., 2008). Performance for stoves that use clean fuels such as LPG or ethanol may be expected to be more robust across laboratory and field conditions, as there are fewer parameters that can impact their performance, although there are still likely to be performance differences. At the other extreme, there may be stoves that can operate extremely cleanly and efficiently under optimal conditions, yet be sensitive to small changes in fuel or operational conditions that cause the stove to be highly polluting and inefficient.

---

[6] Relative fuel savings for the rocket stoves were estimated from laboratory tests based on the amount of fuel required to complete the test (generally WBTs) in comparison to the relevant baseline technology (typically three stone fires), and in-field results are based on the difference in specific consumption (MJ fuel/kg food cooked) from CCTs.

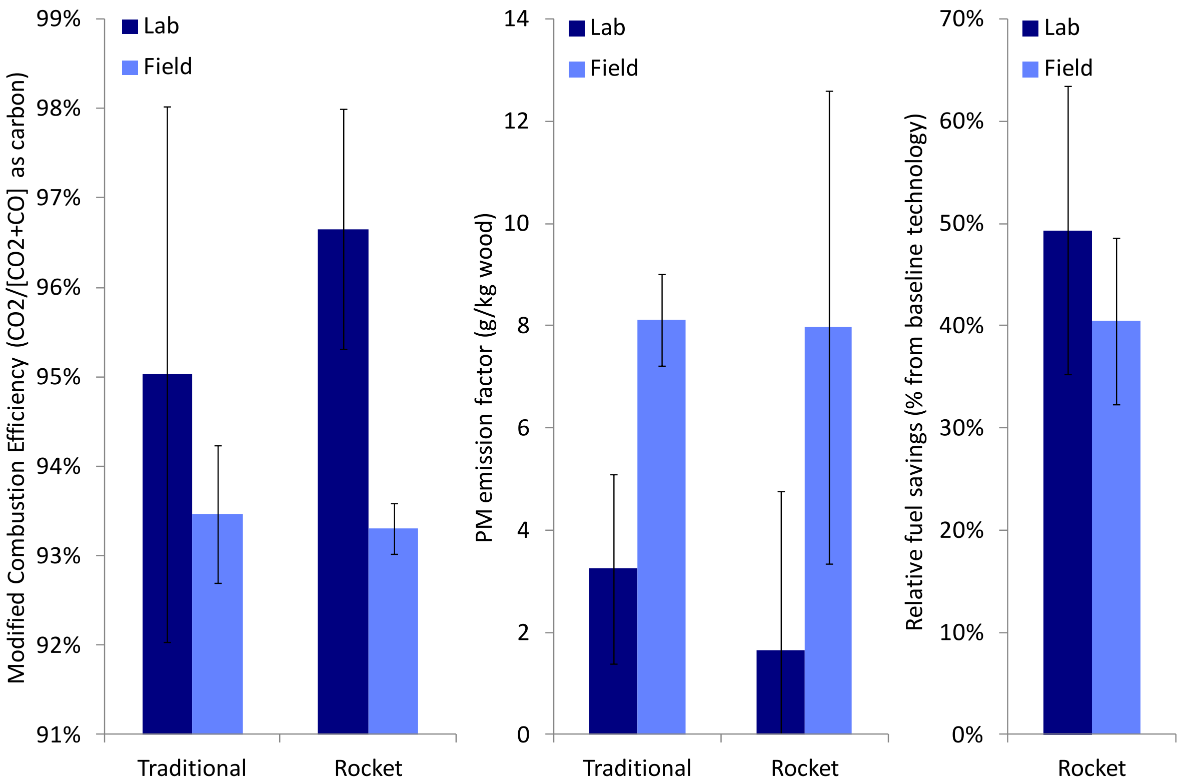

Figure 8. Comparison between laboratory and field performance for traditional and rocket wood-burning cookstoves. Error bars represent ± one standard deviation of the test sets.

Given that reducing emissions and fuel use in homes is the goal, it is important to understand these differences so that stove/fuel technologies are as clean, efficient, and effective as possible for the end users. The handful of studies that have looked at these differences have generally recommended the development of protocols or approaches that better simulate actual user conditions. For example, a recent study by Chen et al. (2012) found that laboratory tests fail to simulate low combustion efficiency events that drive peak particle emissions (Chen et al., 2012). Johnson et al. 2010 also found that the cooking cycles in homes produced patterns of combustion efficiencies and emission rates substantially different from those in laboratory tests.

There have also been several investigations that have sought to characterize impacts on stove performance as a function of various parameters. For example, Coughlin et al. 2008 found that meal size was a key determinant for fuel efficiency of charcoal stoves (Coughlin, 2008). Several studies have looked at the impact of fuel moisture content on fuel consumption and emissions performance (Bhattacharya et al., 2002; Yuntenwi et al., 2008; L'Orange et al., 2011; Jetter et al., 2012), and L'Orange et al. 2011 and Bhattacharya at al. (2002) quantified the impact of several other test parameters on output metrics. The overall message from these studies and those that have systematically characterized factors impacting stove performance is that there is a need for additional and/or refined protocols and/or approaches that can better predict how stoves will perform in homes, which was also a key recommendation in the IWA on Clean and Efficient Cookstoves.

6) Conclusions and Recommendations

Technologies

The inventory shows that liquid and gas fuels along with biomass fan and gasifier stoves have the greatest potential for achieving aspirational health and environmental benefits but are the least tested types of technologies.

- Expand testing of ultra-clean technologies: fan stoves, gasifiers, and liquid fuel stoves across key geographies.

Testing Types and Protocols

The bulk of the inventory data was generated using controlled laboratory testing, which is critical for designing high quality appliances and comparing performance across multiple devices.

