Responses to Reviewer 2's Comments

We appreciate Reviewer 2's recognition of the importance of this work. The comments are very helpful. Our detailed response to each comment is provided below in blue font. The red font shows modifications to the original text.

Main Comments:

1. *"Open burning has low burning efficiency" needs to be backed by measurements of Modified Combustion Efficiency (MCE) to determine burning conditions.*

   Response: The Intergovernmental Panel on Climate Change (IPCC, 2006) uses an oxidation factor (the fraction of material carbon that is fully oxidized to CO_2) as an indicator of combustion efficiency in the estimation of solid waste burning emissions. The oxidation factor is near 100% for MSW incineration and 58% for open burning. We added this information and also added a reference (Velis and Cook, 2021) for the low combustion efficiencies for open burning:

   "While MSW incineration oxidizes nearly all fuel carbon to carbon dioxide (CO_2), open burning only fully oxidizes about 58% of the materials (IPCC, 2006). Open burning has lower combustion efficiencies due to inefficient mixing of fuels and oxygen and low burning temperatures, resulting in emissions of a wide range of air pollutants (Velis and Cook, 2021)."

2. *Line 30 Important recent relevant studies are missing and may need to be included (more are added below related to calculation of emission factors and Africa relevant work*
   - *Gordon et.al "The Effects of Trash, Residential Biofuel, and Open Biomass Burning Emissions on Local and Transported PM2.5 and Its Attributed Mortality in Africa" https://doi.org/10.1029/2022GH000673*
   - *Pokhrel et al. Determination of Emission Factors of Pollutants From Biomass Burning of African Fuels in Laboratory Measurements https://doi.org/10.1029/2021JD034731*
   - *Hodshire et. al. "Aging Effects on Biomass Burning Aerosol Mass and Composition: A Critical Review of Field and Laboratory Studies" https://doi.org/10.1021/acs.est.9b02588*

   Response: Thanks for bringing these references to our attention. We have included them in various locations of the manuscript.

   "It is estimated that exposure to $PM_{2.5}$ from open burning of solid waste causes at least 270,000 premature deaths globally (Williams et al., 2019) and 10,000–20,000 premature deaths in Africa (Gordon et al., 2023; Kodros et al., 2016) each year."

   "Pokhrel et al. (2021) reported PM (≤720 nm) EFs for seven types of African woody biomasses, averaging 19.2 (ranging 13.2–25.1) g kg^{-1} for burns with MCE <0.85, which is lower than that for the 50% moisture sample in this study; on the other hand, PM EFs were 5.0 (ranging 0.82–22.2) g kg^{-1} for burns with MCE≥0.85, which are similar to those for the dry and 20% moisture samples."

“Low EFs for particulate Cl^-, NO_3^-, SO_4^{2-}, and NH_4^+ were also reported by Pokhrel et al. (2021) for African biomass burning emissions.”

“Results were obtained from laboratory tests simulating real-world conditions. However, the differences in fuel mixtures, packing structure, moisture content, burn conditions, dilution, and aging between laboratory and field conditions will cause differences in chemical compositions and EFs (Hodshire et al., 2019). The EFs might need to be adjusted when real-world burning conditions differ significantly from the test conditions used in this study.”

3. *How valid is using food discards from Nevada to be used to represent food discards in Africa. The food discards in Africa are probable fresh from the farm or bakery unlike the processed food with preservative chemicals in the US. How would the preservatives contaminate the samples?*
Response: We matched the food discards collected in Nevada with materials burned in South Africa. Our South Africa collaborator categorized the typical composition of food wastes in their solid waste collection, and we collected similar materials in Nevada. The picture below shows the food discards used in our test, which was included in Figure S1 of the companion paper (Wang et al., 2023). All the ingredients were fresh vegetables and bakery products. We believe there is little contamination by preservative chemicals for the materials tested.

Figure S1.h of (Wang et al., 2023): Photograph of food waste materials used in this study.

The following text is added in Section 2.1:

“Due to customs restriction and potential deterioration during shipping, the compositions of food discards and vegetation collected by the WCI were characterized and similar mixtures were collected in Nevada for testing. Food discards included bread, potato and banana peels, lettuce, cucumbers, and tomatoes (Cronjé et al., 2018) and vegetation included basin wild rye, Sandberg bluegrass, crested wheat grass, red willows, and creeping wild rye, representing African bunch grasses, African sumac, and crab grass.”

4. *Line 97: More details on the burning condition is needed. If a tube furnace is used at 450 it often corresponds to smoldering combustion based on the MCE. Pokhrel et al has shown MCE dependence of emission factors.*
Response: The combustion experiment is described in detail in Section 2.2 Combustion Experiments of the companion paper (Wang et al., 2023), so only a brief description is provided in this paper. Figures 3, 4, S4, S8, S11, S14, S17, S20-S22, S26, and S29 of the

companion show the time series of MCEs determined from testing of each waste material, including the periods designated as flaming or smoldering combustion. Table 2 of the companion paper lists the mean MCEs for the flaming and smoldering phases as well as the entire burns, and Figure S3 shows the EFs for CO_2, CO, NO_x and $PM_{2.5}$ as a function of MCEs. Due to the very different waste material properties, a consistent relation between EFs and MCEs was not observed.

