

Emission Factors of Trace Gases and Particulate Matter Emitted from a "Leaky" Pellet Stove Insert

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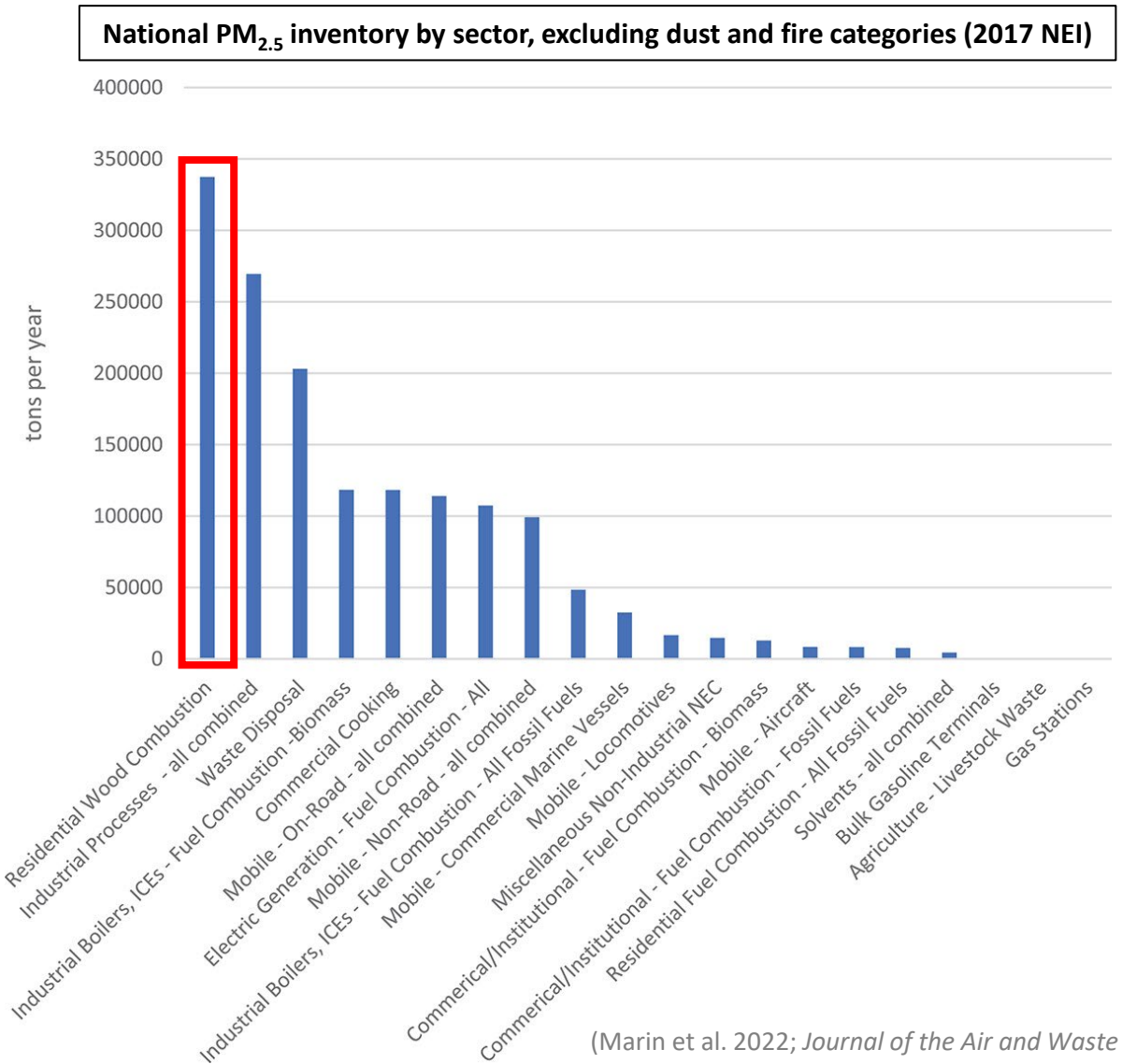
ALASKAN LAYERED POLLUTION AND CHEMICAL ANALYSIS

ALPACA

Residential wood combustion (RWC) is a major source of residential heat globally

- **Worldwide Usage**
  - **Residential Heating**
  - **Recreation (Saunas, campfires, etc.)**
  - **Cooking**
- **Use in the United States**
  - **Primary heat source for 2.25 million homes**
  - **Supplemental heat source for 8.83 million homes**
  - **28.8 million people exposed to wood smoke at home**
  - **Anthropogenic $PM_{2.5}$ emissions are dominated by RWC**

