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BIOMASS PROGRAM

Biomass Cookstoves Technical Meeting: Summary Report

May 2011

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The Office of Energy Efficiency and Renewable Energy's Biomass Program works with industry, academia, and national laboratory partners on a balanced approach to advance biomass as a significant and sustainable energy source for the 21st century.

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Disclaimer

This report is believed to be a fair and objective summary of discussions that took place during the Biomass Cookstoves Technical Meeting in Alexandria, VA, on January 11-12, 2011. Primary and secondary sources believed to be reliable are noted where possible to support data presented to frame the discussions. Early drafts of meeting results were reviewed by the participants and their feedback was incorporated. Opinions expressed are strictly those of the meeting participants and not necessarily those of the U.S. Department of Energy. Recommendations from this meeting, together with inputs received from other sources, may inform the creation of a potential DOE cookstoves R&D program.

Biomass Cookstoves Technical Meeting:

Summary Report

January 11-12, 2011

Alexandria, VA

U.S. Department of Energy

Office of Policy and International Affairs

Office of Energy Efficiency and Renewable Energy

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Preface

The U.S. Department of Energy (DOE) is interested in supporting research to develop low-emission, high-efficiency biomass cookstoves. By focusing on technical research for stoves that use solid biomass fuels, DOE can address the severe climate and health impacts of this fuel that is used by nearly half of the world's population.

DOE's work in this area is part of a coordinated U.S. government effort involving the U.S. Environmental Protection Agency (EPA), Department of Health and Human Services [including the Centers for Disease Control and Prevention (CDC) and the National Institutes of Health (NIH)], State Department, and the U.S. Agency for International Development (USAID). This U.S. effort is part of an international initiative coordinated by the United Nations Foundation through the Global Alliance for Clean Cookstoves. The Alliance has set a goal to disseminate 100 million clean cookstoves by 2020. DOE's technical research will support this larger effort to create sustainable markets for cleaner and more efficient cookstoves.

The Biomass Cookstoves Technical Meeting, organized jointly by DOE's Office of Policy and International Affairs and Office of Energy Efficiency and Renewable Energy, was held near Washington, DC, during January 2011 to identify the technical challenges and opportunities for reducing cookstove emissions and improving efficiency. The meeting was attended by nearly 80 experts, including researchers, stove designers and manufacturers, and project implementers from the United States and countries in Asia, Africa, and Latin America. These participants outlined the state of current cookstove science and engineering and defined remaining challenges and research pathways. The meeting's discussions, together with inputs received from other sources, may inform the development of the proposed R&D program, which may begin in fiscal year 2012, subject to Congressional appropriations. Discussions focused on four topic areas:

- Combustion and Heat Transfer
- Materials
- Controls, Sensors, and Fan Drivers
- Testing Protocols, Field Validation Research, and Product Design.

A number of U.S. and international groups are currently engaged in cookstove research and development. The proposed DOE research program could potentially support these groups in resolving outstanding technical challenges, leading to substantial performance gains. The goal of DOE's proposed research effort is to improve science and technology to support and accelerate implementation efforts.

Acknowledgements

The U.S. Department of Energy (DOE) invests in research and development to achieve technology advances that will help meet energy, climate, and economic goals for the United States and the world. By working in partnership with experts from multiple disciplines, DOE seeks to focus and coordinate its research to accelerate technology innovation and deployment.

DOE acknowledges the many experts who generously made time in their busy schedules to participate in the Biomass Cookstoves Technical Meeting, contribute their ideas and insights to guide research planning, and review the results.

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Executive Summary

In regions where biomass is a traditional fuel for cooking, improved cookstoves can enhance indoor air quality, personal health, livelihoods, and the environment—while substantially reducing greenhouse gas (GHG) emissions. Although ongoing efforts have successfully disseminated improved stoves that achieve many of these benefits, substantially greater emissions reductions are needed to comply with international guidelines for indoor air quality and to limit GHG emissions like black carbon.

The U.S. Department of Energy's (DOE's) offices of Policy and International Affairs (PI) and Energy Efficiency and Renewable Energy (EERE) held a meeting on January 11–12, 2011, to gather input on a proposed DOE research and development (R&D) program to address the technical barriers to cleaner and more fuel-efficient biomass cookstoves. The nearly 80 participants at the meeting evaluated DOE's proposed goals, identified the major research challenges, and defined pathways toward technology solutions.

Key recommendations from meeting participants include the following:

- *At least 90% emissions reductions and 50% fuel savings are appropriate initial targets.* A limited number of improved stoves already meet these targets, but additional technical research and development can lower costs and make these successes more widespread for a range of laboratory and field conditions and for a variety of unprocessed and processed fuels. Measuring progress toward these targets will require clear definitions of baseline performance or absolute targets for emissions and efficiency based on health and climate impacts. Several participants suggested that these targets should be more aggressive to maximize health and climate benefits.

