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An Expert Survey on the Material Types used to Start Cookstoves

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Abstract

Household air pollution generated using solid-fuel cookstoves is a leading risk factor for morbidity and mortality worldwide. Many studies have quantified cookstove emissions with respect to the main fuels used (e.g., wood, charcoal and other biomass fuels). Anecdotal evidence suggests a variety of fuels are used to ignite cookstoves, however quantitative information on startup fuel types is lacking. Emissions from startup materials contribute to household air pollution. As such, understanding startup practices and the choices of startup materials is integral to understanding the full burden of household air pollution from cookstoves on health and the environment. We conducted an expert elicitation style survey to gather information about startup practices worldwide. Twenty-three respondents from academic and private sectors responded to a survey instrument on cookstove startup, providing information that covered 48 geographic locations across 22 countries. Responses to the open-ended questions were analyzed to quantify how startup materials vary according to factors such as location, seasonality, and the main cooking fuel/stove type. A wide variety of materials were reportedly used to ignite cookstoves, including many non-biomass materials that may have toxic combustion byproducts. Paper, plastic, agricultural wastes, waxes and other petroleum fuels (e.g., kerosene), and rubber-like materials (e.g., tires, footwear) were the most commonly indicated startup materials. Additional materials mentioned included fabrics, plastic packaging, soda bottles, snack food wrappers, and trash. Results from this survey can be used to direct future research on the impacts of startup materials on health and the environment, such as justifying the choice of materials to test in the laboratory.

Keywords

cookstoves; fuel; startup material; household air pollution

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1. Introduction/Background

Approximately 2.8 billion people – around 40% of the world's population – use solid fuel as their primary source of domestic energy (Bonjour et al. 2013). Solid fuels are often burned in inefficient and poorly ventilated cookstove systems (Bonjour et al. 2013). Cookstove emissions contribute to indoor and outdoor air pollution that impacts human health and the environment (GBD 2016 Risk Factors Collaborators 2017; IPCC 2014). However, the estimated health and environmental impacts of cookstove emissions are highly uncertain. Thus, work is needed to better understand the practices that lead to cookstove emissions and to quantify the complex mixture of emissions that results.

One potentially important factor for understanding cookstoves emissions and subsequent health impacts is the stove ignition or 'startup' process. During cookstove startup, a fast-burning fuel is often used to ignite the main fuel. Startup could be particularly important for human health, as the cookstove user is often very close to the stove during the startup phase, which might result in high personal exposures. A few laboratory studies have demonstrated that the startup phase contributes substantially to overall emissions, though the contribution can depend on the startup fuel type, method of igniting, and main fuel (e.g. Arora et al. 2014; Bhattacharya et al. 2002; Carter et al. 2014; Lask and Gadgil 2017; Wathore et al. 2017). The pollutant profiles from burning startup materials may be different from that of the main cooking fuels as the composition of these fuels is often different; yet, studies have not isolated the startup fuel emissions from the main cooking fuel emissions. Further, laboratory cookstove studies that attempt to quantify emissions have generally been limited to the use of cleanly-milled wooden shims or kerosene for startup. Yet, anecdotal evidence suggests that a variety of fuels such as plastic bags, agricultural and consumer product waste, and rubber tires are often used to ignite stoves. Although the primary solid-fuel types used worldwide have been documented (OECD/IEA 2006), information on the types and prevalence of startup materials is currently lacking. It is difficult to understand how startup practices contribute to overall cookstove emissions, air pollution, and health – and therefore how modifications to startup practices could reduce pollution and improve health – without first knowing what types of materials are used for cookstove startup. To systematically gather this information first-hand would be a major undertaking because cookstove use occurs across diverse, often rural regions in predominantly low and middle-income countries.

We designed and implemented a survey to collect information about fuel types used to start cookstoves globally. The primary purpose of our survey was to create a list of material types used as startup fuels. Our survey incorporated methods for respondent selection and question style used in expert elicitation. Expert elicitation is a structured method for gathering and synthesizing knowledge in the form of technical, yet subjective judgments from subject-matter experts on questions that have qualitative uncertainty (Cooke 1991; US EPA-SAB 2010). The use of experts as survey respondents can be a useful starting point for gaining insight into areas with limited existing research (Knol et al. 2010). Our survey targeted individuals who work in cookstove development, dissemination, and evaluation, and had spent time working with cookstove users in various communities. We targeted experts rather than cookstove end-users because it allowed us to gather reputable information on a wide

range of locations, communities, and cooking practices in quick and more cost- and resource-effective way. We asked respondents a series of open-response questions to gather information on the types of cookstove startup materials used in areas of the world where they had expertise.