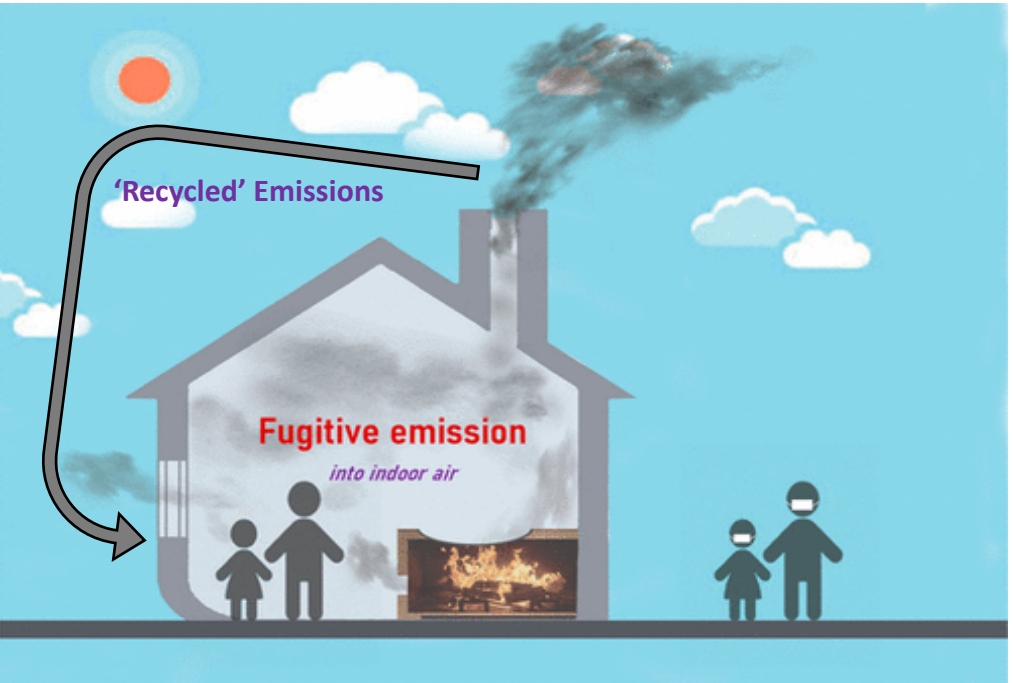


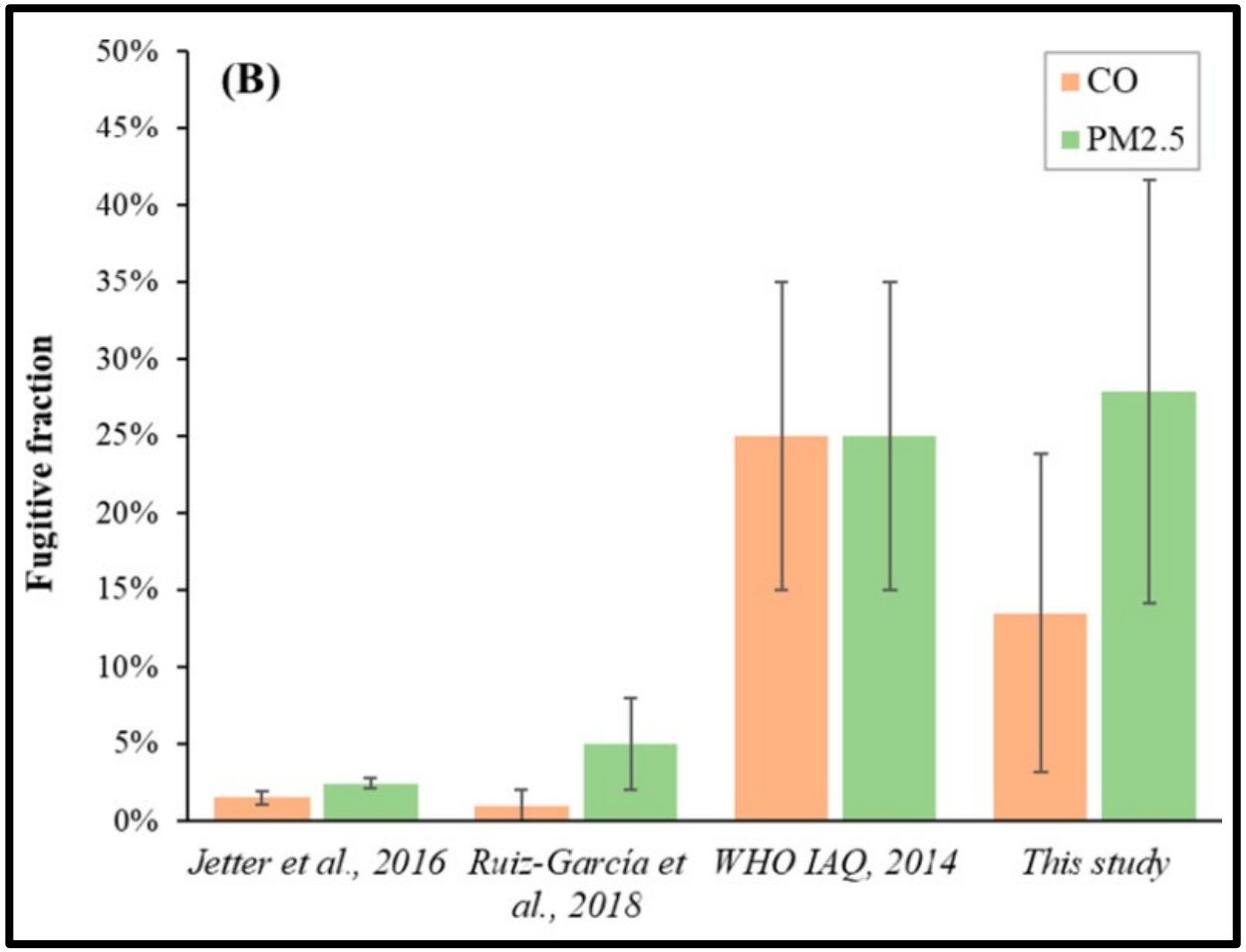
(2020 RECS Survey Data; *Energy Information Administration*)

