Cookstove Laboratory Research
Fiscal Year 2016 Report

Guatemala – Photo credit Nigel Bruce

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Introduction

This document describes the U.S. Environmental Protection Agency's (EPA's) research to evaluate the performance and emissions of various cookstoves and fuels in an in-house laboratory located in Research Triangle Park, North Carolina, and associated activities, including standards development and capacity building for testing centers located in the developing world. This cookstove laboratory research program was first developed to assist the EPA-led Partnership for Clean Indoor Air [1] and is now part of the U.S. Government's commitment to the Global Alliance for Clean Cookstoves (the Alliance) [2]. Goals of the program are to:

1. Support the development of testing protocols and standards for cookstoves through ISO (International Organization for Standardization) TC (Technical Committee) 285: Clean Cookstoves and Clean Cooking Solutions [3].
2. Support the development of international Regional Testing and Knowledge Centers (many sponsored by the Alliance) for scientifically evaluating and certifying cookstoves to international standards [4].
3. Provide an independent source of data on cookstove performance to Alliance partners.

This work supports EPA's mission to protect human health and the environment. Household air pollution, mainly from solid-fuel cookstoves in the developing world, is estimated to cause approximately four million premature deaths per year [5], and emissions of black carbon and other pollutants from cookstoves affect regional and global climate [6]. An Alliance-coordinated multi-national multi-disciplinary approach, including the development of standards and testing, is designed to improve global health and the environment through clean cooking solutions [7].

The focus of this report is on the activities associated with the in-house EPA cookstove laboratory by a research team composed of federal employees, post-doctoral fellows, and on-site contractor personnel. Other ongoing EPA cookstove research and activities, including: (1) EPA Science to Achieve Results (STAR) grants to quantify air quality and climatic impacts of residential biomass or coal combustion for cooking, heating, and lighting, (2) health effects evaluations, (3) life cycle assessment of fuel options, and (4) fieldwork capacity building, are not included. For information on STAR grants, see Reference [8]; for information on other related research and activities, see References [9], [10], and [11].

ISO Standards Development

Background

EPA has provided leadership, research, and data to support the development of cookstove testing protocols and standards through ISO. EPA published data [12] were instrumental in developing the ISO IWA (International Workshop Agreement) 11-2012, Guidelines for Evaluating Cookstove Performance [13] [14]. These guidelines were unanimously affirmed by more than 90 stakeholders at the ISO International Workshop on Cookstoves on February 28-29, 2012, in The Hague, Netherlands. IWA 11:2012 provides guidelines for rating the performance of cookstoves into tiers based on four important indicators: (1) Efficiency/fuel use, (2) Total Emissions, (3) Indoor Emissions, and (4) Safety. These guidelines are being used while further development of testing protocols and standards is underway through ISO Technical Committee (TC) 285 [3]. With 25 participating countries and 15 observing countries, ISO TC 285 has four Working Groups: (1) Conceptual Framework, (2) Laboratory Testing, (3) Field Testing, and (4) Social Impact Assessment; and two Task Groups: (1) Fuels and (2) Communications.

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EPA provided leadership and experimental results that were used by the international community to make significant progress towards the development of an ISO standard for laboratory testing of cookstoves. John Mitchell, EPA Office of Air and Radiation, served as Head of the U.S. Technical Advisory Group Delegation to ISO TC-285. Jim Jetter, the EPA lead for the laboratory cookstove testing, served as Project Leader for Working Group 2, Laboratory Testing. Jim, with support from the Convenor from the Uganda National Bureau of Standards, and with input from 60 international experts, led the development of a draft standard that was accepted as a Committee Draft at the Second Plenary Meeting of ISO TC-285 in Accra, Ghana, November 2-6, 2015. Following the Plenary Meeting, participating countries reviewed the Committee Draft and voted to advance the document to the next stage of the ISO process – Draft International Standard. Only Working Group 2 achieved this stage in the process, and the EPA Project Leader subsequently provided mentorship to other working groups. Ongoing EPA research is providing data and evaluation of testing protocols and methods to support further development of standards.

1 *Participants, ISO TC 285 Plenary Meeting, Accra, Ghana, November 2-6, 2015*

Approximately 100 people participated in the 2016 ISO Plenary Meeting in Ghana including Delegates, Working Group Experts, and Observers. Participants reviewed working drafts, discussed review comments, resolved some contentious issues, worked to build consensus among WG 2 experts, and developed recommendations for TC 285 Resolutions.