- Increase priority of uncontrolled field testing in order to understand and achieve aspirational health and environmental benefits in the real world.
- Promote protocol development efforts that aim to better reflect the span of operational conditions during normal daily stove use.

Almost all of the laboratory testing was done using a water boiling based test, which is not a meaningful assessment tool for stoves that are designed to perform other kinds of cooking tasks, such as making tortillas or chapatis.

- Invest in protocol development for key categories of stoves that are not well served by the water boiling test, including batch-fed stoves, planchas, heating stoves, and others.

Multiple variations of the water boiling test are in use around the world.

- Studies are needed to harmonize these methods and the resulting metrics using the “Rosetta Stone” approach outlined in the IWA on Clean and Efficient Cookstoves.

The specific methods and quality of techniques to measure performance indicators across the various protocols are highly variable and often unclear or not fully presented, nor is there a clear and agreed upon framework for determining what constitutes the quality of the measurement techniques.

- Providing structured guidance on the application and reporting of measurement techniques as part of the protocols (e.g. gravimetric assessment of particulate matter and calibration of equipment) would aid in increasing the quality of data and comparability across reported results.

Protocols for including more performance metrics are needed for more comprehensive stove assessment.

- As resolved in the ISO IWA, test protocols that include assessments of climate relevant emissions and durability are needed, as these are critical for evaluating stoves across a wider range of impacts.

Inventory Next Steps

This initial version of the inventory represents the nucleus of a tool that can serve the sector for the duration of the clean cookstove global scale-up.

- Create an integrated and sustainable system for regularly consolidating and updating data, including regular review of entries.

- Expand the Data and Statistics section of the Alliance's website to include an online version of the inventory that can be queried and filtered.

- Expand the inventory to include additional sources including non-English language papers and reports and studies of indoor air pollution, personal exposure, or health studies.

- Coordinate pro-actively with known efforts underway in order to understand if and how to add them to the inventory. These efforts include, but are certainly not limited to:
  (1) EPA Transect study – measurement of climate-relevant emissions from in-use operation of stoves.
  (2) World Bank Biomass Energy Initiative for Africa (BEIA) – measurement of stove usage, fuel consumption, and indoor air pollution concentrations underway in Uganda, South Africa, and the Gambia.
  (3) Current round of EPA laboratory testing by Jim Jetter.
  (4) Current EPA project for capacity building and data collection of stove performance in the field, which will include data from CCTs, KPTs, and in-home emissions.
  (5) Integrating data from filling out the IWA "Rosetta stone". Efforts are underway in India, China, and South Africa to adapt the stove performance data from their standard. laboratory tests to align with the performance metrics of the ISO IWA Tiers of Performance
  (6) The usage/uptake review funded by DFID (Puzzolo et al., 2011).
  (7) Millennium Challenge Corporation project in Mongolia. This project will provide field performance of heating and cooking stoves.
  (8) Regional stove testing facilities such as CREEC, GERES, and Zamorano University have performance data to contribute.
  (9) Field performance data from Nathan Johnson's work in Mali, which includes recently published articles in *Energy* (Johnson and Bryden, 2012).

- Leverage the Alliance's position as a neutral conduit to compile and/or anonymize data from proprietary sources, including carbon finance PDDs and market studies, so that it can be included in the inventory.

- Update core set of summary statistics annually, including ranges of default values for standard stove/fuel combinations by region for key metrics.

Complementary Focus on Adoption

While this data on the performance of technologies and fuels is critically important to the sector's progress, an equally important parallel relates to understanding user behaviours and stove adoption, which will be critical for achieving the maximum benefits from clean technologies in the real world.

- Build on upcoming systematic review of adoption parameters and commission research to fill identified gaps, including a more nuanced understanding of kitchen management and “stove stacking” across key geographies.
- Provide the sector with common definitions, methods, and metrics for adoption, usage, acceptance, and uptake.
- Set benchmarks and highlight best practice for implementers to ensure successful adoption and appropriate usage.

Abbreviations

BC	black carbon
CCT	controlled cooking test
CH4	methane
CO	carbon monoxide
CO2	carbon dioxide
EC	elemental carbon
g	gram
GACC	Global Alliance For Clean Cookstoves
GHG	greenhouse gas
GWP	global warming potential
HTP	Heterogeneous Test Protocol
IWA	International Workshop Agreement on Cookstove Standards
kg	kilogram
KPT	Kitchen Performance Test
MCE	modified combustion efficiency
MJ	megajoule
MJ-del	megajoule delivered
N	sample size
NCE	nominal combustion efficiency
OC	organic carbon
PM	particulate matter
SA	standard adult
TNMHC	total non-methane hydrocarbons
UCT	uncontrolled cooking test
UFT	uncontrolled field test
WBT	water boiling test

Bibliography

References cited in report

Apple, J., Vicente, R., Yarberry, A., Lohse, N., Mills, E., Jacobson, A., and Poppendieck, D. (2010). Characterization of particulate matter size distributions and indoor concentrations from kerosene and diesel lamps. Indoor Air Indoor Air *20*, 399–411.

Aprovecho Research Center (2011). Test Results of Cookstove Performance (Washington, D.C.: Partnership for Clean Indoor Air).

Berrueta, V., Edwards, R., and Masera, O. (2008). Energy performance of wood-burning cookstoves in Michoacan, Mexico. Renewable Energy 859–870.

Bhattacharya, S.C., Albina, D.O., and Khaing, A.M. (2002). Effects of selected parameters on performance and emission of biomass-fired cookstoves. Biomass & Bioenergy *23*, 387–395.

