Assessing the Climate and Health Co-Benefits of Clean Cooking - Technical Workshop Meeting Report

United Nations Foundations Offices
Washington, DC
July 16 – 17, 2015

Sponsored by the Global Alliance for Clean Cookstoves (Alliance), Environmental Defense Fund (EDF), and Climate and Clean Air Coalition Secretariat (CCAC)

WORKSHOP AGENDA

Day 1—Thursday, July 16th

9:00 – 9:15 AM	Workshop introduction, overview, and objectives Donee Alexander (Alliance)

Part I: Measurements for Estimating Health Impacts — Sumi Mehta (moderator)

9:15 – 9:30 AM	Cookstove Impacts on Health Sumi Mehta (Alliance)
9:30 – 10:15 AM	Estimating exposures to $PM_{2.5}$ for health impact assessment Michael Brauer (University of British Columbia)—35 talk + 10 Q&A
10:15 – 10:30 AM	PAHs: exposure methods and health impacts Amanda Northcross — 10 talk + 5 Q&A
10:30 – 11:00 AM	Black carbon: Perpetrator or indicator? Patrick Kinney (Columbia University)—20 talk + 10 Q&A
11:00 – 11:15 PM	Break
11:15 – 11:45 PM	Tools, approaches, and practical considerations for monitoring health and environmental impacts in the household energy sector Michael Johnson (Berkeley Air Monitoring Group)—20 talk + 10 Q&A
11:45 – 12:45 PM	Discussion —Rufus Edwards, Kalpana Balakrishnan (moderators)
12:45 – 1:30 PM	Lunch

Part II: Cookstove Impacts on Climate—Ilissa Ocko (moderator)

1:30 – 2:00 PM	Overview of impacts of cookstoves on climate Dan Kammen (University of California, Berkeley)—20 talk + 10 Q&A
2:00 – 2:30 PM	Greenhouse gas emissions Drew Shindell (Duke University)—20 talk + 10 Q&A
2:30 – 3:00 PM	Aerosol emissions from cookstove biofuel combustion: measurement, characteristics, and uncertainties Andrew Grieshop (North Carolina State University)—20 talk + 10 Q&A

3:00 – 5:00 PM	Discussion—Chris Wiedinmyer, Shu Tao (moderators)
5:00 – 5:15 PM	Summary and Adjourn
6:00 PM	Informal Group Dinner

Day 2—Friday, July 17th

9:00 – 9:15 AM	Day 1 recap and overview of day 2 Donee Alexander (Alliance)

Part III: Policy-relevant approaches – Bryan Bloomer (moderator)

9:15 – 10:00 AM	Estimating the contribution of household to ambient air pollution • Measured Approach – Zohir Chowdhury (UCSD) • Modeled Approach – Sarath Guttikunda (Urban Emissions)
10:00 – 10:30 AM	Results based financing for clean cooking Lisa Rosen (Gold Standard Foundation)—20 talk + 10 Q&A Cookstove technology switches: a metric for decision-making Ilissa Ocko (Environmental Defense Fund)

Part IV: Discussion

10:30 – 11:00 AM	Prioritizing pollutant species to measure – Nick Lam (moderator)
11:00 – 11:15 AM	Break
11:15 – 12:15 PM	Understanding limitations – Donee Alexander (moderator)
12:15 – 12:45 PM	Next Steps and Closing Remarks – Donee Alexander (moderators)

OVERVIEW AND OBJECTIVES

Approximately three billion people around the world, mostly in developing countries, cook, heat, and light their homes using traditional cookstoves and open fires. Residential solid fuel burning releases a complex mix of health- and/or climate-damaging pollutants, including emissions of some of the most important contributors to climate change: carbon dioxide (CO_2), as well as short-lived climate pollutants, including methane and black carbon (BC). Additionally, cooling pollutants, such as organic carbon (OC), are also emitted from burning solid fuels. Residential solid fuel burning accounts for up to 25% of global black carbon emissions, about 84% of which is from households in developing countries.

Household solid fuel use is associated with over 4 million premature deaths annually, as a result of both direct exposures to household air pollution (HAP) and ambient air pollution (AAP) caused by HAP, with health effects most commonly attributed to fine particulate matter ($PM_{2.5}$), carbon monoxide (CO), and polycyclic aromatic hydrocarbons (PAHs). More recently, associations between exposure to black carbon and adverse health effects have also been observed.

While there is a solid evidence base on the health and climate impacts of traditional cooking, a more integrated understanding of which priority pollutants should be measured in order to evaluate both health and climate benefits of scaling up clean cooking is needed.

The purpose of the meeting was to convene expert scientists from both the health an environment/climate communities to 1) share the latest evidence on the relationship between cookstove emissions and health and climate impacts, including evidence attributable to key pollutants and evaluation methodologies (Here the term 'cookstoves' encompasses the cooking system, i.e. stoves and fuels.); 2) determine which pollutant measurements should be prioritized in order to estimate both health and climate impacts; and 3) discuss shared goals between the two communities, as well as research gaps and needs moving forward.

The meeting was intended to move the communities towards consensus on the priority suite of pollutant species to be measured in order to best estimate health and climate co-benefits.

PRESENTATION SUMMARIES

Introduction – Donee Alexander, Alliance

Dr. Alexander introduced the workshop by providing some background on the Alliance and reviewed the goals for the next two days of presentations and discussion. She noted that the Alliance has around 1200 partners committed to their mission to save lives, empower women, and protect the environment by improving cooking conditions in developing countries. She described the Alliance's market based approach with three core strategies (strengthen supply for cleaner technologies, enhance demand, and enable markets) and how this strategy is being implemented in three phases (initialize global and national efforts, drive investment and innovation, and scale up). Phase 1 of implementation was concluded in 2014. She explained that the goal of replacing 100 million cookstoves was based on what was known about the scope of the problem, and what would be a both compelling and feasible number for scale-up of stove replacement efforts.

Dr. Alexander then previewed the structure of the workshop, by explaining that with 3 billion people dependent upon biomass burning for cooking, we need to know what pollutants in the complex mixture of emissions are most important when it comes to damaging health and damaging climate. This workshop was intended to identify these pollutants of greatest concern, determine the best means of measuring them, and identify critical research gaps for investigation.

She noted that this was the first time that the Alliance had partnered with the Environmental Defense Fund (EDF) to jointly explore a topic of common interest, and introduced Dr. Ilissa Ocko from the EDF. Dr. Ocko briefly described the history of EDF including its role in the campaign to ban dichlorodiphenyltrichloroethane (DDT), the genesis of environmental law, and its current focus on science, non-partisan partnerships, and practical solutions on a large scale. She stated that the EDF had four focus areas: climate and energy, oceans, ecosystems, and health, and that their five-year plan is available on their website.