Capacity Building for International Testing and Knowledge Centers

Background

With sponsorship from the Alliance, EPA hosted the first International Workshop on Stove Testing for Regional Testing and Knowledge Centers in Research Triangle Park (RTP) in January, 2013, and the EPA research team participated in a second workshop in Honduras in December, 2013. These workshops were designed to build capacity through knowledge transfer including laboratory best practices, equipment operation, data processing and analysis, and quality assurance. The goals of the capacity building are to establish a global network of Regional Testing Centers with capability for testing stoves according to international standards being developed through ISO TC-285 and to develop capability of the centers to work with stove developers to improve cooking technologies.

2 *Training Workshops for Cookstove Testing at U.S. EPA in RTP and in Honduras*

FY 2016

The EPA research team provided technical assistance and leadership to support:

- Ongoing round-robin testing among 22 participating Centers, with sponsorship from the Alliance.
- The International Development Design Summit (IDDS) for Cookstoves Innovation in East Africa on August 18-19 as an invited expert, and the Intensive Training on Cookstove Testing at the Centre for Renewable Energy and Energy Efficiency (CREEC) at Makerere University in Kampala, Uganda on August 22-26, 2016. See photos and details below.
- A planned Cookstove Laboratory Testing Workshop in La Paz, Bolivia, on October 3-7, 2016.
- Capacity building through knowledge transfer communications with Regional Testing Centers.

***3** International Development Design Summit for Cookstove Innovation in East Africa (left) and Intensive Training on Cookstove Testing at the Centre for Renewable Energy and Energy Efficiency (CREEC) at Makerere University (right) in Kampala, Uganda, August, 2016*

CREEC is a leading RTKC (Regional Testing and Knowledge Center) co-sponsored by the Global Alliance for Clean Cookstoves. The Intensive Training covered a full range of cookstove testing issues including fuel efficiency, cookstove emissions evaluation, calibration of equipment, data analysis, quality assurance, and reporting. The training provided further capacity building of a global network of RTKCs that will be capable of scientifically evaluating and certifying cookstoves to international standards for air pollutant emissions and fuel efficiency.

Laboratory Assessments of Cookstove Systems

Background

EPA has established the world's leading independent laboratory for to provide high-quality test data on cookstove air pollutant emissions and fuel efficiency. The EPA facility is used to accurately measure both chimney and fugitive emissions of air pollutants using the total-capture dilution-tunnel method. An array of instruments is used for measuring gaseous pollutants and aerosol properties. Based on the quality of the data generated, the EPA laboratory results are trusted and valued by partners including the U.S. Department of State, Centers for Disease Control and Prevention (CDC), Department of Energy (DOE), United States Agency for International Development (USAID), Peace Corps, World Health Organization (WHO), ISO, Global Alliance for Clean Cookstoves, and other Alliance partners. Published EPA data are included in the Alliance's online Clean Cooking Catalog [15].

4 EPA Cookstove Research Facility, Research Triangle Park, NC

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EPA published independent test results on cookstove air pollutant emissions and fuel efficiency in reports available to the public. Each EPA report provides testing results for a cookstove system consisting of the stove, cooking pot, fuel, and operating procedure. A detailed description of the system is provided in the body of each report. During testing, the stoves are operated as intended by the manufacturer. Actual performance of cookstoves used in the field may vary if the system is different (e.g., a different fuel is used) or is not operated as intended.

Cookstove systems are tested using the Water Boiling Test (WBT) Version 4.2.3 [16] and following the ISO IWA (International Workshop Agreement) 11-2012, Guidelines for Evaluating Cookstove Performance [13] [14], described above in the ISO Standards Development section. For measuring air pollutant emissions, the “total capture” method (also known as the “hood” method) is used, as described on Pages 60-61 of the WBT protocol [16] and similar to EPA Method 5G [17]. The protocol specifies that the stove be tested at high power (cold- and hot-start phases) and low power (simmer phase). The cold-start phase begins with the stove at ambient temperature, and the hot-start phase begins with the stove at operating temperature. During both phases, the stove is operated at high power to heat water in the pot from ambient to boiling temperature. During the simmer phase, the stove is operated at low power to maintain the target water temperature at 3 °C below the boiling point. Fuel burning rates determine the power levels. During testing, variation in fuel burning rates between test replications is minimized. Actual performance of cookstoves used in the field may vary if the stove is operated at different fuel burning rates and hence at different power levels.

Each report provides performance ratings obtained in accordance with IWA 11:2012 guidelines, and tier ratings range from 0 (baseline) to 4 (best). Tier 0 represents the performance of typical traditional open three-stone fires used for cooking, and Tier 4 represents aspirational goals for solid-fuel cookstoves. Efficiency/fuel use, total emissions, and indoor emissions are tested at high- and low-power operating conditions, and sub-tier values and ratings are reported for the two power levels, while the overall rating is the lowest sub-tier rating, as specified in the IWA. Sub-tier values and ratings for many different stove types are compared in the reports. A brief description of the performance indicators specified in the IWA is provided below.