Chen, Y., Roden, C.A., and Bond, T.C. (2012). Characterizing Biofuel Combustion with Patterns of Real-Time Emission Data (PaRTED). Environmental Science & Technology.

Coughlin, P.E. (2008). Field Testing for Ceramic Stoves Survey Results from Three Boroughs in Maputo and Matola (Mozambique: EconPolicy).

Cowlin, Shannon, Kaufmann, Rachel, Edwards, Rufus, and Smith, Kirk (2005). Impact of Improved Stoves on Indoor Air Quality in Ulaanbaatar Mongolia (Washington, D.C.: Energy Sector Management and Assistance Programme).

Jetter, J., Zhao, Y., Smith, K.R., Khan, B., Yelverton, T., DeCarlo, P., and Hays, M.D. (2012). Pollutant Emissions and Energy Efficiency under Controlled Conditions for Household Biomass Cookstoves and Implications for Metrics Useful in Setting International Test Standards. Environ. Sci. Technol. *46*, 10827–10834.

Jetter, J.J., and Kariher, P. (2009). Solid-fuel household cook stoves: Characterization of performance and emissions. Biomass and Bioenergy *33*, 294–305.

Johnson, M., Bond, T., Weyant, C., Chen, Y., Ellis, J., Modi, V., Joshi, S., Yagnaraman, M., and Pennise, D. (2011). In-Home Assessment of Greenhouse Gas and Aerosol Emissions from Biomass Cookstoves in Developing Countries. (San Francisco), p.

Johnson, M., Edwards, R., Alatorre Frenk, C., and Masera, O. (2008). In-field greenhouse gas emissions from cookstoves in rural Mexican households. Atmospheric Environment *42*, 1206–1222.

Johnson, N.G., and Bryden, K.M. (2012). Energy supply and use in a rural West African village. Energy.

Khudadad, N., Ali, B., and Jan, K. (2012). Measuring the impact of low carbon technologies and products on domestic fuel consumption. Renewable Energy.

L'Orange, C., DeFoort, M., and Willson, B. (2011). Influence of testing parameters on biomass stove performance and development of an improved testing protocol. Energy for Sustainable Development.

Lam, N.L., Smith, K.R., Gauthier, A., and Bates, M.N. (2012). Kerosene: A Review of Household Uses and their Hazards in Low- and Middle-Income Countries. Journal of Toxicology and Environmental Health, Part B *15*, 396–432.

MacCarty, N., Still, D., and Ogle, D. (2010). Fuel use and emissions performance of fifty cooking stoves in the laboratory and related benchmarks of performance. Energy for Sustainable Development *14*, 161–171.

Pemberton-Pigott, C. (2011). Stove Test Report Summary.

Pokhrel, A.K., Bates, M.N., Verma, S.C., Joshi, H.S., Sreeramareddy, C.T., and Smith, K.R. (2010). Tuberculosis and Indoor Biomass and Kerosene Use in Nepal: A Case–Control Study. Environ Health Perspect *118*, 558–564.

Puzzolo, E., Stanistreet, D., Pope, D., Bruce, N., and Rehfuess, E. (2011). Protocol: What are the enabling or limiting factors influencing the large scale uptake by households of cleaner and more efficient household energy technologies, covering cleaner fuel and improved solid fuel cookstoves? (Social Science Research Unit Institute of Education University of London).

Schare, S., and Smith, K.R. (1995). Particulate emission rates of simple kerosene lamps. Energy for Sustainable Development *2*, 32–35.

SeTAR (2012). Heterogeneous Stove Testing Protocols for Emissions and Thermal Performance.

Smith, K.R., Uma, R., Kishore, V.V.N., Lata, K., Joshi, V., Zhang, J., Rasmussen, R.A., and Khalil, M.A.K. (2000). Greenhouse gases from small-scale combustion devices in developing countries (Washington D.C.: United States Environmental Protection Agency).

Yuntenwi, E.A.T., MacCarty, N., Still, D., and Ertel, J. (2008). Laboratory study of the effects of moisture content on heat transfer and combustion efficiency of three biomass cook stoves. Energy for Sustainable Development *12*, 66–77.

Zhang, J., Smith, K.., Ma, Y., Ye, S., Jiang, F., Qi, W., Liu, P., Khalil, M.A.., Rasmussen, R.., and Thorneloe, S.. (2000). Greenhouse gases and other airborne pollutants from household stoves in China: a database for emission factors. Atmospheric Environment *34*, 4537–4549.

Zhang, J., and Smith, K.R. (2007). Household air pollution from coal and biomass fuels in china: measurements, health impacts, and interventions. Environmental Health Perspectives doi:10.1289/ehp.9479.

Inventory bibliography

Academy for Educational Development (2007). Fuel Efficient Stove Programs in IDP Settings - Summary Evaluation Report, Uganda (USAID).

Academy for Educational Development (2008). Fuel Efficient Stove Programs in IDP Settings - Summary Evaluation Report Darfur, Sudan (Washington, D.C.: United States Agency for International Development).

Adkins, E., Tyler, E., Wang, J., Siriri, D., and Modi, V. (2010). Field testing and survey evaluation of household biomass cookstoves in rural sub-Saharan Africa. Energy for Sustainable Development 172–185.

Anozie, A.N., Bakare, A.R., Sonibare, J.A., and Oyebisi, T.O. (2007). Evaluation of cooking energy cost, efficiency, impact on air pollution and policy in Nigeria. Energy *32*, 1283–1290.

Aprovecho Research Center (2007). Laboratory Testing of Rocket Stoves of Various Capacities As Compared to the Three Stone Fire (Creswell, OR: Aprovecho Research Center).