Part I: Measurements for Estimating Health Impacts — Sumi Mehta, moderator

Cookstove Impacts on Health - Sumi Mehta, Alliance

Dr. Mehta provided an overview of what we know about exposure to household air pollution from solid fuel combustion, and how it affects human health. She noted the different types of measurements and pollutants used to estimate exposure, including $PM_{2.5}$, CO, and BC, among others.

Key issues raised:

- Globally, an estimated 4 million deaths per year are attributed to particulate matter air pollution from household solid fuels combustion. Deaths from severe burns also contribute to the burden of disease.
- Household air pollution (HAP) is a substantial contributor to ambient air pollution in many communities.

- Public health impacts are driven by the exposure to smoke, not emissions from stoves per se. There are many different approaches to estimating human exposures to cookstove exhaust, including measuring and modeling and estimation from biomarker levels.
- Improving public health is not just about scaling-up programs but about coverage of populations.
- The Alliance is currently funding three clean cooking and child survival studies in three countries (Ghana, Nigeria, and Nepal), which are looking at $PM_{2.5}$ and CO as independent predictors of pregnancy and child health outcomes.

Estimating exposures to $PM_{2.5}$ for health impact assessment - Michael Brauer, University of British Columbia

Dr. Brauer discussed the ways in which exposure is estimated for health studies, in terms of which pollutants have been shown to have associations with health effects in large studies. He discussed the International Agency for Research on Cancer (IARC) approach from their recent monograph on air pollution, the Global Burden of Disease approach, and other ways that researchers are attempting to improve their estimations of exposure to cookstove emissions.

Key issues raised:

- Emissions from cookstoves are complex and dynamic, as are their effects on both health and climate.
- Particulate composition is variable and there are many types and sizes of particles. We know the most about $PM_{2.5}$-related health effects as these are the most studied. We do not fully understand the implications of size and composition for health effects, but climate scientists do understand the relative radiative forcing of different particle components.
- $PM_{2.5}$ is a robust indicator for evaluating health impacts of air pollution
    - The exposure-response functions used for burden of disease estimation are based on $PM_{2.5}$ exposure.
    - Risk is a function of $PM_{2.5}$ exposure, regardless of source
- There is insufficient data to differentiate health impacts of different PM constituents, but we can attribute health impacts to different sources (i.e. traffic, power generation, shipping, desert dust, etc.)
- Scientific understanding of the health effects of coarse particles and ultrafine particles is suggestive, but currently inconclusive and focused on short-term health outcomes.
- Modeling approaches for ambient levels of particles and pollutants include fuel use inventories, emissions inventories, dispersion models, chemical transport models, and satellite based measurements (plus combinations of these methods), and ground measurements. SPARTAN (Surface PARTiculate mAtter Network) and field studies are increasingly used to validate these models.
- The most important health outcomes are cardiovascular disease, stroke and childhood acute lower respiratory infections.

PAHs: exposure methods and health impacts - Amanda Northcross, George Washington University

Dr. Northcross briefed the workshop on the sources and types of PAH that are known to be present in smoke from combustion of solid fuel in cookstoves. She also detailed the relationships between $PM_{2.5}$ mass, BC, and PAH in measured emissions and household air pollutant samples.

Key issues raised:

- PAHs are a class of more than 100 chemicals with up to six fused benzene rings which are typically generated by combustion processes. The United States Environmental Protection Agency (USEPA) has flagged sixteen of these as being of high concern for health effects.
- PAHs are mutogenic, toxogenetic, and form deoxyribonucleic acid (DNA) adducts. They are well-known carcinogens, and linked with brain development and cognitive impairment, congenital heart defects, neural tube defects in neonates and children. They have been found to accelerate atherosclerosis in animals.
- Household combustion produces orders of magnitude more PAH than tobacco smoke.
- Emissions of PAH from cookstoves vary by fuel type, with coal cakes producing more than wood, charcoal, or kerosene. PAHs are likely to be a present when BC is measured, although more work is needed to evaluate possible correlations.

Black carbon: Perpetrator or indicator - Patrick Kinney, Columbia University

Dr. Kinney provided an overview of the health effects associated with black carbon measured in $PM_{2.5}$ from epidemiologic studies in human populations. He described how these compare to the health effects associated with $PM_{2.5}$ in the same or similar studies, and the implications for both climate and health.

Key issues raised:

- Household biofuel burning is heavily implicated for producing both health effects and climate effects on a global basis
- BC has strong associations with health effects - particularly cardiovascular health effects - even when $PM_{2.5}$, nitrogen oxide (NO), and nitrogen dioxide (NO_2) exposure are accounted for.
- BC is generally correlated with $PM_{2.5}$, but the ratio of BC to particulate matter (PM) varies by setting. BC was 40-50% of roadside $PM_{2.5}$ in measurements made in Nairobi, Kenya in 2009, which is high compared to developed countries.
- BC vs Elemental Carbon (EC): BC is the “darkness” of particulate matter on a filter and is measured as the amount of light absorbance. EC is the amount of a particular phase of carbon that “burns off” at a specific temperature. They are similar, but measured using very different techniques.
- Per interquartile range, $PM_{2.5}$ and BC health effects are similar; however, in several health studies measuring both $PM_{2.5}$ and black carbon, BC is associated with 7-10 times the risk per microgram per cubic meter that $PM_{2.5}$ is.

- While BC is most strongly associated with cardiovascular outcomes, it is still necessary to evaluate $PM_{2.5}$, as less studied outcomes may be related to components of $PM_{2.5}$ other than BC.

Tools, approaches, and practical considerations for monitoring health and environmental impacts in the household energy sector - Michael Johnson, Berkeley Air Monitoring Group

Dr. Johnson described the kinds of measurements that scientists make in the laboratory and in the field when evaluating various stove designs and cookstove interventions. He described the tradeoffs between measurement simplicity/cost versus their value in representing important health exposures, and the difficulties encountered in simulating field use of stoves under laboratory conditions.

Key issues raised:

- There is a need to develop tests of woodstoves which represent the wide range of fuel and use conditions encountered in the field.
- Water-boiling tests are insufficient for establishing field emission conditions, and other approaches (burn cycle approaches, staple meal cooking, and firepower sweep) are helpful but not completely representative of field performance.
- Climate relevant measurements such as particle size, type of carbon, particle aging and degree of renewable fuel harvesting are expensive to measure; PM and BC measurements may be useful in estimating organic carbon (OC) if locally established correlations exist.
- New and inexpensive monitors are now available for measuring PM, CO, and other pollutants in real time, and both Berkeley and University of Washington are working on more and better instruments for field evaluation.
- The only stove scenarios that reduce household exposure levels below World Health Organization (WHO) annual targets are Tier 4 (for indoor air emissions) liquid and gas stoves, which include liquid petroleum gas (LPG), ethanol, and biogas.

