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## Estimating the Number of Vulnerable People in the United States Exposed to Residential Wood Smoke

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Rogalsky et al. (2014) recently estimated the number of homes and individuals at risk of adverse health effects from exposure to emissions from residential wood combustion in the United States. We appreciate the importance of this topic, particularly to rural and underserved communities. We also understand the authors' emphasis on low-income individuals because this population generally has more difficulty accessing health care services and fewer resources available to improve indoor air quality. However, several factors suggest that the indication of 500,000–600,000 low-income persons exposed to household air pollution (HAP) from the burning of solid fuels may be a very conservative estimate, substantially underestimating the public health importance of residential wood combustion.

First, the estimate of Rogalsky et al. (2014) was limited by their use of the census-based figure of 2.8 million homes using wood as a primary heating fuel. The U.S. Energy Information Agency (2012) noted that another 8.8 million homes use wood stoves or wood-burning fireplaces as a secondary source of heating. Limited data are available on the frequency of use of wood burning as a secondary heating source and the associated exposure to indoor particulate matter (PM), but the 11.6 million homes with an estimated 2.58 persons per household (U.S. Census Bureau 2012) suggest that closer to 30 million people in the United States live in a home where wood burning is used for heating, rather than the 6.5 million people reported by Rogalsky et al.

Second, the authors' estimate of at-risk persons was limited to those with co-occurrence of in-home wood burning as a primary heating source and households below the Federal Poverty Level (FPL) (i.e., 900,000 people that meet both criteria). However, at-risk individuals, including children and the elderly, also reside in homes that are above the FPL threshold. Third, Rogalsky et al. suggested that 53–65% of wood-burning homes in high-poverty communities may exceed health-based standards, but this estimate is based on few studies, with poverty assessed only at the community level. Finally, the authors focused only on direct indoor fugitive emissions in homes

using wood stoves, but exposure risk is not limited to those living in homes with wood-burning appliances. As indicated in several published studies, communities with a high proportion of residential wood-burning households may also have elevated concentrations of ambient wintertime PM (Ward and Lange 2010). Moreover, analyses of infiltration efficiencies suggest that exhausted wood smoke can contribute substantially to indoor PM concentrations in both wood-burning and non-wood-burning homes (Barn et al. 2008), resulting in a higher proportion of homes and their residents experiencing risk from biomass combustion-derived PM. Rogalsky et al. (2014) should be commended for acknowledging these and other limitations in their discussion, and we appreciate the opportunity to provide additional information on these points.

Here we offer an alternative framework for estimating the number of people in the United States exposed to high levels of PM associated with wood burning. Approximately 11.6 million homes in the United States use wood as a primary or secondary source of heat. Of these, 4.8 million homes have wood stove appliances (U.S. Energy Information Agency 2012). Because of the uncertain frequency of fireplace use, we have not included homes with fireplaces in our estimate, although they likely are important sources of indoor PM. Rather than limiting our estimate to those homes below the FPL, we define our at-risk population as the susceptible individuals living within these homes (i.e., children and the elderly). With approximately 0.63 children < 18 years of age per household and 0.33 people > 65 years of age per household (U.S. Census Bureau 2012), we estimate that within the United States alone, approximately 4.8 million susceptible individuals live in homes with substantial exposures to wood smoke-derived PM, an order of magnitude greater than the 0.5–0.6 million estimate of Rogalsky et al. (2014). This estimate is conservative because it does not account for infiltration into non-wood stove households experiencing HAP generated from neighboring wood-burning homes, nor does it account for all household residents that are vulnerable due to chronic health conditions.

As with any estimates of at-risk populations, there is an important balance to strike between underestimating the risk and artificially inflating the public health importance. We suggest that Rogalsky et al.

(2014) erred toward the former. Our estimates are based on a different framework with respect to exposure potential and susceptible populations. Whether the true number of individuals in the United States at risk for adverse health effects from exposure to wood smoke is closer to 0.5 million or 4.8 million, it remains clear that this is an important environmental exposure that disproportionately impacts rural populations.