- *No single solution will adequately address the cookstove challenge.* Multiple stove designs will be needed to accommodate a variety of cooking practices, fuels, and levels of affordability. DOE will need to balance efforts to improve existing stoves with research that could impact a range of stove types and regions. Participants presented a variety of views on how to balance near- and long-term gains.

- *Technical R&D should guide and be guided by field research and implementation programs.* Technical research should be informed by health studies on appropriate emissions levels and by social science and field research on cooking practices. At the same time, new technical insights can be used to stimulate new stove designs, improve existing stoves, and support dissemination and testing efforts. Design guides and tools can make these insights accessible and relevant for downstream efforts. At every stage, laboratory and field work should be integrated into an iterative cycle of feedback and improvement.

- *The cost and performance tradeoffs associated with the use of processed versus unprocessed fuels should be explored*. While processed fuels can improve stove emissions and efficiency, the processing adds additional costs, and these fuels may require a fuel distribution system. Simultaneous efforts are needed to reduce the logistical barriers and costs of processed fuels *and* to improve stove performance with unprocessed fuels.

The two-day meeting focused on four topics: (1) Combustion and Heat Transfer; (2) Materials; (3) Controls, Sensors, and Fan Drivers; and 4) Testing Protocols, Field Validation, and Product Design. This report summarizes the research challenges, pathways, and key contexts identified for each of these topics.

Abbreviations

BC	Black carbon
CCT	Controlled Cooking Test
CDC	Centers for Disease Control and Prevention
CFD	Computational fluid dynamics
CO	Carbon monoxide
CO_2	Carbon dioxide
DOE	U.S. Department of Energy
EERE	Office of Energy Efficiency and Renewable Energy
EPA	Environmental Protection Agency
GHG	Greenhouse gas
IAP	Indoor air pollution
IAQ	Indoor air quality
KPT	Kitchen Performance Test
LED	Light-emitting diode
NIH	National Institutes of Health
OC	Organic carbon
PI	Office of Policy and International Affairs
PM	Particulate matter
TE	Thermoelectric
TEG	Thermoelectric generator
USAID	U.S. Agency for International Development
WBT	Water Boiling Test
WHO	World Health Organization

Introduction: Benefits of Improved Cookstoves

Today, an estimated 2.5 billion people, or about one-third of the world's population, rely on biomass fuel for cooking.[1] According to the World Health Organization (WHO), exposure to smoke from these open fires and cookstoves leads to pneumonia, chronic respiratory disease, and lung cancer[2]—causing an estimated 1.6 million deaths each year. In the developing world, the disease burden from indoor smoke is comparable to the burdens from malaria, tuberculosis, or HIV/AIDS.[3] Improved cookstoves with reduced emissions and greater fuel efficiency can achieve the following:

- Reduce disease and save lives by decreasing exposure to indoor air pollution (IAP).
- Reduce the risk of violence against women and children gathering fuel in conflict areas.
- Reduce the time and cost of procuring fuel, thereby freeing individuals for other productive activities.
- Empower women and communities via engagement in the production, use, and distribution of cookstoves.
- Mitigate climate change by reducing greenhouse gas (GHG) emissions, including black carbon (BC).
- Reduce pressure on forests and other vegetation and facilitate sustainable harvesting of biomass fuels.[4]

Significant progress has been achieved in designing and disseminating cookstoves with reduced emissions and increased efficiency.[5] However, further reductions in

Black Carbon

Black carbon (BC), commonly known as soot, is particulate matter (PM) emitted from burning biomass and diesel fuel. This byproduct of incomplete combustion contributes to climate change by increasing temperatures, increasing ice and snow melt, and changing precipitation patterns. When snow and ice are covered with BC, the additional absorbed sunlight accelerates melting. BC's light-scattering and radiation-absorbing effects alter the amount of sunlight that can reach the earth's surface, trap radiation in the atmosphere, and alter global temperature distributions.

Unlike carbon dioxide, BC lasts in the atmosphere for only a few weeks, so a reduction in BC emissions can immediately reduce the rate of climate change. [Black carbon is distinct from carbon black, which is manufactured under controlled conditions for use in the rubber and printing industries.]

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1 International Energy Agency, *World Energy Outlook 2009* (Paris: Organisation for Economic Co-operation and Development, 2009), iea.org/textbase/nppdf/free/2009/weo2009.pdf.

2 Eva Rehfuess, *Fuel for Life: Household Energy and Health* (Geneva: World Health Organization, 2006), who.int/indoorair/publications/fuelforlife.pdf.

3 World Health Organization (WHO), *Global Health Risks: Mortality and Burden of Disease Attributable to Selected Major Risks* (Geneva: WHO, 2009), who.int/healthinfo/global_burden_disease/GlobalHealthRisks_report_full.pdf.