Part I Discussion -- Rufus Edwards, moderator

What pollutants and health endpoints are of greatest interest when discussing air pollution from cookstoves?

Cardiovascular disease and chronic obstructive pulmonary disease are major health problems in areas where solid fuel use is common. Emerging science has also shown associations between particulate air pollution and diabetes, birth outcomes, and some types of infections. Cognitive impairment in children, mental health issues are also of increasing concern, but baseline data are lacking in developing countries.

How does household pollution figure in to the calculations made by the Global Burden of Disease project?

The global assessments of exposure are global in scope, but the India-only modeling demonstrates that simple information is available and quantitative estimates that show local variations are possible. The difficulty in extending this globally is getting simple exposure information for a range of cooking technologies and practices, and then assimilating all the data. There is an effort to compile all the exposure information for cookstove studies into a single database, which should also make it possible to rate the cost-effectiveness of different interventions based on assumptions of reductions of exposure. However, there is a need to see what actual exposure changes are by country and what improvements are seen after interventions.

What is the context of exposure to solid fuel cookstoves? Heating stoves versus cooking stoves, indoor versus outdoor use?

The WHO guidelines specify a concentration metric, and household exposure levels are altered by where the stove is and what it is used for. Concentration data used as a proxy for exposures is measured differently from emissions data collected to characterize stove performance. At the same time, emissions and exposure, and as a result, potential climate and health, co-benefits change dramatically with usage conditions. Health evidence points to BC as a critical component in household settings. For climate assessment, it would also be important to know the OC emissions, i.e. the BC/OC ratio. This can be done by measuring $PM_{2.5}$ and BC, and scaling to obtain OC, but more precise measurements require equipment that is typically not suitable for remote locations.

What about the size of particulates – what matters for health, what matters for climate?

$PM_{2.5}$ is commonly used for health assessments, but particles smaller than 500nm are of the greatest importance for climate forcing. However, there is a great deal of uncertainty in how climate impacts are estimated, and uncertainty in vertical column effects is far larger than that introduced by a lack of data in that critical particle size range. Most black carbon particles are smaller than one micron, and there is a case to be made for measuring PM_1 as well as $PM_{2.5}$for health studies. The real challenge for the health community is that the health effects of $PM_{2.5}$ are well validated and BC has a good evidence base, but other pollutants/size ranges would take 20 years to produce risk curves.

There are significant and often enormous emission events with cookstoves being used in the field that we simply didn't expect to see from laboratory tests. How important are they overall?

Emissions from stoves during start up, shut down, transition, and low-power smoldering are challenging to simulate in the laboratory, but may contribute substantially to household emissions. Also, optically-based monitoring systems do not measure particulate in the lowest size ranges, so a switch to a high-efficiency stove design that produces particles in a smaller size range (below the limit of detection) may artificially over-estimate improvements in emissions. In terms of climate, effects are driven by the number of particles, and there are huge changes in the climate models depending on particle size assumptions, so the contribution of excursions to the total emissions may be important.

Carbon credit methodologies assume that almost 100% of biofuel harvest is nonrenewable, which is not supported by satellite images, or by recent research. What is the impact of this assumption for climate forcing potential of cookstoves?

This estimate results in an overestimate of potential impacts, and only needs to be a few percent off to make important changes in the climate impacts of biofuel cookstove use with regard to CO_2 and CO and other combustion gases, The new work from Bailis et al. (2015) estimate non-renewability of wood fuel to be much less than previously estimated. Deforestation is the most severe where wood is being made into charcoal for household burning, and the process of producing charcoal varies locally and is not characterized for its emissions.

Part II: Cookstove Impacts on Climate—Ilissa Ocko, moderator

Overview of impacts of cookstoves on climate - Dan Kammen, University of California, Berkeley

Dr. Kammen discussed the pollutants which are emitted by solid fuel cookstoves that have both positive and negative climate forcing impacts. He noted how those pollutant emissions can vary with fuel type and cooking conditions, and deforestation impacts.

Key issues raised:

- There is a wide range of pollutants emitted from solid fuel cookstoves, with impacts ranging from individual and household health to community air quality to climate change. These pollutants include CO, particulate, benzene, oxides of nitrogen (NO_x), and hundreds of different types of PAHs, hydrocarbons, and oxygenated organic chemicals.
- The impetus for interventions has cycled from health concerns to climate concerns and back again multiple times. There are sometimes trade-offs between interventions for health and climate change (not always a win-win situation), e.g. charcoal may be better for individual users, but not for deforestation or local air quality as charcoal production has its own emissions. The entire value chain must be considered.
- A diversity of technologies is needed to meet local needs – there is not one solution. Clean energy systems for households and communities are a lesson in systems thinking about cooking, lighting, cell phone charging, energy access, etc. For example, the aggregate emissions for BC in South Asia (including vehicles and other emitters) show that kerosene for household lighting is a big contributor and that pay-as-you-go systems for fuels are common – could be used for bundled lighting and stove solutions. Should efforts to bring stoves to homes consider electricity access for both improved lighting and stoves? Innovations for lighting with solar panels have shown that bundling together lighting programs and cell phone charging raises uptake, so it may be effective to bundle approved stoves with lighting products and small device chargers. There are also possibilities to develop local “minigrids” for healthier cooking with electricity which

incorporate warnings when the grid has too little power for running high electric appliances (such as the electric rice cookers in Bhutan). Using a red-green warning system in Bhutan, people adapted to power availability by scheduling their cooking and using big multifamily cooking appliances.

- There are many challenges for measuring ambient $PM_{2.5}$ – understanding is still far behind where it needs to be. Validation monitoring for modeled $PM_{2.5}$ is scarce outside developed world and urban China, as monitors are typically not in rural areas. Moreover, one can argue that BC is important, but it is a small part of the greenhouse gas (GHG) story compared to methane (CH_4) and CO_2. Whether BC should be included in social cost of carbon or part of the carbon market depends on how good we get at measuring it. BC is also emitted by power plants and traffic, which makes it difficult to separate BC emissions from cookstoves from other sources.

Greenhouse gas emissions - Drew Shindell, Duke University

Dr. Shindell described the various types of short- and long-lived climate forcing pollutants that may be emitted from burning solid fuel in cookstoves, and how these pollutants may have negative or positive climate forcing effects. He noted the potential for complicated trade-offs when adapting cleaner cookstove technologies, as emissions from cookstoves that improve exposures linked to health outcomes may result in fewer negative climate forcing emissions and/or increased emissions of positive climate forcing pollutants.