(Marin et al. 2022; *Journal of the Air and Waste Mgmt. Assn.*)

Indoor air quality is also degraded by RWC activities

- We spend most of our time indoors, especially in the winter.
- ***Fugitive emissions*** have the potential to make up a large fraction of the total emissions
  - CO (up to 25%)
  - $PM_{2.5}$ (up to 43%)
  - Varies by device type

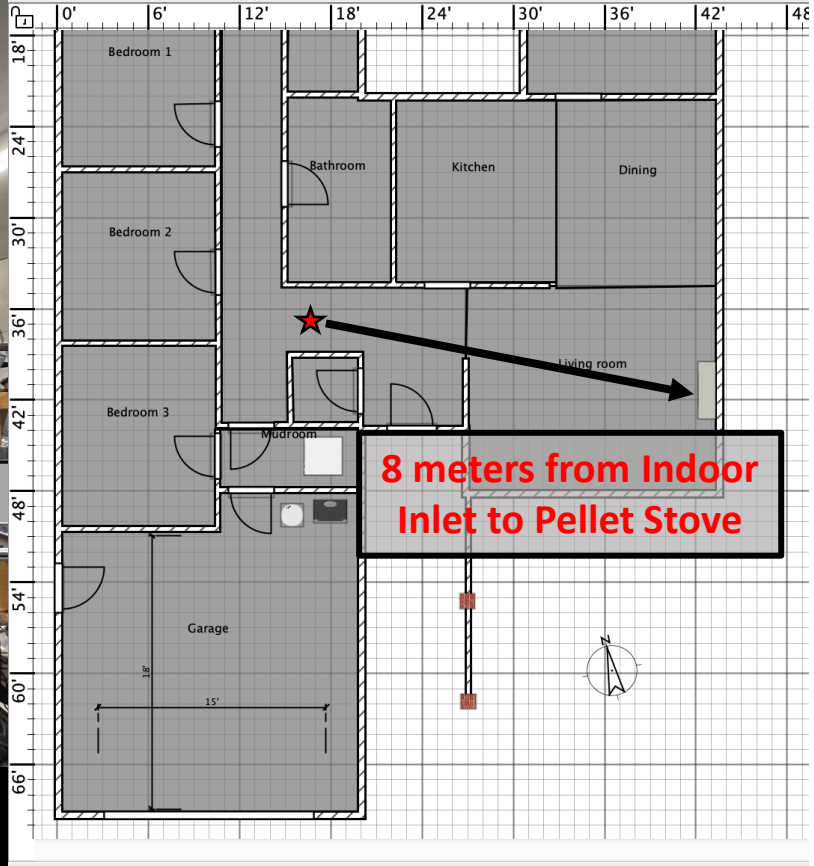


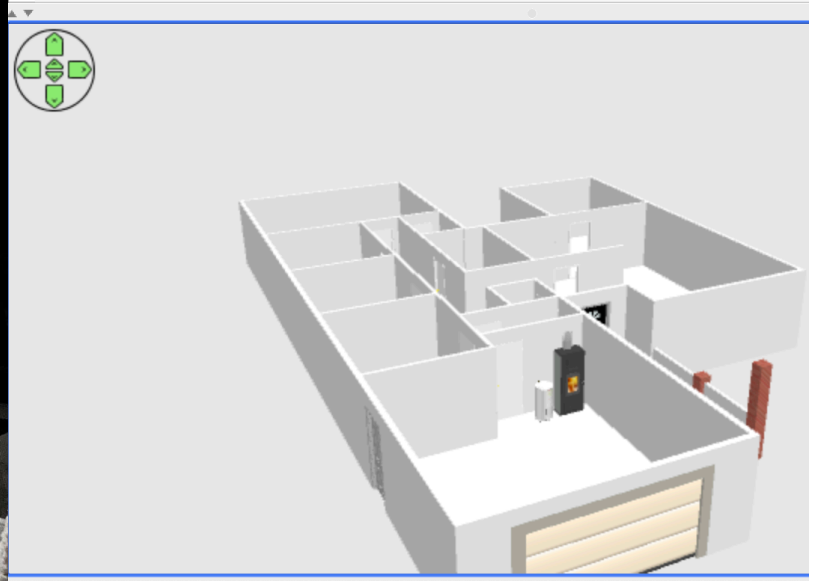


(Shen et al. 2020; *Environmental Science & Technology Letters*)

What are the fugitive emission factors for pellet stove inserts?

- **This study presents 182 fugitive emission factors of an under-characterized source.**
- **Implications for emissions inventories, health impact studies, and policy.**