4 For more information, see:
A. Hines, A. McMichael, K. Smith, I. Roberts, et al., "Public Health Benefits of Strategies to Reduce Greenhouse-Gas Emissions: Overview and Implications for Policy Makers," *The Lancet* 374, no. 9707 (2009): 2104–2114.

5 Information on this progress can be found in the following sources:

Jonathan Rouse, *Evaluating Household Energy and Health Interventions: A Catalogue of Methods* (Geneva: World Health Organization, 2008), who.int/indoorair/publications/methods/en/index.html.

emissions are required to meet WHO guidelines for indoor air quality (IAQ)[6] and achieve significant health benefits. While chimneys improve indoor air quality and health, they do not address climate change. A focused effort, including technical research; product innovation, design, and development; laboratory and field testing; and implementation, is needed to deliver the health and climate benefits associated with reducing emissions by at least 90% and fuel use by at least 50%. The effort will need to address numerous challenges and tradeoffs, such as improved efficiency versus reduced emissions and affordability and usability of advanced technology. Research developments should provide clear guidance for stove design and dissemination. All stages or research and product design should be integrated with field validation of stove performance and user acceptance.

Berkeley Air Monitoring Group, *Evaluation of Manufactured Wood-Burning Stoves in Dadaab Refugee Camps, Kenya* (Washington, DC: U.S. Agency for International Development, 2010), usaid.gov/our_work/economic_growth_and_trade/energy/publications/ Dadaab_wood_stove_evaluation.pdf

Samuel F. Baldwin, *Biomass Stoves: Engineering Design, Development, And Dissemination* (Arlington, VA: Volunteers in Technical Assistance, 1987), http://sleekfreak.ath.cx:81/3wdev/VITAHTML/SUBLEV/EN1/BIOSTOV.HTM

Mark Bryden, Dean Still, Peter Scott, et. al., *Design Principles for Wood Burning Cook Stoves* (London: Shell Foundation; Washington DC: U.S. Environmental Protection Agency, 2006), http://bioenergylists.org/stovesdoc/Pcia/Design%20Principles%20for%20Wood%20Burning%20Cookstoves.pdf.

Tone Smith-Sivertsen, Esperanza Díaz, Dan Pope, "Effect of Reducing Indoor Air Pollution on Women's Respiratory Symptoms and Lung Function: The RESPIRE Randomized Trial, Guatemala," *American Journal of Epidemiology* 170, no. 2 (2009): 211–220, http://aje.oxfordjournals.org/content/170/2/211.abstract.

James Jetter and Peter Kariher, "Solid-Fuel Household Cook Stoves: Characterization of Performance and Emissions," *Biomass and Bioenergy* 33, no. 2 (2009): 294–305, http://dx.doi.org/10.1016/j.biombioe.2008.05.014.

[6] Gary Adamkiewicz et al., *WHO Guidelines for Indoor Air Quality: Selected Pollutants* (Copenhagen: World Health Organization, 2010), euro.who.int/__data/assets/pdf_file/0009/128169/e94535.pdf.

Key Recommendations for a DOE Cookstove R&D Program

Targets for Emissions and Efficiency

DOE sought feedback on its proposed targets to reduce emissions by at least 90% and fuel use by 50% (relative to the baseline technology) in household use—*and* make the cookstoves affordable by families earning $1 per day per capita. Some participants indicated that these targets are feasible yet challenging, especially for stoves in the field. Other participants indicated that the targets should be even more ambitious. Some stoves already meet these targets, yet even better performance is possible. Efforts to refine these performance targets should consider the following issues:

- Emissions reductions of well over 90% may be needed to meet WHO guidelines, particularly for fine particulate matter of 2.5 micrometers ($PM_{2.5}$) or less. [These particulates are small enough to enter the lungs and can lead to serious health issues.] Further studies are needed to establish the levels of emissions reduction needed to deliver significant health benefits.
- Targets could be stated in terms of absolute rather than relative emissions and efficiency. Absolute targets are not tied to the performance of baseline technologies, which are difficult to define and vary with usage conditions. Absolute levels of emissions and efficiency can also be more easily tied to specific health and climate benefits.
- Targets may be prioritized according to causal relationships among emissions, efficiency, and health (e.g., cleaner combustion can increase fuel savings and reduce PM, yet potentially increase carbon monoxide).
- Some cookstoves are designed to use only the volatile components of biomass to produce biochar, which can be used for soil amendment and carbon sequestration. Because these biochar-producing stoves are not designed to completely combust the biomass, DOE's targets for fuel efficiency are not applicable for biochar stoves.
- Stoves can be distributed without charge, financed through carbon credits, or sold using market-based retail approaches. R&D efforts should target increased affordability for a range of household income levels and dissemination strategies.