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## Estimating the Number of Vulnerable People in the United States Exposed to Residential Wood Smoke: Rogalsky et al. Respond

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We appreciate the thoughtful comments by Noonan et al. and consider them an important contribution to the dialogue surrounding the public health issue of residential wood smoke. Their comments accurately reflect and deal fairly with the issues raised in our recent article, “Estimating the Number of Low-Income Americans Exposed to Household Air Pollution from Burning Solid Fuels” (Rogalsky et al. 2014). Absent the availability of new data on household exposure to residential wood smoke in the United States, we agree that it is challenging to develop an accurate estimate of the potential risk. It is true that we were purposefully conservative in our assumptions in order

to estimate the household air pollution (HAP) burden among the most vulnerable Americans. We appreciate the alternate estimate that Noonan et al. have offered, although we would argue that their estimate likely includes a significant number of individuals with only intermittent exposure to high levels of HAP.

Our estimate began with the 2.8 million households that use wood, coal, or coke as the primary means of household heating, but we also recognize that an additional 8.8 million homes use wood as a secondary heating source. Nearly 5 million households from these two groups use a wood-burning stove, whereas the remainder typically use fireplaces. We believe that it is reasonable to assume that primary users heat their homes daily with wood during the heating season, but this assumption does not hold for secondary users. An unknown but significant number of these households may heat their homes with wood only on rare occasions, resulting in less frequent HAP exposure.

Noonan et al. excluded homes with wood-burning fireplaces in their estimate because the frequency of use in this group is unknown, but they did include secondary users of wood stoves for whom there are also no data. Combining all secondary users of a wood stove into the same group as primary users likely includes many homes with infrequent or episodic HAP exposure.

Noonan et al. also note that we were conservative in our estimate by limiting the at-risk households to those below the federal poverty level. Children and the elderly residing in homes that burn wood may certainly reflect an at-risk population regardless of socioeconomic status, and this notion does merit consideration. However, by not focusing on poverty, Noonan et al. bring into their estimate all wood stove users, including the most affluent users most likely to have clean-burning stoves with regular maintenance. This is an important point for discussion and further research because—as is clear from

previous work on this topic, much of it done by Noonan, Ward, and colleagues—even in communities with a relatively high proportion of the population below the federal poverty level, only 53–65% of homes exceed the World Health Organization standard for particulate matter of  $< 2.5 \mu\text{m}/24 \text{ hr}$  (Noonan et al. 2012; World Health Organization 2005). It is unclear, given the current published data on the subject, whether this proportion of homes would be different in more affluent communities, but it seems likely, given the data from international sources that strongly link poverty and HAP from burning solid fuels (World Bank 2011).

Noonan et al. are correct in pointing out the limitations inherent in our estimates. Our estimates did not account for the regional and neighborhood effects of wood smoke. This is relevant because communities with a high proportion of wood-burning homes experience significant infiltration of outdoor air pollution. Unfortunately, from an estimation standpoint, these issues are extremely variable by region and weather patterns and are not easily incorporated into national estimates such as ours. However, it bears repeating that the negative health effects of HAP have been demonstrated most consistently in those with daily, chronic exposure to high concentrations of particulate matter; therefore, it seems likely that frequent direct exposure would correlate most closely with the negative health impacts (World Bank 2011).

Ultimately, in our research, we and Noonan et al. struggle with a lack of available data on exposure to HAP in U.S.-based households. Going forward, we recommend that future studies include measures such as household, personal, and ambient air monitoring to determine whether levels are consistent with impairment of human health and how frequently these levels are attained in such households. We also recommend that the U.S. Census Bureau should, in the next installment of the American

Community Survey, ask respondents to quantify how frequently they use their wood-burning appliances or fireplaces to heat their homes as either a primary or secondary source of heating. This information would allow researchers to better understand the overall number of Americans potentially at risk.

HAP is an environmental justice issue of clear public health importance, both globally and in its disproportionate impact on mostly rural Americans. We wholeheartedly join Noonan et al. in advocating for those affected.

*The authors declare they have no actual or potential competing financial interests.*

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