- **This is the most comprehensive study characterizing fugitive gas- and particle-phase emissions from a pellet stove insert in a real-life scenario.**





House Site

- **Proton Transfer Reaction – Time of Flight – Mass Spectrometer: 176 VOCs**
- **Cavity Ring Down Spectroscopy: CO_2, CO, CH_4, Formaldehyde**
- **Aerosol Mass Spectrometer: Aerosol Composition**
- **Others: SVOCs, BC, NO_x, O_3, $PM_{2.5}$**
- **Automated Indoor/Outdoor Inlet Switching (10-minute Oscillation)**
- **Interior temperature maintained at 20°C by fuel oil furnace**
  - **Constant Recirculation**
- **Indoor Inlet Located Above Central Air Return**
  - **Well-mixed Emissions**

Experimental Design

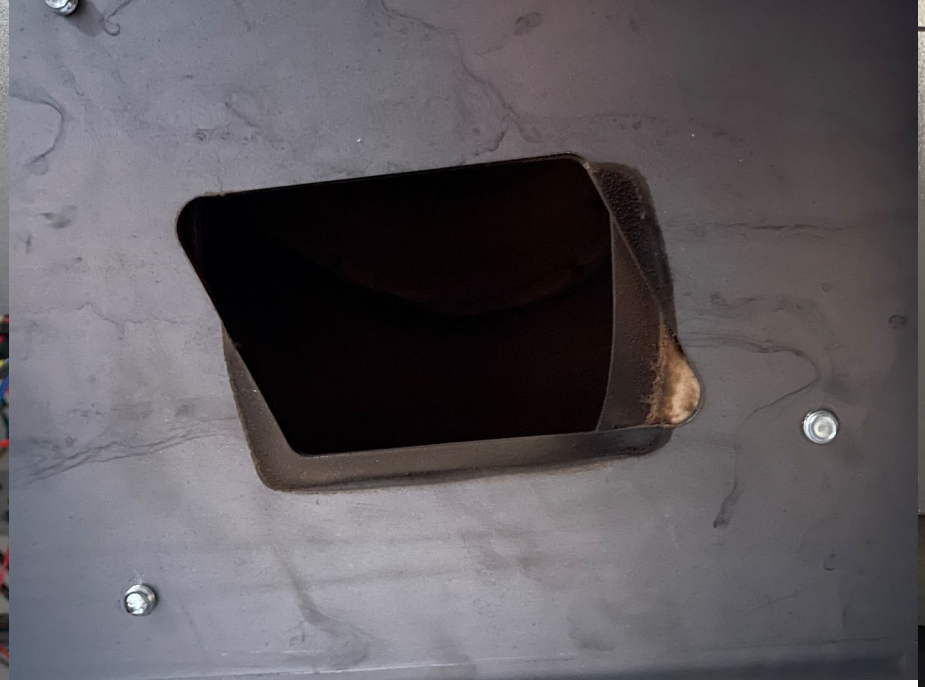
Experiment ID	Length (minutes)	Feed Limit
PS1	180	3
PS2‡	188	3
PS3	189	3
PS4	145	4
PS5	180	4
PS6‡	180	4
PS7†	120	4
PS8†	180	4