Research targets will be revised in conjunction with ongoing efforts by other U.S. agencies to define performance standards, including the World Health Organization and the working groups of the Global Alliance for Clean Cookstoves (an initiative led by the United Nations Foundation).

Multiple Cookstove Options Needed

No single cookstove solution can meet the broad range of conditions and needs. Cookstoves are needed for a wide variety of cooking practices, cuisines, fuel types, markets, and cultures. At times, these stoves are used for additional functions, such as repelling insects or providing space heating. An improved stove often does not completely replace traditional stoves and fires, as many households will continue to use multiple cooking devices for a variety of purposes. Beyond improved emissions and efficiency, stoves need to be durable, affordable, and safe. While each stove typically represents a compromise to address a particular combination of factors, stoves should be robust and operate efficiently under a range of conditions. Multiple cookstoves are also needed to provide affordability or accessibility for diverse household income levels (including the lowest)—whether through market-based systems, social programs, or financing mechanisms.

Research and development on combustion, heat transfer, and materials can lead to long-term progress in cookstove emissions, fuel efficiency, and affordability. At the same time, efforts to develop, test, improve, and disseminate existing prototypes can deliver more immediate benefits. Participants held varied opinions on how to balance these near-term and long-term efforts.

Technical R&D Guided by User Preferences and Health Impacts

Cookstove design must take into consideration user preferences and behavior, which vary considerably by region and culture. Technical research and development will benefit from open communication with the implementation communities about user needs and lessons from previous or ongoing dissemination efforts. Laboratory and field studies can yield different results because of limited understanding of user preferences and behaviors. Social science research on cooking preferences and cookstove usage can provide useful parameters to guide research and design. Improved understanding of preferences and behaviors can be used to develop testing protocols that reflect conditions in target communities.

DOE should coordinate its R&D program with efforts by U.S. and non-U.S. government agencies and non-governmental organizations. Such organizations, including the Global Alliance for Clean Cookstoves, are already studying the benefits of improved cookstoves, improving testing protocols and standards, establishing health-based targets for emissions reductions, evaluating the impacts of behavior changes, training users in stove operation and maintenance, and building human capacity in developing countries.

Technical R&D to Guide Stove Design and Dissemination

Laboratory and technology developments should be applied to stove design, dissemination, and field testing to ensure robustness to a variety of foods, fuels, and other conditions. The durability and transferability of technologies from one region to another will also need to be confirmed through implementation and field testing.

Iterative cycles of feedback between modeling, laboratory and field research, and implementation are necessary for a successful R&D program. The research program should be organized to foster partnerships among researchers from the national laboratories, universities, and groups with significant field testing and dissemination experience.

To accelerate innovation and progress, technical insights should be clearly communicated to stove designers and manufacturers. Guidance documents or a validated, user-friendly, open-source design tool would enable multiple organizations to use these technical insights to optimize stove design for specific cooking needs, preferences, fuels, and local resources. Input from designers, manufacturers, and implementation projects will be invaluable for developing useful tools that effectively support improved cookstove design and dissemination.

Fuel Considerations

This meeting focused on solid biomass fuels for cooking and heating. The wide range of biomass fuels, including variations by season and moisture content, present challenges for technical research and development. Improved characterization of fuel composition and optimization of fuel varieties will facilitate combustion and emissions testing research.

Processed fuels can provide a level of standardization that could be useful for cookstoves development. These fuels may be suitable in some urban areas establishing a market for processed fuels presents many challenges. Unprocessed fuels are more likely to be used in rural areas, especially among the poorest populations, but the wide variations in unprocessed fuels make research and design more challenging. The costs and emissions tradeoffs between stoves designed to use processed versus unprocessed fuels require further examination.

Topic 1: Combustion and Heat Transfer

Overview

The main processes in biomass cookstoves are the combustion of the biomass and the transfer of heat to the cooking vessel or surface. Harmful emissions are formed from incomplete combustion. The efficiencies of both the combustion and heat transfer determine fuel efficiency and cooking times, which, in turn, affect the duration of human exposure to emissions.

There is often a trade-off between cleaner combustion and heat transfer. For example, placing the cooking vessel closer to the fire to increase heat transfer can cause volatiles leaving the fire bed to cool quickly, disrupting combustion and increasing emissions. Thus, combustion and heat transfer are coupled processes and should be considered together in research and modeling. In the initial phases of research, however, separate consideration of these processes can be useful.

Combustion and heat transfer research efforts linking fundamental physics with computational and laboratory work have been successful in many commercial areas, including methane combustion and coal plants. Research for biomass cookstoves can build on developments in these areas. Remaining challenges include better understanding and modeling of 1) wood combustion and pyrolysis; 2) tar, char, and emissions formation; and 3) heat transfer at the scale of a cookstove. Additional factors affect the efficiency of combustion and heat transfer and the formation of emissions, including combustion chamber density and geometry, mixing, and the air-to-fuel ratio. Improved understanding of these factors is needed, especially their impacts across multiple spatial scales and on indoor air pollution and personal exposure levels .