Key issues raised:

- CO is a powerful indirect climate forcing agent due to its interactions with hydroxyl radicals that help degrade methane in the atmosphere.
- Many short-lived climate pollutants come from stove emissions, and some cookstove emissions are negative climate forcers. When discussing climate, we have to look at the whole picture.
- For climate modeling, it is necessary to look at multiple models and use field observations to constrain them. Understanding of the direct and indirect impact of BC forcing on climate has grown in recent years. The direct is fairly high, and the indirect is somewhat unknown, as we don't have confirmatory observations and the resulting uncertainty swamps the magnitude of estimated effects and some models don't converge. There is a similar problem with modeling OC impacts and a lack of observations to constrain models.
- Overall, there is net positive climate forcing from biofuel cooking and heating emissions, but the emissions are complex and that makes exact estimates uncertain. Despite this, avoided warming due to biomass burning efficiency interventions improves the net climate effect of biomass burning by 2050.
- The location of emissions is important for climate change as well. BC is a huge climate forcer in Himalayas where emissions blacken the snow, but is less so in East Africa. It might be best to focus on a particular region in order to maximize climate change benefits. The Saharan region also reflects sunlight, but doesn't seem to be as heavily impacted by nearby cookstove emissions, possibly due to population density and meteorology.

- There is uncertainty in the characterization of source aerosols in climate modelling. It is very difficult to have an idea what net effect on climate could be from cookstoves versus road diesel emissions unless region has particular features, such as ice and snow.
- CO_2 effects of biomass burning on climate are indirect, as unsustainable harvest of renewable fuels means moving carbon from forests and putting it into the air. Preventing deforestation has clear climate benefits over the long term. Renewable minigrid systems for electricity are a fairly ideal solution to health and climate issues. Converting from biomass to LPG may be beneficial, even though that uses fossilized carbon and produces CO_2 and methane emissions, as energy density and efficiency of LPG are much greater. LPG is also a side product of petroleum production that can be sold instead of flaring it, reducing climate impact; however, huge price fluctuations cause problems for the impoverished that may result in negative impacts in a wider analysis of wellbeing.
- Biofuel burning emissions of $PM_{2.5}$ and BC are a huge driver of health impacts, even with uncertainty, as they dominate the concentration-response functions. There are multiple benefits of clean air, and various interventions to improve the exposures. Emissions from cookstoves are usually more important than those from biomass burned for lighting.
- Monetizing the various impacts of solid fuel combustion is one means of putting impacts all on the same scale and calculating the total social cost, including all pollutants. Many pollutants cause net damages, including sulfur (a negative climate forcer), due to health impacts. Air quality impacts are the costliest due to the cost of the health impacts. Overlap between climate and health impacts is important, but the health impacts of air quality are a big motivation to curb climate damage. Within a country, monetization may break the ties that result when there are climate and health tradeoffs.
- How to decide what to do where? Need to know all the direct emissions, and we need to evaluate indirect emissions. While $PM_{2.5}$ reductions are good for health, ideal to maximize benefit when comparing stove options (e.g. reduce BC). Health impacts are relatively short-term impacts, but climate impacts are longer term.
- Clean cookstove programs were previously viewed as a tradeoff between local and global benefits, but regional medium term climate effects are a fairly new concern for climate mitigation. This may change policymaking and decision-making, as a lot of things that we think about are like power plants where we accept a potentially worse climate picture to get health benefits, resulting in a net positive benefit. However, we need local health benefits to motivate change, such that actions create benefits for those taking action. The danger with local and regional focus is that CO_2 reduction motivations are lost, since those are global.

Aerosol emissions from cookstove biofuel combustion: measurement, characteristics, and uncertainties - Andrew Grieshop, North Carolina State University

Dr. Grieshop explained many of the issues related to measuring emissions from various cookstove designs in the field and in the laboratory, including what pollutants are emitted by combustion and how they are measured. He further discussed the reasons why laboratory evaluations of emissions from burning solid fuel in cookstoves can vary widely and vary from field use measurements, and how the processes affecting emissions contribute to our assessment of impacts and co-benefits from clean cookstove implementation programs.

Key issues raised:

- A fire is a complex chemical reactor. Heating with a lack of oxygen (pyrolysis) forms organic carbon if heating stops. Prolonged heating with oxygen results in OC turning to soot, which is rich in BC/EC. Only a tiny fraction of burned biomass ends up as particulate, but carbonaceous materials dominate PM from cookstoves.
- Measurements may be made through optical or chemical methods. Thermochemical methods measure EC, OC, refractory organics (may or may not be brown carbon), while optical methods measure BC, colored organics (brown carbon), and colorless organics (OC). BC and EC are comparable, but not exactly the same as they are measured differently. Optical measurements are made using such equipment as a photo acoustic extinctometer, aethalometer, or reflectometer. Some are very old technologies and thus can be used in developing areas to measure "black smoke". Thermo-optical methods burn off different types of carbon at different temperatures and oxygen levels. EC, OC and other thermochemically measured species are thus operationally defined.
- Comparing rocket stoves versus traditional stoves produces mixed results for PM emissions. In a recent trial, there was a seasonal shift in control groups due to Monsoon season. Rocket stoves emitted slightly less PM overall, but there was a tighter distribution of values and higher emissions than in the lab tests. Non-adoption or partial adoptions of stoves occurred (known as "stove stacking"). EC emissions from the rocket stoves were higher than with the traditional fires, and the ratio of EC to total carbon (TC) went up. There were distinct patterns of emissions of PM based on how the stoves were operated.
- Field and laboratory measurements of emissions don't agree – so what can we do? It is difficult, but researchers are trying to recreate the way stoves are operated in the field in the laboratory testing protocols. It is possible to make a firepower histogram of activity, which is a fingerprint of how a stove is operated in a field setting. Emissions differences between the field and laboratory tests often result from different use patterns: unimodal heating patterns used in laboratories, without much low power smoldering activity, do not replicate field use conditions. The new goal is to recreate the firepower x time histogram from the field. Emissions factors measured in the laboratory now match a bit better with field measurements, and produce a good match with EC emissions.
- Take home points: Burning biomass is complicated, laboratory tests need to represent field use conditions, and it is difficult to duplicate local fuels.
- Organic aerosols are highly dynamic. Aging wood smoke can rapidly generate large amounts of new organic aerosol in aging chamber (which has also been observed in field). This needs to be integrated into models, as the EC/OC ratio changes and this influences the amount of PM.
- A big challenge for modeling with cookstoves is estimating how changing or removing a source changes atmospheric air pollutant levels, such as secondary organic aerosols (SOAs) and other effects changing downwind when stove emissions change. With SOAs, there is so much sulfur

from China that US is affected, making the impact of cookstoves and changes in cookstove emissions impossible to track. Recreating aging is difficult, but wildfire research shows that plumes have different characteristics as secondary pollutants form.