2. Methods

2.1 Survey Development and Content

The online survey was developed using an iterative process of question design, review, and testing. Five individuals currently involved in cookstove research tested the survey to provide feedback on content and clarity; these individuals were not included as respondents in the final survey. The survey was determined to be exempt from the requirements of the human subjects research protections by the Colorado State University Institutional Review Board.

Respondents were asked to identify up to three geographic locations of expertise and provide information about the cookstove technologies they have encountered in those regions. The number of locations was limited to three to control the length of the survey; respondents who had experience in more than three locations were instructed to choose the three where they felt they had the most experience. Additionally, respondents were allowed to define their geographic area(s) of expertise as they saw fit and the response was open-ended (i.e., respondents filled in a blank space rather than selecting from pre-determined options) to allow respondents to be as specific or broad as they felt was justified based on similarities in startup practices across the location. For example, respondents could choose to define a location as specifically as a single community or as broadly as an entire country or world region. For each location, respondents identified the following: the two most commonly used stove types in the area, the main cooking fuel types associated with these stoves, and the two materials most commonly used to start these specific stoves (limited to two for survey length purposes). Additionally, participants were asked to list all other materials they were aware are used as startup materials in the location, whether commonly or uncommonly used and regardless of the stove type or main cooking fuel type with which it is used. Responses for stove types and fuel types (main and startup) were open-ended. This approach allowed the respondent to describe the stoves and fuels using their own terms, rather than limiting them to a predetermined list provided by the researchers. Additionally, respondents were asked whether the use of different startup materials in this location varied depending on factors such as season, availability of fuel types, or other considerations (semi-structured response). Finally, respondents were asked if they had ever collected data on the use of startup materials in the location, and if so, whether they looked at that data to inform their responses or not (respondents were not instructed prior to the survey to look at data or not). After providing information specific to up to three locations, respondents were asked, “in all locations that you have lived or worked, what is the most unique or surprising material you’ve seen used as a startup fuel?” Lastly, respondents answered questions about their years of work experience, their work sector, and their current workplace affiliation. The survey was anonymous as respondents did not provide their name or contact information. The survey is provided in the supplemental material.

2.2 Respondent Identification

While no guidelines currently exist, current recommendations suggest that more than six experts are needed for robust results in expert elicitation style surveys; after inclusion of about 12 experts, the benefit of each additional expert opinion begins to taper as each new respondent does little to change the overarching trends represented by previous respondents (Knol et al. 2010). We therefore aimed to include at least 10 respondents in our survey. We identified potential respondents based on the authors' knowledge of their current involvement and work in cookstove research, development, and dissemination. The final list of targeted respondents was determined with input from professional colleagues who have extensive experience in the cookstoves field. Several targeted respondents were identified through their involvement with various cookstove-related committees (e.g., International Standard Organization Technical Committee 285: Clean Cookstoves and Clean Cooking Solutions), working groups (e.g., Global Alliance for Clean Cookstoves Working Group on Technology and Fuels), and meetings (e.g., annual Engineers in Technical and Humanitarian Opportunities of Service Cookstove Conference). We sought respondents who represented a geographical spread of expertise as well as a range of experience including policy, stove design/testing, exposure/emissions assessment, and health. We also targeted representation from individuals with location-specific knowledge (i.e., individuals with field projects in specific locations), and general knowledge (i.e., individuals who perform non-location specific laboratory work and/or are involved in global policy). We avoided contacting multiple respondents who worked for the same organization or on the same research projects; however, we allowed respondents to share the recruitment email and survey web-link with colleagues. Individuals were contacted between December 15, 2015 and January 15, 2016. The survey remained open for responses until February 15, 2016.

2.3 Analysis

Two individuals (KF, EW) independently coded the response data. The primary coder (KF) developed a coding structure that allowed responses to be categorized and grouped; the secondary coder (EW) applied this structure to the data but also provided suggestions for improvements to the structure in an iterative process. Coding was compared and discrepancies were reconciled by the primary coder.

The primary goal of coding responses to the open-ended survey questions was to identify each time a startup material was mentioned, paired with details about the use of the startup material such as location, stove type, and main cooking fuel type (i.e., the fuel that is ignited with the startup material and used to sustain the cooking event). Each identification of a startup material was counted as a single startup mention. Each respondent had the ability to identify multiple materials used within each location for which they responded as they were asked for the most common and second most common materials associated with different stove types and fuel types as well as "other" materials. Material mentions were categorized and grouped as part of the coding process. When a material description crossed multiple grouping categories, it was counted as both categories (e.g., "wood chips soaked in kerosene" was counted as a mention of both kerosene and kindling material). We tallied all material mentions across all responses and separately tallied responses according to whether

the material was mentioned as a “most commonly used,” “second most commonly used,” “other,” or “most unique” startup material.