Bailis, R., Berrueta, V., Chengappa, C., Dutta, K., Edwards, R., Masera, O., Still, D., and Smith, K.R. (2007). Performance testing for monitoring improved biomass stove interventions: experiences of the Household Energy and Health Project. Energy for Sustainable Development *11*.

Ballard-Tremeer, G., and Jawurek, H.H. (1996). Comparison of five rural, wood-burning cooking devices: Efficiencies and emissions. Biomass and Bioenergy *11*, 419–430.

Belonio, A. (2005). Rice Husk Gas Stove Handbook.

Berrueta, V., Edwards, R., and Masera, O. (2008). Energy performance of wood-burning cookstoves in Michoacan, Mexico. Renewable Energy 859–870.

Bertschi, I.T., Yokelson, R.J., Ward, D.E., Christian, T.J., and Hao, W.M. (2003). Trace gas emissions from the production and use of domestic biofuels in Zambia measured by open-path Fourier transform infrared spectroscopy. J Geophys Res-Atmos *108*.

Bhattacharya, S.C., Albina, D.O., and Khaing, A.M. (2002a). Effects of selected parameters on performance and emission of biomass-fired cookstoves. Biomass & Bioenergy *23*, 387–395.

Bhattacharya, S.C., Albina, D.O., and Salam, P.A. (2002b). Emission factors of wood and charcoal-fired cookstoves. Biomass Bioenerg *23*, 453–469.

Boy, E., Bruce, N., Smith, K.R., and Hernandez, R. (2000). Fuel efficiency of an improved wood-burning stove in rural Guatemala: implications for health, environment and development. Energy for Sustainable Development *4*.

Chen, Y.J., Sheng, G.Y., Bi, X.H., Feng, Y.L., Mai, B.X., and Fu, J.M. (2005). Emission factors for carbonaceous particles and polycyclic aromatic hydrocarbons from residential coal combustion in China. Environ Sci Technol *39*, 1861–1867.

Chen, Y.J., Zhi, G.R., Feng, Y.L., Fu, J.M., Feng, J.L., Sheng, G.Y., and Simoneit, B.R.T. (2006). Measurements of emission factors for primary carbonaceous particles from residential raw-coal combustion in China. Geophysical Research Letters *33*.

Collivignarelli, C., Mazzu, A., Vaccari, M., and Vitali, F. (2010). Comparison of biomass stoves appropriate technologies for household energy in developing countries. Third International Symposium on Energy from Biomass and Waste.

Coughlin, Peter (2008). Field Testing for Ceramic Stoves: Survey Results for Three Boroughs in Maputo and Matola (Maputo, Mozambique: Programme for Basic Energy and Conservation in Southern Africa).

Habib, G., Venkataraman, C., Bond, T.C., and Schauer, J.J. (2008). Chemical, Microphysical and Optical Properties of Primary Particles from the Combustion of Biomass Fuels. Environmental Science & Technology *42*, 8829–8834.

Jetter, J., Zhao, Y., Smith, K.R., Khan, B., Yelverton, T., DeCarlo, P., and Hays, M.D. (2012). Pollutant Emissions and Energy Efficiency under Controlled Conditions for Household Biomass Cookstoves and Implications for Metrics Useful in Setting International Test Standards. Environ. Sci. Technol. *46*, 10827–10834.

Jetter, J.J., and Kariher, P. (2009). Solid-fuel household cook stoves: Characterization of performance and emissions. Biomass and Bioenergy *33*, 294–305.

Johnson, M., Edwards, R., Alatorre Frenk, C., and Masera, O. (2008). In-field greenhouse gas emissions from cookstoves in rural Mexican households. Atmospheric Environment *42*, 1206–1222.

Johnson, M., Lam, N., Brant, S., Gray, C., and Pennise, D. (2011a). Modeling indoor air pollution from cookstove emissions in developing countries using a Monte Carlo single-box model. Atmospheric Environment *45*, 3237–3243.

Johnson, M., Lam, N., Pennise, D., Charron, D., Bond, T., Modi, V., and Ndemere, J.A. (2011b). In-home emissions of greenhouse gas pollutants from traditional and rocket biomass stoves in Uganda (Washington D.C.: United States Agency for International Development).

Johnson, M., Bond, T., Weyant, C., Chen, Y., Ellis, J., Modi, V., Joshi, S., Yagnaraman, M., and Pennise, D. (2011). In-Home Assessment of Greenhouse Gas and Aerosol Emissions from Biomass Cookstoves in Developing Countries. In Greenhouse Gas Strategies in a Changing Climate Air and Waste Management Association, (San Francisco, USA).

Johnson, M., Lam, N., Wofchuck, T., Edwards, R., and Pennise, D. (2009). In-field charcoal stove emission factors and indoor air pollution in Nairobi, Kenya. In Engineers in Technical and Humanitarian Opportunities of Service Conference, (Kirkland, WA),.

Johnson, M., Pilco, V., Torres, R., Joshi, S., Shrestha, R., Yagnaraman, M., Lam, N., Doroski, B., Mitchell, J., Canuz, E., et al. (2011c). Impacts of Household Fuel Consumption for Biomass Stove Programs in India, Nepal and Peru.

Kim Oanh, N.T., Albina, D.O., Ping, L., and Wang, X. (2005). Emission of particulate matter and polycyclic aromatic hydrocarbons from select cookstove–fuel systems in Asia. Biomass & Bioenergy 579–590.

Kituyi, E., Marufu, L., Wandiga, S.O., Jumba, I.O., Andreae, M.O., and Helas, G. (2001). Carbon monoxide and nitric oxide from biofuel fires in Kenya. Energ Convers Manage *42*, 1517–1542.