- There are some big questions about the environmental chemistry of biomass smoke, as bottom up models don't match measured levels and the differences result in the use of "fudge factors" when the models are evaluated against measurements. Some of newer on-line mass spectrometer techniques can devolve it, but attributing secondary pollutants to sources is difficult. The lack of reliable inventories for the sources, including small scale industries in households that we know nothing about, complicates the problem. We also know next to nothing about alternate or seasonal biomass fuels such as crop residue and dung use.

Part II Discussion -- Chris Wiedinmyer and Shu Tao, moderators

There are uncertainties in how we measure, what we measure, and what it means for health impact and climate. Air quality experts look at emission inventories and scale up, but this does not provide a complete understanding of all the components of the emission and exposure picture at all levels of estimation. What can be done about these uncertainties?

The placement of exposure monitors results in uncertainty in estimates of personal exposure. Referring to the figure, we see the effect of exposure patterns. Hatched bars are exposure for steady state monitoring far from fire, while the added bars are for personal exposure measurements. Women between 15 and 50 years old have exposure levels that are 80% underrepresented by room air samples. Unless we perform detailed monitoring or chemical modeling when switching from traditional to more advanced cookstoves, the broader policy message can be confused. Details complicate full dimension of the problem.

What does uncertainty in the estimation of exposure mean for the estimation of attributed health impacts?

The exposure-response curve for $PM_{2.5}$ and acute lower respiratory infections (ALRI) in children has been built from data available from various sources, including household air pollution, ambient air pollution, and smoking. Studies of stove exposure measured 50-600 $\mu g/m^3$ in a trial in Guatemala, but that was only one study in one location. There are currently three Alliance-funded clean cooking and child survival studies ongoing in Ghana, Nepal, and Nigeria with a variety of stove types. We want to know where these new risk estimates will fall, and will they match current curve or will they change it. We have exposure-response curves for other health outcomes and $PM_{2.5}$, but don't have these additional studies.

Exposure variability can matter a great deal, particularly over the important time period relevant for a given health effect of interest. ALRI is a short-term effect and can be related to short term exposures for children. Uncertainty magnifies hugely with 50 year exposure averages, and long term exposure estimates relevant to cardiovascular outcomes and chronic obstructive pulmonary disease (COPD) are often not available or not easily reconstructed. Even with short-term health outcomes, we need more than one measurement to assign exposure - we need repeated measures over seasons, and the current trials do involve repeated 48- to 72-hour measures, in multiple seasons, some over multiple years. Even so, repeated measures can be used to estimate long term averages, even if each measurement is made over a short time.

In impact estimation, assumptions are made about exposure distributions and confidence bands based on formal uncertainty analysis, but those assumptions may be incorrect. Improving exposure estimation has benefits, but if the shape of the risk function is really unknown and there isn't a lot of data, the risk estimates can be wildly off even when complex fitting is done.

What are the effects of changes that happen seasonally and regionally with biomass burning, such as where cooking takes place, what fuels are burned, and how they are burned?

There are seasonal variations in pollutant concentrations measured in kitchens, which are due to differences in meteorological conditions (stagnation events, temperature, etc.). In some areas, the entire source to endpoint relationship changes. All these things contribute to uncertainty, which is why log scales are used for the validation of regional air quality models - this looks good, but predictions and measurements may be off by a factor of 2 to 5. The degree to which uncertainty dominates depends on where the measurements are on the curve, what region is being studied, and other factors. Modeling uncertainty is also more dominant than measurement uncertainty. The larger problem is limited resources: researchers need enough evidence to say that they have observed something, but if you don't do it right first time, you don't get second chance.

What will it take to get to a level of uncertainty in exposure measurements or exposure estimates that we can be comfortable with?

There are pretty good $PM_{2.5}$ networks in urban areas of East Asia and China, which means that predictions in those areas will not be wildly different from reality. Model estimates that reproduce observations within 30% is pretty good compared to uncertainties in the risk functions. In rural areas, monitoring coverage is not as good even though some villages can have higher levels of pollutants than Beijing. Predicting ambient measurements is, however, a very different issue than estimating personal and household exposures.

Estimates help make a compelling case to present to health ministries and other key collaborators, but there is a need to demonstrate that programs are providing solutions with actual health benefits. If we can demonstrate that we have technologies that improve one child health outcome, then we can move to establishing the additional benefits for adults. In Kenya, pre and post-intervention monitoring was done in the field, and exposure reductions correlated with a 50% drop in ALRI, which was sufficient evidence for the Kenya Ministry of Health to move forward with the intervention. However, those proposing programs need to be up front about whether they believe there is a one in two chance of improving exposure and health outcomes versus a one in ten chance.

There are a number of important gaps in data regarding stove programs and health outcomes. There are important health outcomes for which we have no studies with quantitative air pollution measurements. We also have studies with qualitative questionnaire data that compare types of fuels used and see a gradation in health outcomes and symptom questionnaire data, but don't have any quantitative estimates of different pollutants (although these quantitative estimates may not be necessary to make a case for intervention). We have some idea of what technologies improve exposures, but we also do not know how clean is clean, as the exposure response curves at the low end of the exposure range are only now being studied for $PM_{2.5}$. What is required here is global measures of exposure – which means pooling data (which is being done) and making the kind of estimates being made for India for the rest of the world. At the high end of the exposure range, there are data regarding stove type and fuel type and indoor/outdoor cooking data in some areas, but we don't have a good idea what goes on in large areas of the world. There is a need to capture data sources such as national census data, data on the use of agricultural residue and dung and what sorts of pesticides they may contain, and how many people cook indoors versus outdoors on a seasonal basis. China has put together some data, but it is highly uncertain as it is based on harvest and production figures and estimates based on other estimates, but not on specific data. Not much is known about different activity and emission factors for different fuel, stove, and cooking practices, and there are orders of magnitude of uncertainty at each step when estimating exposures for large populations across vast areas. There is a need to identify where the most uncertainty comes from at each step and reduce this uncertainty.

Looking at exposure versus health outcomes is one concern. What about uncertainty in modeled and measured pollutant levels and projected climate impacts?

There are observational constraints when it comes to measurement of organics, secondary aerosols, aerosol behavior, vertical column effects and the like that propagate net uncertainty. Improving accuracy means doing perturbation experiments at each step, and that isn't something that we can do mathematically. Climate models do, however, use much larger grids than ground-level exposure models for human health surveys. Need high spatial resolution to do health surveys – one cell that covers the entirety of Beijing is not good enough. While large grids estimating concentrations from satellite data in the United States do underestimate population variations, they do eventually tend toward providing full converge; however, we don't gain much additional climate impact information at smaller scales.