Computational Fluid Dynamic (CFD) and physics-based modeling can provide qualitative and quantitative insights. Empirical tests and data are needed to validate and improve these models and to apply the model results. Detailed models of combustion and heat transfer should be balanced with simple yet comprehensive models that can be integrated into a user-friendly design tool for stove designers and manufacturers.

Challenges and Pathways

Subtopic	Research Challenges	Pathways to Solutions
Combustion	Lack of definition in design space: stove designs, geometries, options for air flow, usage cycles	Collaborate with social scientists to understand user preferences and needs; develop designs that are robust and transferable for multiple conditions.
Emissions	Need improved understanding of formation of PM, especially BC and organic carbon (OC)	Use available data on composition of emissions to validate and improve models; a reduced-order model for aerosol formation may be sufficient.
	More specific targets for emissions reductions to guide emissions modeling efforts	Target 90% emissions reductions in the near term and use more specific guidance from other organizations like WHO, NIH, EPA, and the Global Alliance working groups for appropriate emissions reductions targets based on health impacts, when available.

Subtopic	Research Challenges	Pathways to Solutions
Heat Transfer	Improved understanding needed for fluid mechanics and heat transfer	Develop models and parameterizations for fluid mechanics and heat transfer appropriate for the scale of a cookstove; validate with empirical data.
Modeling	Need robust and computationally efficient models for wood combustion	Develop plug-ins for modeling packages that model solid pyrolysis and gas-phase chemistries for biomass, gasification mechanisms, mixing, heat transfer, and aerosol formation.
	Lack of integration between combustion, heat transfer, and emissions models	Integrate modeling of combustion, heat transfer, and materials; integrate models to span multiple scales and validate using available empirical and field data.
	Need to compare models	Identify standard geometry for model development and comparison, understanding that models will need to accommodate a variety of geometries.
Validation data	Need empirical data for validating models, with good resolution for boundary conditions	Gather spatially resolved empirical data for biomass pyrolysis, char combustion, gas-phase combustion, flame/pot interaction and quenching, and emissions formation.
Fuel	Lack of data on fuel variety and properties, which are critical considerations for modeling chemical properties, combustion, and heat transfer	Prioritize fuel types; characterize fuel properties and compositions for a variety of fuel options; account for fuel flexibility and evaluate fuel mixing with air.

Key Contextual Issues

- A variety of stoves will be needed to address the range of price points, foods, fuels, resources, and user preferences. Each stove design will need to robustly balance the tradeoffs between practicality, affordability, safety, performance efficiency, and reduced emissions. Combustion and heat transfer research will need to be applicable and accessible to support this broad range of contexts.
- Improved characterization and standardization of fuels and the optimization of fuel size, form, and mixing is useful for combustion and heat transfer research and modeling. Fuel standardization, or even distribution of standardized fuel, can facilitate comparisons of results across laboratories.
- Collaborations among researchers from industry, the national laboratories, and academia in industrialized and developing countries will help to integrate modeling, laboratory and field research, and implementation efforts.
- Behavioral strategies to reduce personal exposure to emissions (e.g., opening windows, keeping children out of the kitchen, training, and stove maintenance) may be as important as improved cookstoves in limiting adverse health impacts.

Topic 2: Materials

Overview

Cookstoves require a variety of materials for the combustion chamber, insulation and envelope, accessories, thermoelectric generators (TEGs), heat conducting probes, and heat sinks. These materials need to endure relatively high temperatures, large thermal gradients, thermal cycling, aggressive chemical environments, and physical stress from cooking or other impacts. Materials considerations also include durability, functionality, safety, cost, availability, and ease of manufacture, which can conflict with each other. For the development and selection of materials, additional considerations include the composition and emissions profiles of the biomass fuels; the combustion or gasification process; the presence of water vapor, alkalis, tars, and other aggressive chemical species; and the temperature profile. One participant identified combustion chamber degradation as a critical limiting factor in the life expectancy of cookstoves. The broad range of cooking preferences and available resources will require diverse materials solutions, with each solution robust to multiple contexts.

A dedicated engineering approach to materials development will help to balance these constraints and overcome the tradeoffs between reduced costs and improved performance. This integrated materials engineering approach should include use of experimental data and simulations of operating conditions. Computational design tools developed to aid stove designers and manufacturers should integrate materials considerations with modeling of combustion and heat transfer. Materials degradation from wear, high-temperature corrosion, thermal fatigue, shock, and creep can be recreated (with models or in the lab) to improve materials selection and contribute to accelerated lifetime testing. After field testing, materials should be recharacterized to validate laboratory testing and lifetime models and to improve understanding of degradation under realistic conditions.