We categorized results according to location, stove type, and main fuel type to compare differences in the materials used across these variables. Locations were coded to the country level as well as to a world region. We defined five regions (Africa, Mexico/Central America, East/South East Asia, South Asia, and South America) that encompassed all reported locations with a reasonable spread of responses per region (i.e., each defined region had at least three responses and no region contained more than approximately one third of the total responses) using the World Health Organization member state regions (World Health Organization 2017) as a rough guide. Stove types were grouped and coded as open/three stone fires, traditional stoves (including ceramic, clay, mud, or non-insulated metal), improved stoves (insulated metal or ceramic designs, such as jikokoa, rocket elbow, and gyapa style stoves), built-in stoves (larger stoves with chimneys, including griddle, plancha, chulha, and patsari styles), improved built-in stoves (including “ONIL”, “lorena”, or other built-in styles where respondent specified it was an improved rather than traditional type), or advanced stoves (any that specifically used an advanced fuel type such as kerosene, electric, or liquid petroleum gas [LPG] as the main fuel source). Main fuel types were coded as wood, charcoal, coal, dung and agricultural/crop residues, LPG, or kerosene. If a main fuel description crossed multiple grouping categories, it was counted as both categories (e.g., “wood and charcoal” was counted as both wood and charcoal). We calculated percentages across these various categories as the number of material mentions for a given material compared to the total number of material mentions in that category.

For questions about the respondents’ expertise/focal areas, we coded respondents into one of three cookstove sectors according to their workplace affiliation and job titles: academia (university researchers), policy (non-academic institutions conducting advocacy and/or energy policy work), and other private sector (e.g., non-academic groups conducting stove testing, stove development/design, or other traditional-style stove research). Participants provided an open-ended response describing their involvement in the cookstove field; these responses were used to group participants into the following focal areas: emissions testing (conducting tests of stove performance with regards to pollution emissions), health (any mention of working with health impacts of cookstoves), design (directly designs cookstoves or works with stove manufacturers), adoption/social aspects (involved with the social aspects of cookstove use, mentions “interventions” generally, or describes work on clean cookstove adoption or cooking behaviors), and field studies (any mention of conducting in-country, hands-on work with stove users). Respondents could be categorized as working under multiple focal areas.

The survey was created and hosted using Google Forms (Google, 2016). Qualitative coding was conducted using Microsoft Excel (2013). Analysis of coded responses was conducted using R (version 3.3.1, The R Foundation for Statistical Computing).

3. Results

3.1 Respondent Characteristics, Experience Levels, and Locations

We directly contacted 41 individuals to participate in the survey. Several contacted individuals forwarded the recruitment message to colleagues; one individual posted the message to a cookstoves email listserv. As such, it is difficult to know how many total individuals saw the call to participate, but we estimated it to be 45-60. We received completed survey responses from 23 individuals. Twelve of the respondents (52%) were employed in private research/design, seven (30%) were in academia and the remaining four (~18%) were involved in policy. Experience in cookstoves work ranged from 1 to 30 years (mean: 9 [standard deviation 7], median: 8; see Table 1). Although responses were anonymous and workplace affiliation was not included, based on the combination of identified locations and employment sector/focal area, we do not believe there was considerable overlap of respondents from the same employers or who worked on the same projects. Respondents provided information on 49 locations in 22 countries (see Table 2). Most respondents chose to identify a country or specific region within a country. Aggregated by region, responses were not evenly distributed. At the country level, India was the most highly cited with 14 responses, other countries were cited between one and four times.

The majority of respondents reported that they had not formally collected data on the startup materials used in the location for which they were responding (29 of the 49 locations; 59%) and based their responses on memory. Of those who had collected data (35%), two-thirds stated that they looked at that data to inform their responses to the survey (11 of the 49 locations [22%]), while the remaining third reported that they had collected data but did not look at the data while responding to the survey (6 of the 49 locations; additionally, 6% did not respond to this question [3 of the 49 locations]).

3.2 Main Stove and Fuel Types

The stove types identified as the primary/most common and secondary/second-most common included a roughly even spread of three-stone fires (25 responses [27% of the 92 total responses]), traditional style rudimentary stoves (ceramic or clay/mud pots/rings or non-insulated metal; 21 responses [23%]), improved styles (insulated metal and ceramic stoves such as rocket elbow or gyapa stoves; 18 responses [20%]), and built-in biomass stoves (traditional and improved combined; 21 responses [23%]), with a lesser representation of advanced-fuel burning stoves like kerosene and LPG (7 responses [8%]). Three-stone fires were relatively common across all regions (25-50% of reported stove types per region) except East/Southeast Asia, where no respondent identified use of a three-stone fire as the most common or second most common stove type. Similarly, traditional-style, non-built-in stoves were relatively common (17-26%) across all regions except Mexico/Central America (only 2 responses, representing 9% of the mentioned stoves for that region), though notably this region had high reported use of traditional built-in style stoves (6 responses [27%]). Built-in style stoves, including regular and improved designs, were more commonly reported in South Asia (8 responses [29% of total responses for that region]), Mexico/Central America (10 responses [45%]), and East/Southeast Asia (2 responses [25%]) than in Africa (only 1 response [4%]) and South America (no responses).