5. *Some details need to be provided on how trash burning experiments are done. The trash in trash damps in Africa are a mixture of food discards, plastics, paper products and vegetation. How is this exactly done? Furthermore, there is evidence of fuel type dependent emission factors for biomass fuel are reported. When the authors indicate vegetation, it is quite broad, and the type of vegetation needs to be described. The results from the combined waste do not quite match with the results of individual types of trash. If the combination of fuels or trash contains everything, then all the EF's pollutants should show in proportional amounts. How do the authors explain this?*

   Response: As described in Section 2.1, we tested emissions from nine individual waste categories as well as the combined materials by mixing all categories based on their mass fractions representative of MSW in South Africa township. The combustion experiment, including pictures of the waste materials before and after burning, was described in detail in Section 2.2 Combustion Experiments of the companion paper (Wang et al., 2023).

   As described in the response to Comment 3, the vegetation used in this study included: basin wild rye, Sandberg bluegrass, and crested wheat grass representing African bunch grasses; red willows representing African sumac; and creeping wild rye representing crab grass. We acknowledge that vegetation includes many more varieties, and the derived emission factors apply to the materials reported in this manuscript. The companion paper shows that our 0% and 20% moisture vegetation EFs for CO_2, CO, and SO_2 were in good agreement with those derived for Savanna vegetation (Akagi et al., 2011), while the $PM_{2.5}$ EFs for 50% moisture vegetation burning were about one order of magnitude higher than literature values.

   We recognize that the mass-weighted sum of EFs from individual waste material does not equate to the combined materials EFs. The companion paper cautioned the readers for using separate or combined emission factors in Section 3.5 as follows (Wang et al., 2023):

   "However, it should be cautioned that the burning behaviors differ between separated and combined waste materials, causing emissions to change. Table S5 compares the measured EFs for the combined materials and the values calculated from $EF_{p,i}$. The calculated EFs agree with the measured values within 10% for CO_2 and NO_x; however, the calculated EFs for CO and PM are over 50% and 600% higher, respectively. It is possible that more efficient combustion in the combined materials lowered CO and PM emissions as compared to less efficient individual burns, particularly for materials that only smoldered and had high EFs for CO and PM. Additionally, laboratory measured $EF_{p,i}$ or EF_p might differ from field values given the complex waste mixtures and burning conditions. Adjustments to laboratory $EF_{p,i}$ might be needed when estimating real-world EF_p. Future studies comparing in situ measurement from a variety of representative real-world burns with laboratory data would assist in establishing adjustment factors."

6. *The major concern is missing information on how Emission factors are calculated for each species. Table 1 is an important table, and I am sure all the authors these results are compared to have provided the methods and assumptions used in calculating emission factors Pokhrel et al. and other references.*
Examples are

Yokelson, R. J., J. G. Goode, D. E. Ward, R. A. Susott, R. E. Babbitt, D. D. Wade, I. Bertschi, D. W. T. Griffith, and W. M. Hao (1999), Emissions of formaldehyde, acetic acid, methanol, and other trace gases from biomass fires in North Carolina measured by airborne Fourier transform infrared spectroscopy, Journal of Geophysical Research-Atmospheres, 104(D23), 30109-30125, doi:10.1029/1999jd90081

Andreae, M. O., and P. Merlet (2001), Emission of trace gases and aerosols from biomass burning, Global Biogeochemical Cycles, 15(4), 955-966, doi:10.1029/2000gb001382.

Selimovic, V., Yokelson, R. J., Warneke, C., Roberts, J. M., de Gouw, J., Reardon, J., & Griffith, D. W. T. (2018). Aerosol optical properties and trace gas emissions by PAX and OP-FTIR for laboratory-simulated western US wildfires during FIREX. Atmospheric Chemistry and Physics, 18(4), 2929–2948. https://doi.org/10.5194/acp-18-2929-201

Weyant, C. L.; Chen, P.; Vaidya, A.; Li, C.; Zhang, Q.; Thompson, R.; Ellis, J.; Chen, Y.; Kang, S.; Shrestha, G. R.; et al. Emission measurements from traditional biomass cookstoves in south Asia and Tibet. Environ. Sci. Technol., 2019, 53 (6), 3306-3314. DOI: 10.1021/acs.est.8b05199.