How does uncertainty in pollution estimates affect the larger picture of the net benefits and impacts of changes to cleaner cookstoves and fuels? What factors complicate understanding and affect implementation efforts?

Before measuring or modeling, it is important to define the objective of the analysis and consider various approaches. Uncertainty and variability are not the same: high variability is difficult to establish, but is usually far larger than measurement error. If the purpose of the analysis is a social analysis of the entire impact of the pollution or the intervention, then aggregation is appropriate. For the impact on individual households, no aggregation is needed. Also, how much precision is necessary? Sometimes the estimates only need to be good enough to motivate policymakers.

Do we have the risk profile we need to demonstrate that there is a problem? If so, do we have solutions to mitigate risks? What are the options? The roller coaster where interventions are implemented and then don't work and then the next intervention to come along is tried, etc., can prevent momentum in eventually implementing solutions that will work. While it is great to precisely demonstrate the problem, what does "uncertainty" mean for how we act?

Well-functioning chimney stoves can be a good technology option for biomass in some settings, but then there are the considerations of the emissions generated outside, creating ambient air pollution. Health impact analyses have to consider the availability of stove technologies, fuel, fluctuations in fuel costs, subsidies, etc. as these all impact the cost-benefit analysis and vary geographically.

In studies of the impact of biomass burning on health, stove programs often are not producing the reductions in pollutant concentrations that we need to reach the WHO air quality guidelines. Toward that end, interventions are moving toward clean fuels (pellets, LPG, ethanol, biogas, charcoal in chimney stoves). Exposure curves show that clean fuels have the potential to meet appropriate health impact reductions. This conversation is different for reaching climate goals, but for health we want best available options. Sometimes, the structure of the air quality intervention has impacts at different levels, such as in China, where provinces may be told to reduce coal consumption without being told how. The simplest way is to reduce availability of coal for household heating and cooking, but that is very expensive compared to shutting down generating stations. China replaced coal in Beijing households by providing financial incentives.

Given these difficulties, how can we get beyond the uncertainties in studying the health and climate impacts of cookstove implementation programs to improve biomass-burning related air quality issues on a global scale?

When we see things like the RESPIRE study or other studies demonstrate clear unambiguous health benefits without even evaluating the climate benefits, that will be a winner. This is a place where producing a well written op-ed would really help. This group could also produce a consensus statement of brief position paper. A World Bank led BC study group is already recommending that climate and health scientists need to form a consensus with financiers to create a document that has actual credibility and meaning from health/climate science perspective that bankers and policy makers can understand. The consensus statement from Our Common Future in Paris left out the impacts of household biomass burning, but it would be great to use language that fits in to that framework.

Part III: Policy-relevant approaches – Bryan Bloomer, moderator

Estimating the contribution of household to ambient air pollution, Part I: Modeled Approach - Sarath Guttikunda, Urban Emissions

Dr. Guttikunda explained that household air pollution is an important contributor to ambient air pollution, but its impacts are often underestimated due to a lack of understanding by the energy and emissions communities. While global inventories such as GAINS are important, they can lack important spatial resolution required to estimate impacts at local and regional levels. He then described his work in assembling national scale inventories on biomass burning in India from various sources of data (such as on-ground surveys and India specific surveys on efficiency of different fuels and households) and how these will be used in the future to estimate urban and rural air pollution variations resulting from cooking, water heating, space heating, and lighting at the district level.

Key issues raised:

- Urban inventories of ground-based emissions in South Delhi show that biomass burning emissions ($PM_{2.5}$) are largely residential, show substantial variation, and result primarily from stoves in residential use. In cities in India, vehicular emissions of PM are quite high, but up to 10% comes from indoor/household.
- Researchers set up a domain with 25km resolution grids and the 640 administrative districts using 2011 census codes. Grids were tagged according to their urban and rural status. Census data from 2011 provided the share of household fuel use by category for firewood, crop residue, cow dung, coal/charcoal, kerosene, LPG, biogas, electrical and other, as well as whether people cooked inside, outside, or didn't cook. Population was estimated at the grid level, and GIS techniques were used to estimate useful energy per year (mean energy use per capita for districts, by rural and urban based on cooking patterns and fuels), share of fuels used inside/outside and in rural or urban areas, heat efficiency, and other key factors.
- Of the total energy used for cooking, wood is 66%, and crop residue and dung were 11% each, and that cooking patterns in some areas shift by season (e.g. less wood burning, more crop residue during harvest time). Heating fuel use estimates varied with altitude, latitude, and meteorology. There were distinct patterns at aggregate levels based on the expected need for warmth, and space and water heating were also dependent on season and on population classes – including outdoor workers in cold times using portable heaters, and the custom of children and elderly bathing in warm water. Fuel use for lighting differed by area according to fuel class and region. Strong urban and rural gradients also exist – rural skews to cooking, urban to heating.
- Dispersion modeling of pollutant emissions based on this inventory is the next research step. Overall, the gridded estimates fuel use totals for all household energy uses indicate that emissions are likely to be highly seasonally dependent, particularly in Northern India. As this inventory focuses on ambient emissions, individual and household estimates cannot be

calculated. Modeling should also consider the latest rounds of field tests which find that emission factors that are substantially higher in field than in the laboratory.

Estimating the contribution of household to ambient air pollution, Part II: Measured Approach - Zohir Chowdhury, University of California at San Diego

Dr. Chowdhury described his efforts to measure the $PM_{2.5}$ emissions from biomass cookstoves, analyze the chemical makeup of those particulate emissions, and then use that data for source apportionment to determine the contribution of cookstove emissions in ambient air pollution samples. Source profiles were constructed for emissions from burning of several different fuel types, including biomass fuels and coal from India, China, and Bangladesh.