Li, X., Duan, L., Wang, S., Duan, J., Guo, X., Yi, H., Hu, J., Li, C., and Hao, J. (2007). Emission Characteristics of Particulate Matter from Rural Household Biofuel Combustion in China. Energy & Fuels *21*, 845–851.

Li, X., Wang, S., Duan, L., Hao, J., and Nie, Y. (2009). Carbonaceous Aerosol Emissions from Household Biofuel Combustion in China. Environ. Sci. Technol. *43*, 6076–6081.

MacCarty, N., Ogle, D., Still, D., Bond, T.C., and Roden, C.A. (2008). A laboratory comparison of the global warming impact of five major types of biomass cooking stoves. Energy for Sustainable Development *12*,.

MacCarty, N., Still, D., and Ogle, D. (2010). Fuel use and emissions performance of fifty cooking stoves in the laboratory and related benchmarks of performance. Energy for Sustainable Development *14*, 161–171.

MacCarty, Nordica (2008). Testing Results of the Ecocina Cooking Stove from El Salvador.

Makonese, T., Robinson, J., Pemberton-Pigott, C., and Annegarn, H. (2011). A Preliminary Comparison Between The Heterogeneous Protocols And The Water Boiling Test.

Oanh, N.T.K., Reutergardh, L.B., and Dung, N.T. (1999). Emission of Polycyclic Aromatic Hydrocarbons and Particulate Matter from Domestic Combustion of Selected Fuels. Environmental Science & Technology *33*,.

Oommen, R., and Jayaraman, S. (2001). Development and performance analysis of compound parabolic solar concentrators with reduced gap losses – oversized reflector. Energy Conversion and Management *42*, 1379–1399.

Panwar, N.L., and Rathore, N.S. (2008). Design and performance evaluation of a 5 kW producer gas stove. Biomass and Bioenergy *32*, 1349–1352.

Pemberton-Pigott, C. (2011). Mongolia Stove Test Report Summary.

Pemberton-Pigott, C. Development of a low smoke Mongolian coal stove using a heterogeneous testing protocol.

Pennise, D., Charron, D., Wofchuck, T., Rouse, J., and Hunt, A. (2010). Evaluation of Manufactured Wood Stoves in Dadaab Refugee Camps, Kenya (United States Agency for International Development).

Robinson, J., Ibraimo, M., and Pemberton-Pigott, C. The uncontrolled cooking test: Measuring three-stone fire performance in Northern Mozambique.

Roden, C.A., Bond, T.C., Conway, S., Benjamin, A., and Pinel, O. (2006). Emission factors and real-time optical properties of particles emitted from traditional wood burning cookstoves. Environ Sci Technol *40*, 6750–6757.

Roden, C.A., Bond, T.C., Conway, S., Pinel, A., MacCarty, N., and Still, D. (2009). Laboratory and field investigations of particulate and carbon monoxide emissions from traditional and improved cookstoves. Atmospheric Environment *43*, 1170–1181.

Smith, K.R., Uma, R., Kishore, V.V.N., Lata, K., Joshi, V., Zhang, J., Rasmussen, R.A., and Khalil, M.A.K. (2000). Greenhouse gases from small-scale combustion devices in developing countries (Washington D.C.: United States Environmental Protection Agency).

Still, Dean (2006). Initial Development of a Charcoal Burning Rocket Stove (Creswell, OR: Aprovecho Research Center).

Stokes, Harry, Lambe, Fiona, Bates, Liz, Luceno, Brady, Couto, Regina, Obueh, Joe, Murren, James, Munangagwa, Chidochashe, Graham, Megan, Lakew, Hilawe, et al. (2010). Ethanol as a Household Fuel in Madagascar: Health Benefits, Economic Assessment and Review of African Lessons for Scaling up - Component B (Warwickshire, UK: World Bank, Practical Action Consulting).

Tian, L., Lucas, D., Fischer, S.L., Lee, S.C., Hammond, S.K., and Koshland, C.P. (2008). Particulate and Gas Emission from a Simulated Coal-Burning Household Fire Pit. Environ. Sci. Technol. *42*, 2503–2508.

Venkataraman, C., and Rao, G.U.M. (2001). Emission factors of carbon monoxide and size-resolved aerosols from biofuel combustion. Environ Sci Technol Environ Sci Technol *35*, 2100–2107.

Wagutu, A.W., Thoruwa, T.F.N., Chhabra, S.C., Lang'at-Thoruwa, C.C., and Mahunnah, R.L.A. (2010). Performance of a domestic cooking wick stove using fatty acid methyl esters (FAME) from oil plants in Kenya. Biomass and Bioenergy *34*, 1250–1256.

Wallmo, K., and Jacobson, S.K. (1998). A social and environmental evaluation of fuel-efficient cook-stoves and conservation in Uganda. Environmental Conservation *25*, 99–108.

Wang, S., Wei, W., Du, L., Li, G., and Hao, J. (2009). Characteristics of gaseous pollutants from biofuel-stoves in rural China. Atmospheric Environment *43*, 4148–4154.

Wanjohi, P. (2006). Improved Stoves Baseline Survey Study (GIZ and Promotion of private sector development in agriculture and GIZ).

Winrock International (2009). Commercialization of Improved Cookstoves for Reduced Indoor Air Pollution in Urban Slums of Northwest Bangladesh (Washington, D.C.: United States Agency for International Development).

Witt, Mark, Weyer, Kristina, and Manning, David (2006). Designing a Clean-Burning, High-Efficiency, Dung-Burning Stove: Lessons in cooking with cow patties (Creswell, OR: Aprovecho Research Center).