Across all stove types, wood was the most frequently named main fuel source (63 responses [68% of the 92 total responses]). Wood was identified as a main fuel source in more than 50% of the responses (54-91%) in all regions except East/Southeast Asia, where total responses were low but wood was still highly represented (3 responses out of only 8 responses for this region). Charcoal was the second-most commonly identified main fuel source (15 responses [16%]); though this was driven primarily by a high number of charcoal responses in Africa (10 responses out of 24 total responses for Africa). Other noted main fuel sources were LPG (6 responses [7%]), agricultural/crop residues and dung (3 responses [3%]), coal (1 response [1%]), kerosene (1 responses [1%]), and a combination of multiple fuels like wood and charcoal together (2 responses [3%]).

3.3 Types of Startup Materials Used Globally

Named startup materials were first tallied across all responses irrespective of what stove type, main cooking fuel type, or question posed to understand the scope of startup materials used world-wide. A total of 292 startup material mentions occurred over the course of the full survey; the groups and total count of responses per group are provided in Table 3. More than 40 unique materials were mentioned. These materials were categorized into eight main groups: accelerants, plastics, paper, kindling biomass, agricultural wastes, high-resin wood, rubber, and fabric. Types of materials that could not be categorized into one of the main eight categories were grouped as “other”; only 12 mentions fell into this category. The category included animal dung (three mentions, associated with India, Guatemala, and general Central America), butter/”ghee” (one response, India), “insulation” (two responses from same respondent, Cambodia), “carbon” (one response, Mexico), old shoes (two responses from same respondent, Guatemala), household trash (two responses, China and Honduras), and an unspecified other wood type (one response, Honduras). Most materials that could not be categorized were mentioned by respondents as unusual or uncommonly used.

Accelerants, paper, and plastic together represented nearly half (49%) of the materials mentioned across all respondents. Common responses for accelerant materials included kerosene (37 of the 51 total mentions), but also waxes/paraffin and oils; these materials are reportedly used alone (poured over the main fuel source in a combustion chamber and then lit with a match to help in ignition of the main fuel source) or sometimes in conjunction with other materials. For example, according to one respondent, sawdust soaked in kerosene is a “traditional starter available on the market” in Mali, whereas in Cambodia, the traditional market-available starter is a bundle of leaves with resin (Respondent 4). Newspaper was the only paper type identified specifically. Similarly, plastic bags were the most common plastic type identified. Many individuals noted plastic materials as the most unique or surprising material type they have seen used as a fire starter, such as “broken basins [and] jerrycans” (Respondent 19, seen in high poverty rural area), “Coca Cola bottles and fried chip envelopes” (Respondent 8, seen in “the most poor villages” in rural Mexico), and “expanded polystyrene” packaging from electronic items (Respondent 9, seen in India).

Biomass-based materials (kindling, agricultural waste, and high-resin wood such as ocote or other pine species) represented about one third (36%) of the total startup material mentions.

Kindling types were highly varied, including materials like “wood sticks with dried leaves attached” (Respondent 6, China), “small pieces firewood- peeled off the [main] firewood to be used” (Respondent 16, Kenya), “twigs & other small biomass” (Respondent 11, Guatemala), and “dry grass”, “dry leaves”, or “straw” (Respondent 16, Kenya, and Respondent 18, Malawi). Agricultural residues or wastes also varied by location, often indicative of the local crops – for example, corn cobs/maize stalks in Honduras, Guatemala, Kenya, and southern China, and rice straw in India and Nepal. Other unique agricultural waste mentioned included “bamboo, palm fronds, coconut husks” in Central America (Respondent 15), mustard stalks in India (Respondent 12), and “palm oil press residues” in Togo and Ghana (Respondent 19).

Rubber materials included “assorted [types] from insulation to tire tubes to flip flops” (Respondent 1, Cambodia), though the most common responses included tire tubes/scrap and flip flops. Rubber materials were often noted as a low use material (i.e., not the most commonly used material, but still a notable material) or as a material that the respondent felt was unique or surprising (e.g., “rubber nipples soaked in gasoline” seen in Tibet by Respondent 2, or an “old tennis shoe” seen in rural Guatemala by Respondent 15).