Key issues raised:

- Methods included ambient monitoring of $PM_{2.5}$, source emission testing, and chemical analysis. There are two popular methods of source apportionment modeling to establish source-ambient relationships: chemical mass balance with positive matrix factorization, and organic tracer techniques. This exploration involved measuring $PM_{2.5}$ mass and then using chromatography to assay the particulate for soluble ions, thermal-optical carbon analysis for EC and OC, and x-ray fluorescence for trace elements.
- Stove experiments used coals from China, India, and Bangladesh, along with samples of locally important biofuels, such as rice straw, dung patties, jackfruit wood, coconut branches, and synthetic rice husk fuels from Bangladesh. He measured a suite of emissions known to be associated with biofuels (levoglucosan, manosan, galactosan), and also noted high chlorine and potassium in emissions from cow dung and coconut leaves. Potassium and Chlorine have been measured in ambient air pollution in slums in Bangladesh where biomass burning is common. Stigmasterol is also a marker for animal dung burning, with picene a marker for coal burning and cholesterols for cooking of meat. Source profiles like these already exist for diesel, gasoline, road dust, fuel oil, and coal burning.
- Source apportionment modeling, which ties ambient samples to source characteristics, has demonstrated that household biomass burning contributes 10-30% of total $PM_{2.5}$ emissions in Delhi, and Health Effects Institute Special Report 18 estimated that biomass from household sector was responsible for as much as 30% of the total $PM_{2.5}$ in South Asia. There is newer work being done with source apportionment in Africa in Cameroon and Benin. That work is currently focused on getting data for baseline in West Africa in the dry season when ambient air pollution is high.
- Source apportionments can vary substantially on a regional basis, particularly for EC, OC, and other carbonaceous compounds, where proportions vary with size of particulate being considered (EC is less than 10% of PM, OC is as high as 50% of $PM_{2.5}$; Ratio of $PM_{2.5}$ to coarse particulate matter (PM_{10}) is about 0.6-0.7). A further limitation of this work is that coal is mined in a variety of places in India and China, so one set of coal samples may not produce broadly representative emissions. Another source of uncertainty in source apportionment is that, in

areas where field burning is a part of agriculture, it is difficult to distinguish from household biomass burning through source apportionment as the markers are similar. This particular investigation did not explore the effects of atmospheric aging of biomass and coal burning pollutants and only used samples taken during a single season.

Results based financing for clean cooking - Lisa Rosen, Gold Standard Foundation

Dr. Rosen introduced the Gold Standard Foundation (GSF), explaining their history and role in certifying projects for carbon credit/offset programs, outlining recent changes to their organization and its methods, and then providing an overview of their health-directed methodology for evaluating programs intended to reduce emissions of BC.

Key issues raised:

- The GSF started as the World Wildlife Fund's carbon market organization, and was established as a nonprofit to certify carbon reduction projects in 2005. GSF then became the standard certifiers for carbon projects for the United Nations (UN). Their focus is on projects with global impacts, but with local sustainable impacts on the ground. Assessment features include sustainability assessments, a do no harm assessment, stakeholder consultation guidelines, sustainable development matrix, and a sustainability monitoring plan. Their certification process is public and transparent.
- According to the Global Burden of Disease project, solid fuel burning in cookstoves results in 4.3 million premature deaths annually and BC emissions are responsible for nearly 20% of global warming. As the science on BC exposure and health effects has improved, GSF has launched certification project.
- The first version of the BC methodology was intended to supplement their existing cookstove program evaluation methodology, as they did not want to add administrative burden, and provides a mechanism to quantify and monitor emissions reductions of black carbon and other climate pollutants (BC, CO, NO_x, non-methane volatile organic compounds (NMVOCs), Sulfates) achieved by clean cookstove projects.
- This certification gives investors some added transparency around what they are funding and what co-benefits are also accruing from a project funded for carbon credit. For example, one analysis of a cookstove project showed that there was a $151 per carbon credit returned in co-benefits, mostly improved health.

Cookstove technology switches: a metric for decision-making – Ilissa Ocko, Environmental Defense Fund

Dr. Ocko explained that the science of black carbon as both a cause of health effects and as a positive climate forcer is growing, and that new understanding underlies changes in climate and health policy. She then described her work to adapt an EDF-designed modeling system designed for evaluating climate warming potential tradeoffs (Technology Warming Potential) in switching from coal to natural gas (Alvarez, 2012)[1] in order to evaluate tradeoffs in switching between different stove designs and fuels.

Key issues raised:

- Technology Warming Potential (TWP) is a way to compare two technologies to one another to evaluate their relative climate benefits and explore sensitivities to uncertainties in parameters and inputs. It is the ratio of net radiative forcing of alternative technologies compared to original as a function of time. A TWP<1 implies that the alternative technology improves the climate forcing picture.
- For cookstoves, a three-stone wood burning fire was considered as the baseline when comparing different stove types and fuels. The simulations also evaluated sensitivity scenarios focusing on gas versus aerosols, gas only, and only the positive forcer emissions.
- The results showed that TWPs in all cookstove change scenarios were less than one. Looking at gas emissions only changed the ranking, omitting OC from picture shifted the time curves, and incorporating calculations based on sustainable harvest of wood did not matter. She is still analyzing data for fuel switches, and did not use an International Organization for Standardization (ISO) tiered stove analysis due to uncertainties. The model was sensitive to BC/OC ratio, with high OC emitting stoves meaning that climate benefits lost if OC reduced but not BC. If the BC/OC ratio is low for the baseline stove, then the stove switch doesn't help climate (but still may have significant health benefits).
- Takeaway: not all improved stoves are improved for climate; it is important to include all emitted species, particularly absorbing and scattering aerosols; and radiative efficiency uncertainties don't change TWP results unless the initial BC/OC ratio is low.

OVERALL DISCUSSON

Donee Alexander, the Alliance and Nick Lam, University of Illinois, moderators
Priority pollutants for climate and health

Measurement of CO concentrations is inexpensive and relatively easy to accomplish in the field. However, with few exceptions, measuring CO is not as important for health outcome studies as measurement of PM. The epidemiologic literature associating $PM_{2.5}$ in particular with cardiovascular disease outcomes is substantial and strong. While there are studies associating CO and cardiovascular disease outcomes in the literature, older studies may be confounded by the lack of $PM_{2.5}$ measurement and others demonstrate weaker associations than those found for the $PM_{2.5}$ in the exposure source. Measuring CO is not a substitute or proxy for measuring $PM_{2.5}$, as the most significant health outcomes are driven by $PM_{2.5}$ exposure independent of CO exposure. However, in birth outcome studies, it is desirable to measure both CO and PM, as they both may have important effects. While high CO levels are not typically recorded in households with wood burning stoves, levels of CO measured in households

[1] Alvarez et al. 2012. Greater Focus Needed on Methane Leakage from Natural Gas Infrastructure. Rep. Proceedings of the National Academy of Sciences of the United States of America PNAS, Proceedings of the National Academy of Sciences.

using indoor charcoal burning stoves may be quite high and well above the WHO guidelines, as seen in some African studies.

BC is important for climate, as it is a measurement of light absorbance by particulate, and measuring OC is desirable as well. Measuring EC is roughly equivalent to measuring BC in terms of estimating climate forcing potential. There is a growing body of evidence linking both BC and/or EC with important cardiovascular health outcomes, but scientific consensus has yet to be reached on the importance of measuring BC or EC versus the importance of measuring $PM_{2.5}$. Measuring BC is more cost-effective and accessible than measuring EC if $PM_{2.5}$ samples are being collected, as the measurement of EC requires pre-baked, quartz filters and more expensive analysis methods. BC measurement does tend to vary by instrument, so there is some room for standardization between devices. It is possible to take co-located samples to correlate BC and EC, but those correlations tend to be study or site specific.