Efficiency/fuel use is an important indicator, especially for cookstoves used in areas where fuel is scarce or expensive or where forest degradation is an issue due to unsustainable harvesting of wood for fuel. Greater fuel efficiency is desirable, but increased efficiency does not always correlate with reduced emissions of air pollutants. Efficiency/fuel use tier levels are based on thermal efficiency at high power and specific energy use at low power, per the IWA.

Total emissions of air pollutants from cookstoves have potential impact on human health and climate change. CO (carbon monoxide) and $PM_{2.5}$ (fine particulate matter) are indicator pollutants specified in IWA 11:2012, and emissions of additional pollutants are quantified in the reports, including gaseous pollutants CO_2 (carbon dioxide), THC (total hydrocarbons), CH_4 (methane), and NO_X (nitrogen oxides), as well as particulate OC (organic carbon), EC (elemental carbon), and BC (black carbon). Total emission tier levels are based on the mass of pollutant emitted per unit of useful energy delivered at high power and the specific emission rate at low power, per the IWA.

Indoor emissions have a potential direct impact on human health, and emissions may be reduced by stoves with cleaner combustion and/or with chimneys (flues). Stoves without chimneys are tested for total emissions into the indoor space, and stoves with chimneys are tested for fugitive emissions from the stove. Indoor emissions tier levels are based on emission rates, per the IWA.

Safety is also an important indicator included in IWA 11:2012 for evaluation of stoves for protection from risk of burns and other injuries, but safety is not evaluated in the EPA reports.

Cooking power is not an IWA performance indicator, but it is reported because it can be important for meeting user needs.

Fuel burning rates are reported to define the test conditions.

IWA tier ratings are based on the performance of the stove system operated as intended with low-moisture fuel. Additional test results are provided in the reports for energy efficiency, fuel use, and air pollutant emissions for both low- and high-moisture fuel. Discussion of results, observations, and quality assurance is also included in each report.

Following are brief descriptions of cookstoves with test results published in FY 2016.

Test Report – BioLite™ HomeStove™ with Wood Fuel – Air Pollutant Emissions and Fuel Efficiency

***5** BioLite HomeStove*

The BioLite™ HomeStove™ shown in the figure is a forced-draft (fan) type of stove. A thermoelectric generator, powered by the heat from combustion, provides electrical power to the fan and may be used as an auxiliary source of electricity for low-power applications such as charging a mobile device (e.g., cellular phone) or operating a light emitting diode (LED). The stove is designed to burn fuel wood sticks that are manually fed into an opening in the lower front of the stove. The fan operates automatically with no user controls and no rechargeable battery. The HomeStove was rated at Tier 3 for total emissions, Tier 2 for indoor emissions, and Tier 2 for energy efficiency, with tier levels established from 0 (worst) to 4 (best). For more information, see the full EPA report [18] and the BioLite web site [19].

Test Report – CleanCook Model A1 Stove with Alcohol Fuel – Air Pollutant Emissions and Fuel Efficiency

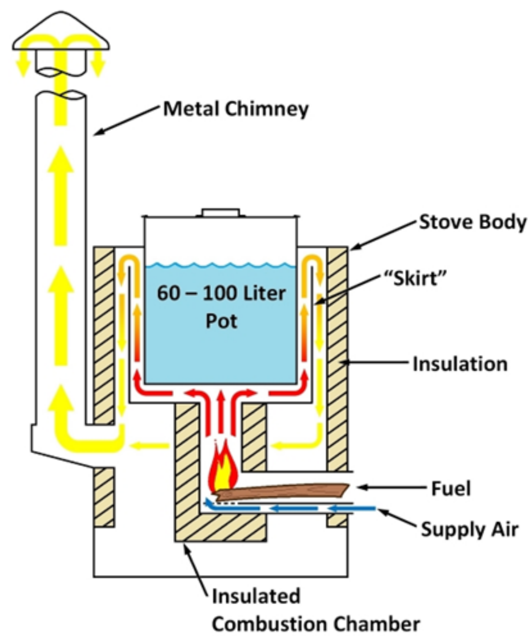
The CleanCook Model A1 stove shown in the figure is an unpressurized liquid-fuel type of stove designed for alcohol (ethanol and/or methanol) fuel. Evaporating liquid fuel burns as a gas, and no pressurized container or wick is required. Alcohol is contained in a fuel tank filled with an absorptive ceramic fiber material – adding a non-alcohol liquid fuel (such as kerosene) can damage the fuel container. Capacity of the fuel tank is 1.2 liters. The Model A1 that was tested has a single burner and a mechanical regulator – a lever moves a metal disk that uncovers an opening for evaporating fuel. The regulator can be used to adjust or extinguish the flame. The CleanCook was rated at Tier 4 for total emissions, Tier 4 for indoor emissions, and Tier 4 for energy efficiency, with tier levels established from 0 (worst) to 4 (best). For more information, see the full EPA report [20] and the CleanCook web site [21].