3.4 Variations by Region

The breakdown of responses according to region is shown in Figure 1. For most regions, responses indicated that a wide range of materials are used for stove startup. Responses from Africa and South Asia covered all eight of the categories used to group materials; East/Southeast Asia had responses for all categories except paper, and Mexico/Central America had responses for all categories except rubber and fabric. Accelerants and kindling were the most common materials mentioned for Africa, with 18 mentions each out of 82 for this region, followed by plastics, which were mentioned 17 times and paper, which was mentioned 11 times. High-resin woods, fabric, rubber, and agricultural waste were all noted infrequently. Accelerants were also the most commonly mentioned material in South Asia (20 out of 79), though paper received a similar percentage of responses (19 out of 79). Agricultural waste was more commonly mentioned in South Asia than in other regions, with 17 out of 79 mentions. Resinous pinewood species were the most commonly noted startup material in Central America with 17 out of 72 mentions; this category was rarely mentioned across all other regions.

3.5 Variation in Startup Material Choice across Different Stove Types and Main Fuels

Reported use of startup materials varied with the main fuel used as well as by stove type, as seen in, Figure 2. Wood was the most commonly reported main fuel type (138 total responses out of 201 total); the most frequently mentioned startup materials used with wood-burning stoves were paper (28 responses) and plastic (23 responses), but agricultural waste, kindling, accelerant, and high-resin woods like pine and ocote were also commonly mentioned (20, 19, 18, and 17 responses, respectively). Rubber and fabric were rarely mentioned for igniting wood (3 and 2 responses, respectively). Responses from other main fuel types were considerably fewer (only 37 responses relevant to charcoal stoves and 9 for liquid fuel stoves); however, charcoal appears to follow a similar trend as wood, with more commonly reported use of accelerants, plastic, paper, and kindling materials than rubber,

fabric, or other types of materials. Responses for liquid fuels (LPG, kerosene) indicate that no startup material is used with these stoves, or if one is, it is a small amount of the same material as the main fuel (e.g., kerosene). Similarly, reported use of startup materials varied with stove type (see Figure 3). Paper, plastic, kindling, agricultural waste, and accelerant are commonly reported materials across three-stone fires, traditional designs, and improved designs.

3.6 Other Reasons for variation in Startup Material Choice

Nearly half of the respondents (22/46, 48%) indicated that choice of startup material varied with season, availability of main fuel, or other factors. Variation in startup material choice was reported more frequently in South America and South Asia (67% and 62%, respectively, answered “yes” to the question of whether startup material choice varied). In Africa, East/Southeast Asia, and Mexico/Central America the majority of respondents indicated no variation in startup choice (62%, 75%, and 64% respectively). Of those who did say that the startup materials varied, reasons provided for that variation included availability of different materials, the cost of materials and/or affluence of families to afford certain fuel types, level of education of the cooks, seasonality (e.g., dry vs. rainy seasons), and differing practices in urban versus rural locations.

Availability of certain materials was the most commonly cited reason that startup choice might vary (12 mentions); seasonality was the second most commonly cited reason (7 mentions). Respondents generally indicated that individuals will burn “whatever burns quickly and is available” (Respondent 4, Mali and Cambodia). Concepts of availability also intersected with location and season. For example, one respondent stated that in rural Honduras, “there are different wood species across the study villages based on location near certain forests, so different people will use whatever is the most easily/cheaply available” (Respondent 5). The agricultural seasons were a major cited influence on availability of different startup materials. “Crop residues are seasonal” (Respondent 12, India) and materials like maize stalks, corn husks, and corn cobs are “plentiful after [the] harvest” (Respondent 16, Kenya). Similar to preferentially burning agricultural wastes when available, individuals might preferentially burn household waste materials like plastic and paper when these materials are available as this doubles as a waste management solution (Respondent 9, India). Several respondents also noted that “wet or dry season makes a difference” (Respondent 14, Bolivia), because “the moisture content present in the [main] fuel” impacts how an individual starts their stove/fire (Respondent 23, India), and a “lack of dry materials” during a rainy season may drive individuals to purchase kerosene or other commercially-available starter materials instead (Respondent 18, Madagascar).

Two respondents indicated that education and economic situation explained choices in startup materials. One respondent stated that “Justa [improved] stove owners receive training to not burn trash in their new stove, so they might be less likely to startup their fires with things like newspaper, plastic, etc.” (Respondent 5, Honduras). Similarly, another respondent stated that startup material choice “relies on economic and educational level of the ladies”, as “in Villages where government programs of health care are implemented, they are aware of health risks associated with the use of plastic or other smoky [materials]” (Respondent 8,

Mexico). This same respondent also noted that startup material choice “depends on family size and... life stage,” explaining that “there are a lot of rural villages in Mexico where the men are working in the US and the lady is not able to go out ... far [from] her house and has small children”, so these women would “use whatever they have available in their houses” (Respondent 8, Mexico).