Stockwell, C. E., Jayarathne, T., Cochrane, M. A., Ryan, K. C., Putra, E. I., Saharjo, B. H., et al. (2016). Field measurements of trace gases and aerosols emitted by peat fires in Central Kalimantan, Indonesia, during the 2015 El Niño. Atmospheric Chemistry and Physics, 16(18), 11711–11732. https://doi.org/10.5194/acp-16-11711-2016

Vakkari, V.; Beukes, J. P.; Dal Maso, M.; Aurela, M.; Josipovic, M.; van Zyl, P. G. Major secondary aerosol formation in southern African open biomass burning plumes. Nat. Geosci., 2018, 11 (8), 580-583. DOI: 10.1038/s41561-018-0170-0.

Response: Thanks for providing relevant references. Indeed, past studies and approaches to estimate emission factors (EFs) were examined. Our companion paper (Wang et al., 2023) documented the EF calculation in Eq. (2). We made the assumption that fuel carbon emitted as methane and volatile organics is negligible. A unique feature of this study is that we included carbon in the ash and PM in the EF calculation, and evaluated the effects of neglecting these terms. Section 3.4 of Wang et al. (2023) shows that without including ash and/or PM carbon, changes in EFs are <5% for flaming dominated combustions. However, the consequences of not including ash or PM carbon are larger for smoldering fuels. For smoldering plastic bottles, not including carbon in PM resulted in an EF overestimation of 577%; in addition, if ash carbon was not included, the EFs would be overestimated by 623%.

Data from Andreae (2019) are added in Table 1 because it has EFs for BC and PAHs for biomass and garbage. The other studies are not included because they either do not have BC and PAH EFs or the fuel and burning conditions are different from open burning (e.g., peat or cook stoves).

Minor comments:

7. *Line 10. Is household trash burning a large source of pollutant worldwide or Global South. Developing countries in current literature is now referred to as Global South*
   Response: As suggested, "developing countries" is replaced as "Global South" in the text. Trash burning is a source of pollution worldwide and in the Global South.

8. *Line 12: what does activity data mean?*
   Response: Activity is a term used in emission inventories to reflect emission generation activities. Typical activities include amount of fuel burned, vehicle kilometers traveled, etc. (IPCC, 2006). Emissions are generally estimated as (U.S. EPA, 2017):

   $$E = A \times EF \times (1 - ER / 100)$$

   where E is the total emissions, A is activity indicator, EF is emission factor, and ER is overall emission reduction efficiency in percent. For MSW open burning, the activity data is the amount of waste burned. The text is revised as follows:

   "Despite the large environmental impacts of uncontrolled MSW open burning, its emissions are not included or are poorly represented in local, regional, and global emission inventories due to lack of information on emission factor (EF) and amount of MSW burned (activity) (Cook and Velis, 2021; Ramadan et al., 2022)"

9. *Line 13: Scarcer? Is it grammatically, correct?*
   Response: We believe "Detailed particulate matter (PM) chemical speciation data is even scarcer" is grammatically correct. However, the word scarcer is replaced with "less available".

10. *Line 21: Plastic bottles, plastic bags, rubber and .. (remove "and between plastic bottles and bags)*
    Response: Revised as suggested.

11. *Line 30: Global south instead of developing countries*
    Response: Revised as suggested.

12. *Line 35-36: Instead of communities with low socioeconomic status better use Low-income communities*
    Response: Revised as suggested.

13. *Line 42" emission factor and activity data? What is activity data?*
    Response: Please see response to Comment 8.

14. *Line 58: ...highlighted a large variation instead of the*
    Response: Revised as suggested.

15. *Line 60: Detailed PM chemical composition data are.. (data is missing)*
    Response: Revised as suggested.

16. *Line 65: PM light scattering, and absorption properties depend on its chemical composition and associate hygroscopicity and optical properties. change to "PM optical properties depend on chemical composition and hygroscopicity" absorption and scattering are the optical properties*

    Response: The overall PM optical properties depend on the optical properties of individual chemical components. We revised the sentence as below to be clearer:

    "PM light scattering and absorption properties depend on the hygroscopicity and optical properties of its chemical components."

17. *Line 77: Ef's for acidic… remove including elements*

    Response: The sentence is revised as below:

    "This paper focuses on speciated source profiles and EFs for ~~including~~ elements, acidic and alkali gases and ions, PAHs, nitro-PAHs, n-alkanes, and phthalates."

18. *Line 244: Higher combustion temperature doesn't indicate burning condition. Need MCE*

    Response: The MCE information is added:

    "The modified combustion efficiencies (MCEs) for the dry (MCE = 0.88) and 20% moisture (MCE = 0.91) vegetation samples were higher than the 50% moisture vegetation sample (MCE = 0.79) (Wang et al., 2023). One would expect that the dry and 20% moisture vegetation samples would cause higher EFs for HF than particulate F^- due to preferred partition in the gas phase at higher combustion temperatures and MCEs."

19. *Line 385: dearth of measurements "of is missing"*

    Response: Revised as suggested.

20. *Line 255: please correct the unit (g kg^{-1}).*

    Response: Revised as suggested.

References

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