***6** CleanCook Model A1 alcohol stove*

Test Report – InStove 60-Liter Institutional Stove with Wood Fuel – Air Pollutant Emissions and Fuel Efficiency

The InStove 60-Liter Institutional Stove is a natural-draft type of cookstove designed for wood or other biomass fuel. Electrical power is not required for natural-draft stoves (power is required for some forced-draft stoves). As shown in the figures, a chimney provides draft and may be used to vent emissions to outside the cooking space. A rocket-type combustion chamber is located under the cooking pot. A "sunken-pot" design provides an integral pot skirt to enhance heat transfer to the sides, as well as the bottom, of the pot. The stove is designed to burn fuel sticks of wood or other biomass (e.g., biomass briquettes) that are manually fed into an opening in the lower front of the stove. Cooking power is controlled by the amount of fuel fed into the combustion chamber. A cap on top of the chimney prevents rain from entering the stove. The stove is designed to be manufactured in a small factory. InStove has developed drinking-water pasteurization and hospital-grade autoclave systems for use with the stove, but EPA tested the stove with only the cooking pot. The InStove was rated at Tier 4 for total emissions, Tier 3 for indoor emissions, and Tier 4 for energy efficiency, with tier levels established from 0 (worst) to 4 (best). For more information, see the full EPA report [22] and the InStove web site [23].

__7__ InStove 60-Liter Institutional Stove

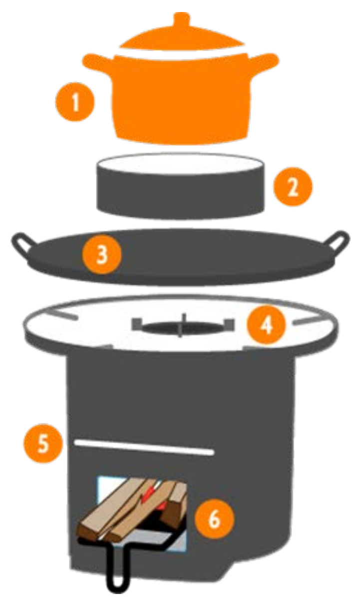


__8__ Side-view cross-section showing internal design. Credit: InStove

Test Report – StoveTeam International, Ecocina Stove with Wood Fuel – Air Pollutant Emissions and Fuel Efficiency

The StoveTeam Ecocina Stove is a natural-draft rocket-type of cookstove designed for wood fuel. Electrical power is not required for natural-draft stoves (power is required for some forced-draft stoves). As shown in the figures, the stove may be used with a cooking pot or comal (a griddle, also known as a plancha) for making tortillas or frying foods. For cooking with a pot, the comal may be removed to expose the pot directly to flames and hot combustion gases for improved efficiency. A rocket-type combustion chamber is located under the cooking pot or comal. An adjustable pot skirt enhances heat transfer to the sides, as well as the bottom, of the pot. The stove is designed to burn sticks of fuel wood or other biomass (e.g., corn cobs) that are manually fed into an opening in the lower front of the stove. Cooking power is controlled by the amount of fuel fed into the combustion chamber. The stove is manufactured with local materials in small factories in El Salvador, Guatemala, Honduras, and Mexico. The Ecocina was rated at Tier 1 for total emissions, Tier 0 for indoor emissions, and Tier 2 for energy efficiency, with tier levels established from 0 (worst) to 4 (best). For more information, see the full EPA report [24] and the StoveTeam web site [25].

***9** Ecocina stove with pot skirt*



***10** Ecocina components: 1 Pot, 2 Pot Skirt, 3 Comal, 4 Pot Supports, 5 Body, 6 Fuel Wood Support*
Credit: StoveTeam International

These EPA test reports on stove and fuel combinations are used to support the development of testing protocols and standards, and the reports are used by Alliance partners to evaluate stoves for further testing in the field. Performance evaluations provide incentives for developers to improve stove and fuel technologies. Testing of additional stoves and fuels is ongoing.