4. Discussion and Conclusions

Nearly 40% of the world’s population currently cooks over open fires or rudimentary cookstoves, which is a large source of air pollution with local, regional, and global implications. Documenting the range of cooking practices that occur around the world is important in order to design behavioral change interventions that reduce emissions. Almost no published documentation exists regarding stove startup practices. Indeed, the majority of the cookstove experts interviewed for this research reported that they had never specifically collected data about cookstove startup practices. The startup process could be important for overall cookstove emissions and air pollution exposures; further, the types of materials burned during startup may be an important determinant of emissions. Understanding what materials are commonly used during startup is a necessary first step towards understanding the impact of the startup process on overall emissions and exposures and subsequently how changes to this process (such as encouraging the use of certain startup materials over others) might result in decreased emissions or lower exposures. This expert elicitation was an efficient and effective first step to gather information on startup materials relevant to a range of locations globally.

Our survey results indicate that a wide variety of materials are used to ignite cookstoves globally, but there are also commonalities to these materials. Three of the material groups identified - accelerants, paper, and plastic - together represented nearly half of the mentioned materials. Biomass-based materials (kindling, agricultural waste, and high resin wood) represented about one third of the responses. Understanding startup material choice is an important first step towards understanding the contribution of startup materials to overall cookstove emissions and their subsequent health and environmental impacts.

The startup materials reportedly used with “improved” stove types have a similar pattern as those used with three-stone fires and traditional stove types. A wide variety of materials are used across all stove types, with similar frequency between several major groups (accelerants, plastics, paper, kindling, and agricultural waste). More advanced stoves burning liquid fuels almost exclusively do not require a startup material, and if one is used, it is a similar advanced liquid fuel type (accelerants). Although it is difficult to draw conclusions on the comparison of startup practices across different fuel types due to the limited number of responses for some fuels, responses similarly indicated that a difference in startup practices is seen only when comparing kerosene or LPG fuels to other types of biomass fuels (e.g., wood, charcoal). These results are important because they suggest that researchers interested in understanding health impacts of cookstove practices may not need to be concerned about startup practice differences across traditional or improved stoves or with different biomass fuels; results from one stove/fuel combination may be reasonable extrapolated to other stove/fuel combinations.

Our survey respondents may have overrepresented users of improved or advanced stoves and therefore over-represented the associated startup materials. The Global Alliance for Clean Cookstoves estimates that over 60 million households have transitioned from open fires and traditional-style stoves to more efficient improved or advanced stoves (Global Alliance for Clean Cookstoves 2015). These statistics indicate a considerable number of improved or advanced stoves are in use globally; however, they also imply that the vast majority of the 2.8 billion cookstove users worldwide are still using rudimentary or traditional style stoves. In our survey, about 30% of responses were for improved or advanced stoves, which is likely greater than the percentage of cookstove users who use improved/advanced stoves compared to traditional or open fires. This likely occurred because we sought respondents who had expertise in the cookstove sector and therefore work with communities on research and projects aimed at understanding clean cookstove adoption. However, reported startup practices were similar across three-stone fires/traditional stoves and improved designs, so this over-representation is unlikely to have a major impact on our overall conclusions.

Our survey provided a reasonable representation of the main fuel types used globally, which gives us confidence that the global startup material breakdown is representative. Our survey responses indicated 50 to 90 percent wood use depending on the region (average 68%) and 8% use of LPG and kerosene. Charcoal was a commonly reported main fuel in Africa but not elsewhere. These results align with estimates from The World Bank that 60 to 80 percent of households in developing countries use wood as their primary energy source and charcoal use is limited except in Africa (Malla and Timilsina 2014). Advanced fuel use is estimated to be higher than indicated by our survey, around 20% of energy consumed in developing countries (Malla and Timilsina 2014). However, this estimate includes use for heating, lighting, and other energy requirements, so is an overestimate of residential cookstove consumption.

Total responses for our survey were dominated by input relevant to Africa and South Asia (primarily India). Although these regions represent a large percentage of global cookstove users, more representation for East/Southeast Asia and South America is needed to confidently draw conclusions that the relative representation of different materials by survey respondents matches true global startup material use patterns. It should be noted that our survey results are not weighted to the population of cookstove users within a given country. For example, approximately 64% of the population of India (roughly 832 million of the 1.3 billion people) use solid fuel cookstoves, whereas only 9% of the Americas region (approximately 90 million of the one billion people) uses solid fuels for cooking (see Table 2). Yet, our survey contained 14 responses from India and comparatively 11 responses relative to Mexico and Central America. Furthermore, region-to-region comparisons may be problematic using our results, due to the limited number of responses in some regions compared to others. The apparent lack of geographic variability among startups is an important result because while biomass stove type may show wide geographic heterogeneity (i.e., the type of stove varies from one region to the next), the use of startup fuels is more homogeneous. However, in regions with fewer responses (for example, South America), the patterns of responses may not be representative but rather indicative of limited and specific experiences of the small number of respondents. When enough experts are included, additional expert respondents do not result in mentions of new types of startup materials not

mentioned by other respondents, or the ratio of responses indicating “kerosene” versus “rubber” as the primary startup material remains the same with additional responses. Reaching this critical level of responses provides confidence that the responses are representative of a consensus across a population of experts. This consensus was reached across the total global perspective in this survey, as evident by the repetition of named startup materials with less than 5% (12/292) of responses not fitting into one of eight main groups. However, when broken into regional subsections, it is less clear whether this type of consensus was reached.