Zhang, J., Smith, K.., Ma, Y., Ye, S., Jiang, F., Qi, W., Liu, P., Khalil, M.A.., Rasmussen, R.., and Thorneloe, S.. (2000). Greenhouse gases and other airborne pollutants from household stoves in China: a database for emission factors. Atmospheric Environment *34*, 4537–4549.

Additional sources considered for inventory inclusion

Akter Lucky, R., and Hossain, I. (2001). Efficiency study of Bangladeshi cookstoves with an emphasis on gas cookstoves. Energy *26*, 221–237.

Alakali, J.S., Kachataiya, G.T., and Kucha, C.T. (2011). Evaluation of powered charcoal stove by using different biomass fuels. Int J Agric & Biol Eng *4*.

Amrose, S. (2008). Development and Testing of the Berkeley Darfur Stove (Lawrence Berkeley National Laboratory).

Aprovecho Research Center (2011). Test Results of Cookstove Performance (Washington, D.C.: Partnership for Clean Indoor Air).

Ballard-Tremeer, G. (1997). Emissions of Rural Wood-Burning Cooking Devices. University of the Witwartersrand, Department of Engineering.

Ballard-Tremeer, G., and Jawurek, H.H. (1999a). Evaluation of the dilution chamber method for measuring emissions of cooking devices. Biomass and Bioenergy *17*, 481–494.

Ballard-Tremeer, G., and Jawurek, H.H. (1999b). The “hood method” of measuring emissions of rural cooking devices. Biomass and Bioenergy *16*, 341–345.

Bhatt, B., and Sachan, M. (2004a). Firewood consumption along an altitudinal gradient in mountain villages of India. Biomass and Bioenergy *27*, 69–75.

Bhatt, B.P., and Sachan, M.S. (2004b). Firewood consumption pattern of different tribal communities in Northeast India. Energy Policy *32*, 1–6.

Bond, T.C., Covert, D.S., Kramlich, J.C., Larson, T.V., and Charlson, R.J. (2002). Primary particle emissions from residential coal burning: Optical properties and size distributions. Journal of Geophysical Research *107*,.

Brocard, D., and Lacaux, J.-P. (1998). Domestic biomass combustion and associated atmospheric emissions in West Africa. Global Biogeochem. Cycles *12*, 127–139.

Brouwer, R., and Falcão, M.P.M.P. (2004). Wood fuel consumption in Maputo, Mozambique. Biomass and Bioenergy *27*, 233–245.

Carter, S., and Shackley, S. (2011). Biochar Stoves: an innovation studies perspective.

Chen, Y.J., Bi, X.H., Mai, B.X., Sheng, G.Y., and Fu, J.M. (2004). Emission characterization of particulate/gaseous phases and size association for polycyclic aromatic hydrocarbons from residential coal combustion. Fuel *83*, 781–790.

Couto, Regina (2007). Tapping the Potential of Proalcool for the Household Energy Sector (Gettysburg Pennsylvania: Shell Foundation, Project Gaia).

Cowlin, Shannon, Kaufmann, Rachel, Edwards, Rufus, and Smith, Kirk (2005). Impact of Improved Stoves on Indoor Air Quality in Ulaanbaatar Mongolia (Washington, D.C.: Energy Sector Management and Assistance Programme).

El Tayeb Muneer, S., and Mukhtar Mohamed, E.W. (2003). Adoption of biomass improved cookstoves in a patriarchal society: an example from Sudan. The Science of The Total Environment *307*, 259–266.

Forkong Njiti, C., Mbpengong Kemcha, G., and others (2003). Survey of fuel wood and service wood production and consumption in the Sudano-Sahelian region of Central Africa: the case of Garoua, Cameroon and its rural environs.

G/Egziabher, Amare, Murren, James, and O’Brien, Cheryl (2006). An Ethanol-fueled Household Energy Initiative in the Shimbela Refugee Camp, Tigray, Ethiopia: A Joint Study by the UNHCR and the Gaia Association (Gettysburg Pennsylvania: Shell Foundation, UNHCR, Project Gaia).

GERES (2008). Monitoring Activities for Second Verification of GERES Cambodia’s New Lao Stove Project.

GERES (2009). Dissemination of domestic efficient cookstoves in Cambodia (Cambodia: Groupe Energies Renouvelables, Environnement et Solidarités).

Granderson, J., Sandhu, J.S., Vasquez, D., Ramirez, E., and Smith, K.R. (2009). Fuel use and design analysis of improved woodburning cookstoves in the Guatemalan Highlands. Biomass & Bioenergy *33*, 306–315.

Grupp, M., Balmer, M., Beall, B., Bergler, H., Cieslok, J., Hancock, D., and Schröder, G. (2009). On-line recording of solar cooker use rate by a novel metering device: Prototype description and experimental verification of output data. Solar Energy *83*, 276–279.

GTZ-SUN (2009). Water Test Results of Various Types of Household Wood Stoves for Non-Injera Cooking.

GTZ-SUN (2011). Memo: Result of Stove Testing.

Gulilat, A. (2011). Stove Testing Results: A Report on Controlled Cooking Test Results Performed on "Mirt with integrated chimney" and "Institutional Mirt" Stoves.

Guoliang, C., Xiaoye, Z., Sunling, G., and Fangcheng, Z. (2008). Investigation on emission factors of particulate matter and gaseous pollutants from crop residue burning. Journal of Environmental Sciences *20*, 50–55.

Gupta, S., Saksena, S., Shankar, V.R., and Joshi, V. (1998). Emission factors and thermal efficiencies of cooking biofuels from five countries. Biomass and Bioenergy *14*, 547–559.