Journal Publications

Environmental Health Perspectives 124. July 2016. DOI:10.1289/ehp.1509852

Mutagenicity and Pollutant Emission Factors of Solid-Fuel Cookstoves: Comparison with Other Combustion Sources

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Background: Emissions from solid fuels used for cooking cause ~four million premature deaths per year. Advanced solid-fuel cookstoves are a potential solution, but they should be assessed by appropriate performance indicators, including biological effects.

Objective: We evaluated two categories of solid-fuel cookstoves for eight pollutant and four mutagenicity emission factors, correlated the mutagenicity emission factors, and compared them to those of other combustion emissions.

Methods: We burned red oak in a 3-stone fire (TSF), a natural-draft stove (NDS), and a forced-draft stove (FDS), and we combusted propane as a liquefied petroleum gas control fuel. We determined emission factors based on useful energy (megajoules delivered, MJ_d) for carbon monoxide, nitrogen oxides (NO_x), black carbon, methane, total hydrocarbons, 32 polycyclic aromatic hydrocarbons, $PM_{2.5}$, levoglucosan (a wood-smoke marker), and mutagenicity in *Salmonella*.

Results: With the exception of NO_x, the emission factors per MJ_d were highly correlated ($r \geq 0.97$); the correlation for NO_x with the other emission factors was 0.58–0.76. Excluding NO_x, the NDS and FDS reduced the emission factors an average of 68 and 92 %, respectively, relative to the TSF. Nevertheless, the mutagenicity emission factor based on fuel energy used ($MJ_{thermal}$) for the most efficient stove (FDS) was between those of a large diesel bus engine and a small diesel generator.

Conclusions: Both mutagenicity and pollutant emission factors may be informative for characterizing cookstove performance. However, mutagenicity emission factors may be especially useful for characterizing potential health effects and should be evaluated in relation to health outcomes in future research. An FDS operated as intended by the manufacturer is safer than a TSF, but without adequate ventilation, it will still result in poor indoor air quality.

11 Cookstoves compared in mutagenicity and pollutant emission factors study

In Review

Particulate polycyclic aromatic hydrocarbon emissions from burning kerosene, liquid petroleum gas, and wood fuels in household cookstoves

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Guofeng Shen, Ph.D., joined the EPA cookstove research team in April, 2015, under an ORISE (Oak Ridge Institute for Science and Education) postdoctoral fellowship. Dr. Shen received his Ph.D. in 2012 from Peking University under the distinguished scientist, Professor Shu Tao, and Dr. Shen was a Visiting Scholar for one year at the Georgia Institute of Technology. Dr. Shen has 25 first-author articles and more than 30 co-authored articles published in leading scientific journals, including several in *Environmental Science & Technology*. His knowledge of past and ongoing stove research in China is valuable for assisting with developing standards for stoves though ISO TC 285 and for working with colleagues at Regional Testing and Knowledge Centers in China.

Cookstove Events

ISO (International Organization for Standardization) Technical Committee 285, Clean Cooking Solutions, Plenary Meeting, Accra, Ghana, Nov. 3-6, 2015.
See report above under ISO Standards Development section above, and for more information, see the web site: http://cleancookstoves.org/events/160.html, last accessed August 9, 2016.

Clean Cooking Forum, Global Alliance for Clean Cookstoves, Accra, Ghana, Nov. 10-13, 2015.
EPA provided leadership and co-sponsored this event. The Clean Cooking Forum followed the ISO TC-285 Plenary Meeting (see above). More than 500 people participated in the Clean Cooking Forum. EPA Personnel served on two expert panels: (1) ISO Standards and WHO Guidelines and (2) New Developments in Laboratory and Field Testing. Both panels were well attended with approximately 100 participants in the ISO/WHO session and 60 participants in the Lab/Field Testing session. EPA participated as speakers in sessions (1) No Boundaries: Household to Ambient Pollution, (2) Consumer Awareness of Cookstoves Technology and Fuel Performance and (3) the Closing Plenary and Forum Observations. EPA led a session on Clean Cooking and Climate: Insights from EPA. Further information is available at the web site: https://www.cleancooking2015.org/, last accessed August 9, 2016.

For other events, see the web site: http://cleancookstoves.org/events/index.html?mode=list, last accessed August 9, 2016.

Media

EPA cookstove research featured on Voice of America:
http://www.voanews.com/media/video/researchers-test-for-better-cleaner-cookstoves/2706121.html, last accessed August 9, 2016.

EPA podcast on cookstove research:
http://www2.epa.gov/sites/production/files/2015-07/sciencebite_cookstoves.mp3, last accessed August 9, 2016.

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