Measuring PAHs may be important for health studies and useful for characterizing combustion conditions, but it is expensive. Detailed analysis of a small set of samples for PAH could be important, as it desirable to verify that a stove switch does not raise PAH emissions. Instruments exist for continuous measurement of PAH, but they sample the particle phase only and gaseous PAH inhalation may be an important route of exposure for women using cookstoves.

Measurement program considerations

The purpose, size, and type of stove program or study should dictate how and when measurements are made and what pollutants are measured. For health evaluation purposes, PM and BC are the most important pollutants to measure, and BC is important for climate evaluation. Pollutant measurement resources and expertise are often very limited in small organizations and small stove programs and health studies, but many can manage to collect a small number of outdoor ambient samples to evaluate ambient air quality and potential climate impacts.

Personal and household measurement of pollutants is important for studying health in stove programs, but not for climate research. However, researchers should also measure the ambient background levels of pollutants of interest in order to establish community background conditions.

Understanding the transfer of pollutants from the cooking environment to the ambient environment is important for estimating climate impacts from stove programs. This not only requires measurement of such factors as humidity and temperature, but also ventilation rates for the home if cooking takes place indoors. Some studies, such as one in Nepal, have used continuous measuring equipment to measure tracer pollutants in order to estimate the transfer of cookstove emissions to the outdoor environment; however, such studies generate enormous quantities of data that may be difficult and expensive to analyze. Some organizations have constructed regional models of stove use impacts using housing, fuel, and fuel use characteristics, but these models cannot be directly applied for other regions due to differences in climate and housing features. For many factors that relate stove use to climate change, modeled estimates of pollutant impact are locally or regionally dependent, meaning that different models need to be constructed and validated for each distinct area.

Programmatic Considerations

Small NGOs will likely need to collaborate with exposure assessment experts to assess stove adoption, intensity of usage, and/or monitoring. This could be promoted through auditing guidelines that require that specific expertise be available or that consultants be hired. Stove use monitoring, which is cheaper and less complicated than pollutant monitoring, could also benefit from a set of guidelines for sampling and data collection. Following a set of such guidelines could be a way for small organizations to avoid hiring experts, although field experience indicates that many groups need assistance analyzing data.

There are some new tools and technologies which could be used to simplify sampling and analysis, but there may be more need for study planning input rather than for guidance documents. Field standards are under development as part of the ISO standards development process, but these may not cover small programs. Overall, there is a need for minimum thresholds and guidance on sampling/monitoring and more accessible technology to improve deployment. Creating a registry of data from small programs accessible to researchers might help solve the analysis issues and allow for aggregation of data.

The overall cost of monitoring needs to be considered if the specifications are to be realistic. We need to let programs know how much expect to spend on monitoring and provide some guidance for budgeting. If we develop a methodology, it needs to be simple, easy to deploy in terms of technological and human resources, and yet provide sufficient baseline data to be worthwhile. However, the stove program community appears to have moved away from the "everyone do everything" approach toward a "do what you do best and ask for help" approach. It may thus be best to have existing research and technical groups help NGOs with monitoring.

Long- and Short-term Climate and Health Impacts

Carbon markets and funding organizations split global climate into "climate stabilization" benefits and "near term climate" benefits. This requires measuring or estimating the entire causal chain from fuel to combustion to emissions to dispersion to ventilation. Health outcomes and impacts can and should be included in these valuations, and can be added to the methodological process at each stage when establishing certification for needs of financial markets, providing a menu of additional benefits that people can value. Ultimately, however, the real challenge of doing long term studies and interventions is in validating that programs worked. The results of many cookstove intervention programs are written up far too early to fully evaluate permanent changes in health outcomes and climate benefits.

NEXT STEPS

- A subgroup of volunteers will draft an op-ed or position paper ahead of the 21st session of the Conference of the Parties to the United Nations Framework Convention on Climate Change in December 2015, making the case that there is an ongoing partnership between cookstove, health, and energy groups, and emphasizing how the connections between household energy use and climate stabilization make cookstove programs a priority for global scale-up.
- $PM_{2.5}$, BC, and CO are priority pollutants associated with health effects, and BC is a pollutant associated with climate impacts. Therefore, it may be desirable to promote BC reductions as a driver for cookstove changes, as they affect both climate and health outcomes.

- There is a need to draft guidelines for evaluating cookstove programs. Convening a group of experts to craft a consensus position on key measurements and indictors would be desirable. However, any such group would need to include input from people familiar with stove program implementation folks in order to ensure feasibility in the field and fully understand the costs of evaluation.
- There are co-benefits resulting from cookstove programs beyond climate and burden of disease that should be both enumerated and emphasized. These include livelihood improvements, social impacts (including gender), reductions in co-pollutants (ozone damage to crops), among others. There is a need to establish an analytic framework to evaluate projects along these axes, while maintaining a level of evidence to support cookstove programs as public health interventions.
- Most climate and health evaluations could be promoted and implemented as national priorities, even though climate and health are often the responsibilities of separate agencies. It is relatively simple and feasible to create national rankings using available data where climate and health intersect with cookstove usage.

TABLE OF ACRONYMS

AAP	ambient air pollution
ALRI	acute lower respiratory infection
BC	black carbon
CH_4	methane
CO	carbon monoxide
CO_2	carbon dioxide
COPD	chronic obstructive pulmonary disease
DDT	dichlorodiphenyltrichloroethane
DNA	deoxyribonucleic acid
EC	elemental carbon
EDF	Environmental Defense Fund
GHG	greenhouse gases
GSF	Gold Standard Foundation
HAP	household air pollution
IARC	International Agency for Research on Cancer
ISO	International Standards Organization
LPG	liquefied petroleum gas
NMVOC	non-methane volatile organic compounds
NO	nitrogen oxide
NO_x	oxides of nitrogen
NO_2	nitrogen dioxide
OC	organic carbon
PAH	polycyclic aromatic hydrocarbons
PM	particulate matter
PM_1	particulate matter less than 1μm in aerodynamic diameter
$PM_{2.5}$	particulate matter less than 2.5μm in aerodynamic diameter
PM_{10}	particulate matter less than 10μm in aerodynamic diameter
SOA	secondary organic aerosols
SPARTAN	Surface PARTiculate mAtter Network
TC	total carbon
TWP	Technology Warming Potential
UN	United Nations
USEPA	United States Environmental Protection Agency
WHO	World Health Organization