James Robinson, Crispin Pemberton-Pigott, Tafadzwa Makonese, and Harold Annegarn (2010). Heterogeneous Stove Testing Protocols for Emission and Thermal Performance. (Cape Town, South Africa).

Johnson, N.G., and Bryden, K.M. (2012). Energy supply and use in a rural West African village. Energy.

Kaushik, S.C., and Gupta, M.K. (2008). Energy and exergy efficiency comparison of community-size and domestic-size paraboloidal solar cooker performance. Energy for Sustainable Development *12*, 60–64.

Khudadad, N., Ali, B., and Jan, K. (2012). Measuring the impact of low carbon technologies and products on domestic fuel consumption. Renewable Energy.

Kimambo, C. (2007). Development and performance testing of solar cookers.

Kimemia, D.K., Annegarn, H., Robinson, J., Pemberton-Pigott, C., and Molapo, V. (2011). Optimizing the Imbaula stove.

Kituyi, E., Marufu, L., O. Wandiga, S., O. Jumba, I., O. Andreae, M., and Helas, G. (2001). Biofuel availability and domestic use patterns in Kenya. Biomass and Bioenergy *20*, 71–82.

Kumar, R., Adhikari, R.., Garg, H.., and Kumar, A. (2001). Thermal performance of a solar pressure cooker based on evacuated tube solar collector. Applied Thermal Engineering *21*, 1699–1706.

L'Orange, C., DeFoort, M., and Willson, B. (2011). Influence of testing parameters on biomass stove performance and development of an improved testing protocol. Energy for Sustainable Development.

Lewis, J.J., and Pattanayak, S.K. (2012). Who Adopts Improved Fuels and Cookstoves? A Systematic Review. Environ Health Perspect.

Lodoyasamba, S., and Pemberton-Pigott, C. (2011). Mitigation of Ulaanbaatar city's air pollution -- From source apportionment to ultra-low emission lignite burning stoves.

Ludwig, J., Marufu, L.T., Huber, B., Andreae, M.O., and Helas, G. (2003). Domestic combustion of biomass fuels in developing countries: A major source of atmospheric pollutants. J Atmos Chem *44*, 23–37.

Mabaso, M.C. (2009). The socio-economic efficacy of improved wood stoves upon two non-electrified, low income peri-urban areas of Pietermaritzburg, South Africa.

MacCarty, N., Still, D., Ogle, D., and Drouin, T. (2008). Assessing Cook Stove Performance: Field and Lab Studies of Three Rocket Stoves Comparing the Open Fire and Traditional Stoves in Tamil Nadu, India on Measures of Time to Cook, Fuel Use, Total Emissions, and Indoor Air Pollution. Aprovecho Research Center.

MacCarty, Nordica (2009). Results of Testing the CleanCook Stove for Fuel Use and Carbon Emissions (Cottage Grove, OR: Aprovecho Research Center).

MacCarty, Nordica, and Still, Dean (2006). Comparing the Charcoal Burning Rocket and Jiko Stoves (Creswell, OR: Aprovecho Research Center).

Marufu, L., Ludwig, J., Andreae, M.O., Meixner, F.X., and Helas, G. (1997). Domestic biomass burning in rural and urban Zimbabwe -- Part A. Biomass & Bioenergy *12*, 53–68.

Matsumura, K. (2011). Improved Stove Evaluation.

McCracken, J.P., and Smith, K.R. (1998). Emissions and efficiency of improved woodburning cookstoves in highland Guatemala. Environment International *24*, 739–747.

Mcdonald, J.D., Zielinska, B., Fujita, E.M., Sagebiel, J.C., Chow, J.C., and Watson, J.G. (2000). Fine Particle and Gaseous Emission Rates from Residential Wood Combustion. Environmental Science & Technology *34*,.

Mehmet, E. (2004). Thermal performance of a solar cooker integrated vacuum-tube collector with heat pipes containing different refrigerants. Solar Energy *76*, 751–757.

Miah, M.D., Al Rashid, H., and Shin, M.Y. (2009a). Wood fuel use in the traditional cooking stoves in the rural floodplain areas of Bangladesh: A socio-environmental perspective. Biomass and Bioenergy *33*, 70–78.

Miah, M.D., Al Rashid, H., and Shin, M.Y. (2009b). Wood fuel use in the traditional cooking stoves in the rural floodplain areas of Bangladesh: A socio-environmental perspective. Biomass and Bioenergy *33*, 70–78.

Miah, M.D., Foysal, M.A., Koike, M., and Kobayashi, H. (2011). Domestic energy-use pattern by the households: A comparison between rural and semi-urban areas of Noakhali in Bangladesh. Energy Policy *39*, 3757–3765.

Mukunda, H.S., Dasappa, S., Paul, P.J., Rajan, N.K.S., Yagnaraman, M., Kumar, D.R., and Deogaonkar, M. (2010). Gasifier stoves - science, technology and field outreach. Curr Sci India *98*, 627–638.

Murren, James, and Debebe, Milkyas (2006). Project Gaia’s Ethanol-fueled CleanCook Stove Initiative and its Impact on Traditional Cooking Fuels Used in Addis Ababa, Ethiopia (Addis Ababa, Ethiopia: Shell Foundation, Project Gaia).

Murthy, M.S., Agiwal, S.A., Bharambe, M.A., Mishra, A., and Raina, A. (2011). Modified Kerosene Stove for Burning High Percentage Non Edible Straight Vegetable Oil Blends. IEEE First Conference on Clean Energy and Technology.

Muthukumar, P., and Shyamkumar, P.I. (2011). Development of novel porous radiant burners for LPG cooking applications. Fuel.