Metals and ceramics are both widely used in cookstoves. Metals are lightweight, mechanically robust, resistant to thermal shock, and allow for flexible designs. Ceramics also offer useful properties for stove construction; options include locally available ceramics for artisanal production and technical ceramics, if costs can be minimized. Efforts to apply and improve currently available materials should be balanced with efforts to develop new materials.

Challenges and Pathways

Subtopic	Research Challenges	Pathways to Solutions
Life testing and modeling	Managing a wide range of variables (fuels, combustion temperature, abrasive resistance, etc.) for accelerated life-cycle testing and generating lifetime models Establishing the field relevance of life-cycle testing and modeling	Develop methodology and models to perform accelerated life-cycle testing that accounts for a wide range of variables and incorporates modeling of combustion and heat transfer. Foster partnerships between laboratory and field researchers.
Database of material properties	Need data on material properties that are relevant and meaningful to field and original equipment manufacturers	Survey the methods used to determine material properties; define the set of desired data to ensure accessibility and field relevance of the

Subtopic	Research Challenges	Pathways to Solutions
		database; establish plan to maintain data integrity.
Metals	Need to overcome materials challenges of corrosion, thermal cycling, cost, sourcing, and availability	Foster partnerships between lab and field researchers to balance the variety of constraints for specific contexts.
Ceramics	Need to overcome materials challenges of strength, brittleness, durability, resistance to abrasion, cost, local variability, and availability	Foster partnerships between lab and field researchers to balance the variety of constraints for specific contexts.
	Development of materials that accommodate artisanal or industrial producers	Develop relationships with industrial partners who may incorporate skills of artisanal producers.

Key Contextual Issues

- Whether ceramics or metals are used, development of advanced materials should consider affordability, adaptability, and whether the materials will be applied to artisanal or industrial-scale production.
- Materials research and development should be informed by field testing to ensure that the materials developed are relevant for users and meet performance requirements for households and communities.

Topic 3: Controls, Sensors, Fan Drivers

Overview

Cookstoves with mechanisms for forced ventilation (e.g., fans) not only reduce emissions through better air-fuel mixing and improved combustion but also improve heat transfer to the cooking vessel. Current fan-driven stove technologies meet or are close to meeting the stated performance targets (reduce emissions by 90% and improve fuel efficiency by 50%). While costs for fan-driven stoves have recently decreased, further price reductions can make these technologies more widely affordable.

Fans require a power source, and a promising option is the thermoelectric generator (TEG), which is able to harness a stove's thermal gradients to produce power on demand. Of the thermal energy produced from a traditional stove, only a small fraction is required to generate the electricity needed to drive a fan. TEGs can also be designed to optimize efficiency by adjusting the fan in response to thermal gradients. Current TEGs require no external power source, are scalable, reliable, and—unlike photovoltaics—generally do not require energy storage or rely on the weather. TEGs can also be used to charge small electronic devices or to power light-emitting diodes (LEDs) for lighting. TEG designs can be improved to provide low shear stress and scalability for various power levels. Other major applications of thermoelectric module technology, such as automotive waste heat recovery, are expected to increase the efficiency and lower the cost of this technology over the next decade. More complex and potentially more efficient mechanisms to generate electrical power are also being developed and tested, such as steam-piston generators and thermo-acoustic electric co-generators.

Sensors and controls can significantly improve cookstove performance and enable real-time tracking of stove use and performance. IAP sensors can provide laboratory and field measurements at all stages of stove development and scale-up (Figure 1) and can be especially useful for measuring particulate chemical composition. Sensors for measuring PM and carbon monoxide (CO) are available and relatively inexpensive, but measurement of BC has been complex and expensive, particularly in the field.

Figure 1: Sensors can be used during all stages of stove development and scale up

In-field monitoring of emissions remains expensive, requiring highly trained personnel, expensive instrumentation, and extensive follow-up for data compilation and analysis. Alternative sensor systems are available to measure practices in the field, potentially enabling integration of field data with lab testing. These systems, such as the Stove Use Monitoring System, can provide a record of stove temperature at regular intervals during cooking events. Future developments may include wireless data transmission and recording of fuel consumption.

Challenges and Pathways

Subtopic	Research Challenges	Pathways to Solutions
Sensor Selection and Development	Lack of data about available sensors and measurements, including processes for standardization and calibration to ensure compatibility	Catalog available sensors and possible applications; develop standardized measurements and strategies for calibration.
	Need better tools to study end-user behavior and performance in field	Identify or develop sensors for field studies, especially those to monitor emissions and health; explore existing software options for data analysis.
Power Systems Development	Existing thermoelectric (TE) devices not optimized for stoves	Evaluate and develop low-cost, low shear stress, and stove-specific TE power systems and strategies for reliable fan power at all times.
	Need understanding of stove characteristics that allow for auxiliary devices	Engage neutral party to conduct field study of stoves and assess compatibility with auxiliary devices.
Control Systems	Need to account for a variety of user behavior patterns during cooking	Explore and optimize a variety of active and passive control strategies, then validate them in the field.
Systems Integration	Need fans optimized for stove applications	Identify fan specifications (coupled with combustion modeling) and develop fans optimized for stoves.
	Need lab and field measurements of impacts of fan drives and control systems on emissions	Empirically verify PM size, mass, and count, which can be accomplished with available testing methodologies.