While this survey provides new information about the types of materials that are used during cookstove startup, there are still many gaps related to understanding startup practices. The use of respondents with experience in the cookstove field allowed us to gather information from relatively few individuals in a resource-effective way, while still representing a wide variety of regions and cooking practices. However, further work to survey actual cookstove users would be beneficial to obtain a more comprehensive understanding of practices across different communities and to ensure that the experts’ responses are representative of the prevailing real-world conditions. Most respondents indicated that they had not ever formally collected data on cookstove startup practices, which means their responses are subjective. While the repetition and overlap of responses across experts provides confidence in their responses, more empirical evidence would be a logical next step. All respondents indicated on-the-ground field study experience; researchers currently involved in cookstove studies could add survey questions on startup practices to their existing studies. For example, respondents indicated that there may be variability in startup practices according to location, primary stove type, main cooking fuel type, seasonality, or other factors – yet, conclusions about how these factors play into a cookstove user’s choice in startup practice are limited by the size and representativeness of our survey. Future surveys could be conducted to better understand what determines startup material choice, which would be critical to any intervention work aimed at changing startup practice behaviors for purposes of reducing exposures and improving health.

More empirical evidence would help support the information provided by the experts in this survey. Field studies conducted around the world could incorporate systematic observations or simple surveys about the startup practices used in the studied communities. Additionally, work is needed to understand how various startup materials contribute to the health impacts of cookstove use. Since individuals may experience high exposures from being in close proximity to the stove during the startup process, these emissions may be of particular importance when considering the overall impact of cookstoves on human health. Field studies need to consider that a range of startup materials and practices may be used across communities, whether they are investigating them or controlling for them. The pollutant mixture emitted from burning startup materials is presumably different than the mixture emitted from the main cooking process, particularly for rubber and plastic materials and plastic materials, and therefore the health and climate impacts may vary. However, such emission remain poorly documented. Further, information is lacking on how emissions differ across different types of startup materials. The results presented here can serve as a foundation for further work, such as justification for the choice of a limited number of materials to test in the laboratory (Fedak et al. 2018). The reported commonality of a small

number of material types is useful as it can provide confidence that results from emission campaigns that are only able to test a small number of materials could still be generalizable to a wide population.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Abbreviations

LPG liquefied petroleum gas.

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Highlights

- We conducted a survey to understand the types of materials used to ignite cookstoves.
- Twenty-three respondents provided information on 48 locations in 22 countries.
- Paper, plastic, agricultural biomass, kerosene, and rubber were often reported.
- Fabrics, plastic packaging, snack food wrappers, and trash were also noted.
- Commonly used startup materials may lead to harmful combustion byproducts.

Figure 1. Materials Used for Startup: Responses by Region. Bar charts show the number of responses for each startupmaterial category. Each unique mention of a startupmaterial (associated with a primary or secondary stove, primary or secondary main fuel, or generally mentioned as an additional material) was included. Material categories are defined according to Table 3. Bars are colored by material type and arranged in the same left-to-right order for each plot. “Ocote” group includes all high-resin woods; “agwaste” is agricultural waste. The left panel shows response counts for all regions combined; right panel contains separate charts for the startup materials mentioned for each region. See Table 2 for list of countries represented within each region.

Figure 2. Materials Used for Startup: Responses by Main Fuel Type. Bar charts show the number of responses for each startup material category. Material categories are defined according to Table 3. Bars are colored by material type and arranged in the same left-to-right order for each plot. “Ocote” group includes all high-resin woods; “agwaste” is agricultural waste. Separate charts are provided for each main fuel source. Individual plots for coal and “wood and charcoal” combined were excluded because of the limited number of responses (1 and 3, respectively).

Figure 3.

Materials Used for Startup: Responses by Stove Type. Bar charts show the number of responses for each startup material category. Material categories are defined according to Table 3. Bars are colored by material type and arranged in the same left-to-right order for each plot. “Ocote” group includes all high-resin woods; “agwaste” is agricultural waste. Separate plots are provided for the startup materials mentioned across each stove type.

Table 1.
Survey Respondent Expertise and Characteristics.

Respondents were categorized into sectors according to their workplace affiliation and job titles. Respondents were categorized into focal areas based on their involvement in the cookstove field. Respondents could be categorized as working under multiple focal areas.