Natarajan, R., Karthikeyan, N.S., Agarwaal, A., and Sathiyanarayanan, K. (2008). Use of vegetable oil as fuel to improve the efficiency of cooking stove. Renewable Energy *33*, 2423–2427.

Nexant, Inc. (2010). Assessment of Haiti Alternative Cooking Technologies Program (Washington, D.C.: United States Agency for International Development).

Pantangi, V.K., Mishra, S.C., Muthukumar, P., and Reddy, R. (2011). Studies on porous radiant burners for LPG (liquefied petroleum gas) cooking applications. Energy *36*, 6074–6080.

Panwar, N.L. (2009). Design and performance evaluation of energy efficiency biomass gasifier based cookstove on multi fuels. Mitig Adapt Strateg Glob Change *14*, 627.

Panwar, N.L. (2010). Performance Evaluation of Developed Domestic Cook Stove with Jatropha Shell. Waste Biomass Valor *1*, 309–314.

Pine, K., Edwards, R., Masera, O., Schilmann, A., Marrón-Mares, A., and Riojas-Rodríguez, H. (2011). Adoption and use of improved biomass stoves in Rural Mexico. Energy for Sustainable Development *15*, 176–183.

Rajvanshi, A.K., Patil, S.M., and Mendonca, B. (2007). Low-concentration ethanol stove for rural areas in India. Energy for Sustainable Development *11*, 94–99.

Ramachandra, T.V., Subramanian, D.K., Joshi, N.V., Gunaga, S.V., and Harikantra, R.B. (2000). Domestic energy consumption patterns in Uttara Kannada District, Karnataka State, India. Energy Conversion and Management *41*, 775–831.

Ruiz-Mercado, I., Masera, O., Zamora, H., and Smith, K.R. (2011). Adoption and sustained use of improved cookstoves. Energy Policy *In Press, Corrected Proof*,.

Simbini, Tichakunda, and Oageng, Masego (2008). Assessment of Energy Efficient Cooking Devices in Botswana (Tlokweng, Botswana: Programme for Basic Energy and Conservation in Southern Africa).

Singh, G., Rawat, G.S., and Verma, D. (2010). Comparative study of fuelwood consumption by villagers and seasonal “Dhaba owners” in the tourist affected regions of Garhwal Himalaya, India. Energy Policy *38*, 1895–1899.

Still, Dean (2003). ETHOS June 2003 Stove Testing & Design Seminar Summary (Cottage Grove, OR: Aprovecho Research Center).

Still, Dean, Bentson, Sam, Thompson, Ryan, and Leslie, Megan (2010). Charcoal Stoves for Haiti (Creswell, OR: Aprovecho Research Center).

Tenna, Billa (2006). The Clean Cook Stove Project: The Case of Ten Sub Cities of Addis Ababa City Administration Improvement in Cooking Times and Emission (Addis Ababa, Ethiopia: Gaia Association).

Torres-Rojas, D., Lehmann, J., Hobbs, P., Joseph, S., and Neufeldt, H. (2011). Biomass availability, energy consumption and biochar production in rural households of Western Kenya. Biomass and Bioenergy *35*, 3537–3546.

Troncoso, K., Castillo, A., Masera, O., and Merino, L. (2007). Social perceptions about a technological innovation for fuelwood cooking: Case study in rural Mexico. Energy Policy *35*, 2799–2810.

Troncoso, K., Castillo, A., Merino, L., Lazos, E., and Masera, O. (2011). Understanding an improved cookstove program in rural Mexico: An analysis from the implementers' perspective. Energy Policy 7600–7608.

Tsai, S.M., Zhang, J. (Jim), Smith, K.R., Ma, Y., Rasmussen, R.A., and Khalil, M.A.K. (2003). Characterization of Non-methane Hydrocarbons Emitted from Various Cookstoves Used in China. Environ. Sci. Technol. *37*, 2869–2877.

Umogbai, V.I., and Orkuma, J.G. (2011). Development and Evaluation of a Biomass Stove. Journal of Emerging Trends in Engineering and Applied Sciences *2*, 514–520.

Urban, G.L., Bryden, K.M., and Ashlock, D.A. (2002). Engineering optimization of an improved plancha stove. Energy for Sustainable Development *6*, 9–19.

Venkataraman, C., Habib, G., Eiguren-Fernandez, A., Miguel, A.H., and Friedlander, S.K. (2005). Residential biofuels in south Asia: Carbonaceous aerosol emissions and climate impacts. Science Science *307*, 1454–1456.

Venkataraman, C., Negi, G., Brata Sardar, S., and Rastogi, R. (2002). Size distributions of polycyclic aromatic hydrocarbons in aerosol emissions from biofuel combustion. Journal of Aerosol Science *33*, 503–518.

Visser, P. (2005). The testing of cookstoves: data of water-boiling tests as a basis to calculate fuel consumption. Energy for Sustainable Development *9*,.

Wilkinson, P., Smith, K., Davies, M., Adair, H., Armstrong, B., Barrett, M., Bruce, N., Haines, A., Hamilton, I., Oreszczyn, T., et al. (2009). Public health benefits of strategies to reduce greenhouse-gas emissions: household energy. Lancet *374*,.

Winrock International (2008). Peru Health Kitchen/Healthy Stove Pilot Project (Washington, D.C.: United States Agency for International Development).

Yu Kuwabara Thermal efficiency and fuel use of cookstoves Plancha versus open fire in San Lorenzo.

Yuntenwi, E.A.T., MacCarty, N., Still, D., and Ertel, J. (2008). Laboratory study of the effects of moisture content on heat transfer and combustion efficiency of three biomass cook stoves. Energy for Sustainable Development *12*, 66–77.