Key Contextual Issues

- TEGs can provide a means to charge additional electronic devices, like cell phones. The possibility that biomass will be burned solely to charge these devices could negate the benefits of cleaner and more efficient stoves. One strategy to mitigate this issue is to allow auxiliary power use only when the stove is being used for cooking, but enforcing such a constraint would be difficult.

Topic 4: Testing Protocols, Field Validation & Product Design

Overview

Improved laboratory studies and testing protocols are needed to more accurately reflect field conditions and improve field results. The discrepancies between laboratory and field testing have hindered previous cookstove development and dissemination efforts. Many complementary laboratory and field tests are currently used, e.g., the Water Boiling Test (WBT), Controlled Cooking Test (CCT), and Kitchen Performance Test (KPT), and a range of tests are likely to be needed to cover all phases of stove design and use (Figure 1). For example, laboratory tests can enhance stove design, and field tests are important to validate stove performance under realistic conditions.

New testing protocols incorporate a variety of fuels, field conditions, and cooking practices. Recent developments include a new, publicly evaluated version of the WBT protocol; the Indian Standard WBT adopted by India's improved National Biomass Cookstove Initiative; a testing approach that recreates burn cycles from field conditions;[7] and EPA's research plan for testing (currently under preparation). New testing approaches that evaluate multiple performance measures at multiple powers and test loads could overcome some limitations of the current framework of laboratory and field tests.

Efforts to improve cookstoves (reducing fuel use, increasing efficiency, lowering emissions, and improving health) would benefit from a standard set of metrics, baselines, and targets, but consensus is lacking on such standards and measurement protocols. The community is working to determine which variables are most appropriate to measure and which methods are best to measure them. In addition, efforts are needed to establish the number of samples and contexts needed to provide robust feedback to stove designers and project implementers.

Cooking devices, fuels, foods, and cooks should be considered together. Multiple fuels and cooking devices are routinely used in various combinations throughout the world, and each combination represents interactions affecting fuel efficiency and emissions. Laboratory and field testing should therefore account for the entire cooking system.

Challenges and Pathways

Subtopic	Research Challenges	Pathways to Solutions
Metrics and Baselines	Inability to compare emissions and efficiency results for different stoves and studies due to multiple metrics and baselines	Define a baseline, three-stone fire (even if arbitrary) to enable data comparisons; may use U.S. and WHO indoor air quality standards as targets for improvements.
Laboratory Testing	Need universally accepted standards, calibration methods, and test protocols to	Standardize and coordinate lab and field testing protocols during the design, monitoring, and evaluation process.

[7] Michael Johnson et al., "New Approaches to Performance Testing of Improved Cookstoves," 2010, *Environ. Sci. Technol.*, 2010, *44* (1), 368–374, http://pubs.acs.org/doi/abs/10.1021/es9013294.

Subtopic	Research Challenges	Pathways to Solutions
	validate designs and demonstrate potential health benefits	
Field Testing	Need to characterize real-life conditions to inform laboratory research and design	In addition to standardized field and lab protocols, develop wider range of lab tests; link lab and field groups with defined statements of work that incorporate iterative feedback.
	Instrument cost, limited sample sizes in field studies due to difficulties with data transmission and usability	Develop lower-cost, more user friendly testing methods and long-lasting data logging instruments with wireless capability.
	Complex and difficult-to-measure composition of PM (including BC) especially in the field	Develop more field data and improved methods for measuring the components of PM emissions and for distinguishing between BC and OC.
Characterization of cooking practices	Diverse, insufficiently characterized cooking practices	Develop standardized and comparable tests that account for cooking practices and ventilation; develop testing approaches that evaluate multiple performance measures at multiple powers and test loads

Key Contextual Issues

- Achieving these research goals will require close collaboration among laboratory and field researchers from industrialized and developing nations. Implementing organizations will be essential to disseminate products and ensure that the products meet acceptable standards. International organizations can facilitate effective, accurate communications among researchers, stove designers, manufacturers, and users (Figure 2).

Figure 2: Iterative cycle of feedback between laboratory and field studies to improve stove design and performance.

Looking Ahead

The valuable and actionable insights gained at the meeting will guide the development of a DOE cookstoves R&D program. The cookstove research community may be asked for additional information to assist in further defining the program and building consensus on targets, standard baselines, and protocols. DOE's subsequent issuance of funding opportunity announcements will depend upon Congressional appropriations.