	Total Sector	By Focal Area [*]				
		Stove Design	Emissions	Health	Adoption/ Social	Field Studies
All Sectors						
Number of Respondents	23	9	9	7	12	10
Years of Experience [average±standard deviation (min, max)]	9.0±7.1 (1, 30)	14.8±7.2 (8, 30)	11.1±8.8 (2, 30)	5.4±3.6 (1, 10)	8.0±8.3 (1, 30)	5.3±3.1 (1, 9)
Academics						
Number of Respondents	7	1	1	4	4	6
Years of Experience [average±standard deviation (min, max)]	5.9±3.3 (1, 10)	8	8	6.0±3.9 (1, 10)	4.0±3.1 (1, 8)	5.2±3.1 (1, 8)
Policy						
Number of Respondents	4	1	0	2	2	2
Years of Experience [average±standard deviation (min, max)]	6.8±5.85 (2, 14)	14	NA	5.5±4.0 (2, 9)	8.0±8.4 (2, 14)	5.5±4.9 (2, 9)
Private Research/Stove Design						
Number of Respondents	12	7	8	1	6	2
Years of Experience [average±standard deviation (min, max)]	11.5±8.4 (2, 30)	15.9±7.75 (8, 30)	11.5±9.3 (2, 30)	3	10.7±10.5 (3, 30)	5.5±3.5 (3, 8)

* Respondents were allowed to identify multiple focal areas.

Table 2.
Locations Represented by Survey Responses.

Locations were coded to the country level as well as to a world region. We defined five regions influenced by the World Health Organization Regions, to encompass all reported locations with a reasonable spread of responses per region.

Region/Country	Number of Responses	% of Responses	% of population using solid fuels, 2013*
South Asia	16	33	63[^]
Afghanistan	1	2	80
India	14	29	64
Nepal	1	2	80
Africa	13	27	79
Benin	1	2	94
Burkina Faso	1	2	95
Ethiopia	1	2	>95
Ghana	1	2	83
Kenya	4	8	84
Madagascar	1	2	>95
Malawi	1	2	>95
Mali	1	2	>95
Nigeria	1	2	75
Zambia	1	2	82
Mexico/Central America	11	22	9^{&}
El Salvador	1	2	19
Guatemala	2	4	65
Honduras	4	8	50
Mexico	2	4	15
Nicaragua	1	2	53
Unspecified	1	2	--
East/Southeast Asia	4	8	40[#]
Cambodia	2	4	88
China	2	4	45
South America	3	6	9^{&}
Bolivia	1	2	23
Peru	2	4	34
Unspecified	2	4	--
Urban	1	2	--
Rural	1	2	--

* source: World Health Organization, Global Health Observatory Data Repository (<http://apps.who.int/gho/data/node.main.135?lang=en>).

[^] estimate for WHO South-East Asia region only (includes India and Nepal, does not include Afghanistan)

[&] estimate for WHO Americas region (includes North America, Central America/Latin America, and South America)

[#] estimate for WHO Western Pacific Region (includes China and Cambodia)

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Table 3.
Materials Used for Startup: Categories and Total Count of Responses across All Locations.

Each identification of a startup material in response to any question within the survey was counted as a single “mention.” Questions asked about the most commonly and second most commonly used materials associated with the two most common stove types and fuel types as well as “other” materials and “unique” materials within a given location; respondents could provide information relevant to up to three locations. When a material description was compound and crossed multiple grouping categories, it was counted as both categories.

Category	Definition	Any mention	Most commonly used	2 nd most commonly used	Other	Most unique/surprising
Total responses	All startup materials, including a response of “None”	292	104	97	73	18
Accelerant	Kerosene, paraffin/wax, or burning charcoal material transferred from a previously lit stove	51	18	19	12	2
Plastic	Plastic bags, bottles, packaging material, polythene, and unspecified types	49	15	18	10	6
Paper	Including newspaper	42	11	21	10	0
Kindling	Small branches, leaves, twigs, sawdust, grass clippings, or other biomass based “tinder”; sometimes combined with resin or kerosene (<i>if so, “accelerant” also selected</i>)	40	13	11	12	4
Agricultural waste	Rice straw, dry maize/corn stalks and husks, crop/garden residues such as weeds and grasses	37	16	7	13	1
High resin wood	Wood types that burn easily, mainly ocote or other pinewoods	25	14	7	4	0
Rubber	Bike tires/tubes, flip flops, shoe soles, and other assorted rubber scraps	13	6	0	4	3
Other	Mostly animal dung; some mention of food scraps, general rubbish, insulation materials, and other uncommonly mentioned materials	12	2	2	2	1
Fabric	Strips of fabric, including weaved fabrics	7	3	2	6	1
None	Respondent specifically stated that no starter is used	16	6	10	0	0