DOE's program will be coordinated with other U.S. government agencies and through the Global Alliance for Clean Cookstoves. The Alliance will facilitate DOE interaction with other U.S. agencies, international governments, non-governmental organizations, and the private sector.

DOE research projects should be tightly integrated with product design, development, and sustainable implementation, with each of these stages informed by testing, monitoring, and evaluation. Research findings may be made widely accessible through publications, guidance documents, and design tools. The goal of DOE's R&D program is to ensure that outstanding technical research can continue to stimulate innovations that improve health and livelihoods throughout the world.

Appendix

Agenda

January 11–12, 2011 • Westin Alexandria • Alexandria, Virginia

The goal of this workshop is to identify the principal R&D needs and challenges and the research pathways to develop clean, efficient, affordable biomass cookstoves that deliver at least 50% fuel savings and at least 90% emissions reductions in household use, and at a cost that is accessible to people living on $1 a day.

TUESDAY, JANUARY 11, 2011

7:30 am	**REGISTRATION CHECK-IN**
8:30 am	**WELCOME REMARKS** ▪ **Cathy Zoi**, Acting Under Secretary**,** U.S. Department of Energy
8:40 am	**AGENDA REVIEW AND INTRODUCTIONS** ▪ **Doug Brookman**, Public Solutions, *Moderator*
8:55 am	**BRIEF OVERVIEW OF PROJECT** ▪ **Sam Baldwin**, U.S. Department of Energy
9:05 am	**PRESENTATION** **Global Alliance for Clean Cookstoves** ▪ **Leslie Cordes**, United Nations Foundation
9:20 am	**MODERATED DISCUSSION** **Key Trends and Drivers Affecting the Development of Clean Cookstoves**
10:00 am	**BREAK**
10:20 am	**PRESENTATIONS AND DISCUSSION** **Topic 1: Combustion and Heat Transfer Issues for Clean Cookstoves**
	▪ **Bryan Willson**, Colorado State University ▪ **Mark Bryden**, Ames Laboratory Iowa State University ▪ **Ashok Gadgil**, Lawrence Berkeley National Laboratory ▪ **Ashwani Gupta**, University of Maryland ▪ **Moderated Q&A**
12:15 pm	**WORKING LUNCH**

1:15 pm	**PRESENTATIONS AND DISCUSSION** **Topic 2: Controls, Sensors, and Fan Drivers**
	- **Rama Venkatasubramanian**, RTI International - **Jonathan Cedar**, BioLite - **David Pennise**, Berkeley Air Monitoring Group - **Moderated Q&A**
2:45 pm	**BREAK**
3:00 pm	**PRESENTATIONS AND DISCUSSION** **Topic 3: Testing Protocols, Experience from the Field, Field Validation Research, and Product Design**
	- **Rajendra Prasad**, Indian Institute of Technology, Delhi - **Jim Jetter**, U.S. Environmental Protection Agency - **Dean Still**, Aprovecho Research Center - **Omar Masera**, National Autonomous University of Mexico, Morelia - **Moderated Q&A**
4:30 pm	**MODERATED DISCUSSION** **Key R&D Gaps Identified**
5:00 pm	**SUMMARY REMARKS** - **Arne Jacobson**, U.S. Department of Energy - **Rick Duke**, Deputy Assistant Secretary for Climate Change Policy, U.S. Department of Energy
5:15pm	**ADJOURN**
5:30 pm	**RECEPTION**
7:30 pm	**NO-HOST DINNER AT THE JAMIESON GRILLE (LOBBY LEVEL OF THE HOTEL)** **Please note that each person is responsible for their own bill.*

Wednesday, January 12, 2011

7:30 am **Coffee and Conversation**

8:00 am **Moderated Discussion**

Key Issues Identified on Day 1

8:30 am **Presentations and Discussion**

Topic 4: Materials Challenges for Advanced Yet Affordable Clean Cookstoves

- **Omer Dogan**, National Energy Technology Laboratory
- **Bruce Pint**, Oak Ridge National Laboratory
- **Warren Wolf**, Consultant
- **Richard LeSar**, Ames Laboratory Iowa State University
- **Moderated Q&A**

10:00 am **Break**

10:15 am **Concurrent Breakout Sessions Begin**

Proceed to Assigned Breakout Room

Combustion & Heat Transfer	Controls, Sensors & Fan Power Systems	Testing Protocols, Field Validation & Product Design	Materials Development
Room: Banneker	Room: Curie	Room: General Session	Room: Wright

12:30 pm **Working Lunch**

1:30 pm **Report Back and Discussion**

2:45 pm **Break**

3:00 pm **Moderated Discussion**

Key Issues, Actions, and Next Steps

4:15 pm **Closing Remarks and Adjourn**

- **Sam Baldwin**, U.S. Department of Energy

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