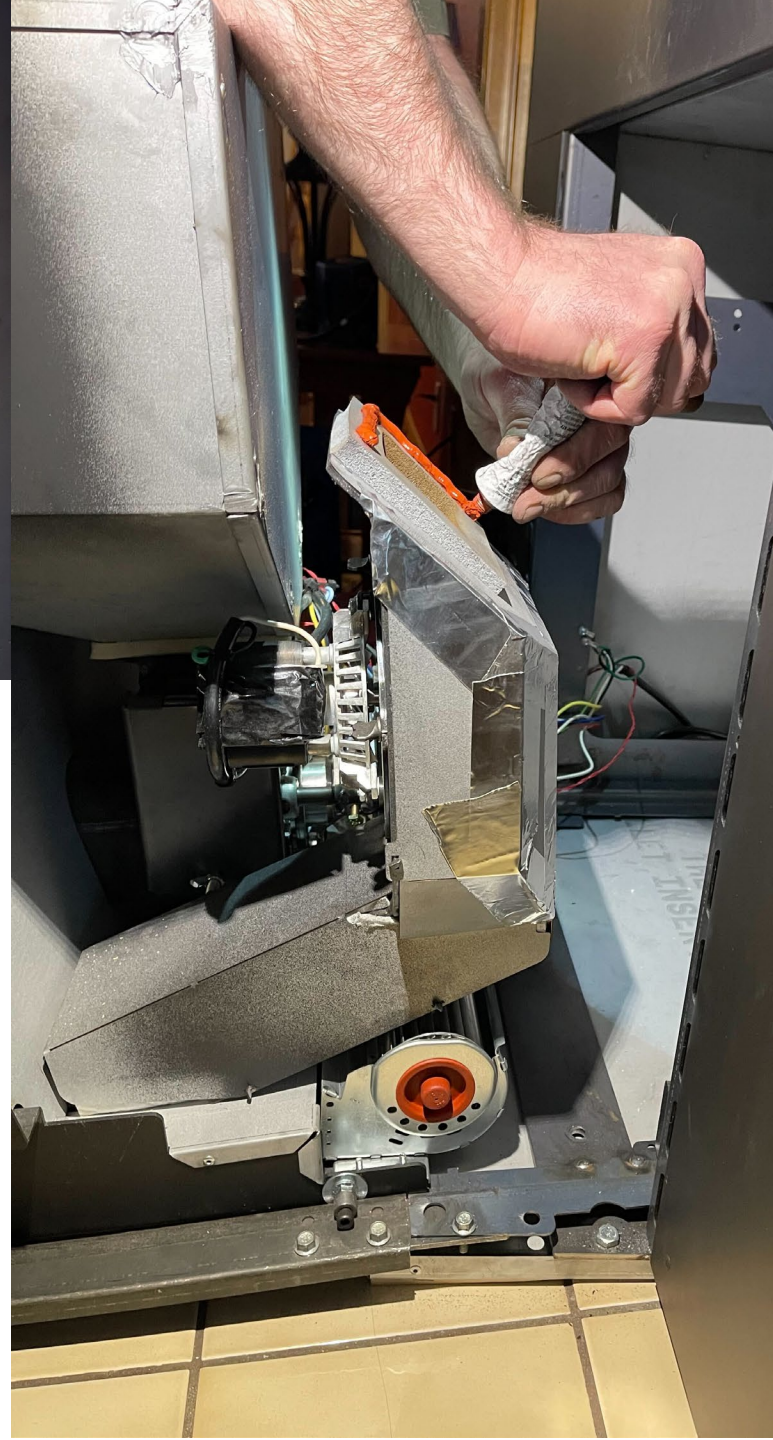
‡ Fire died out. Restarted stove.
† Post-Repair

Harman P35i Pellet Stove Insert

EFs for 176 VOCs, CO, CO_2, CH_4, BC, OA, NO_x (as NO)

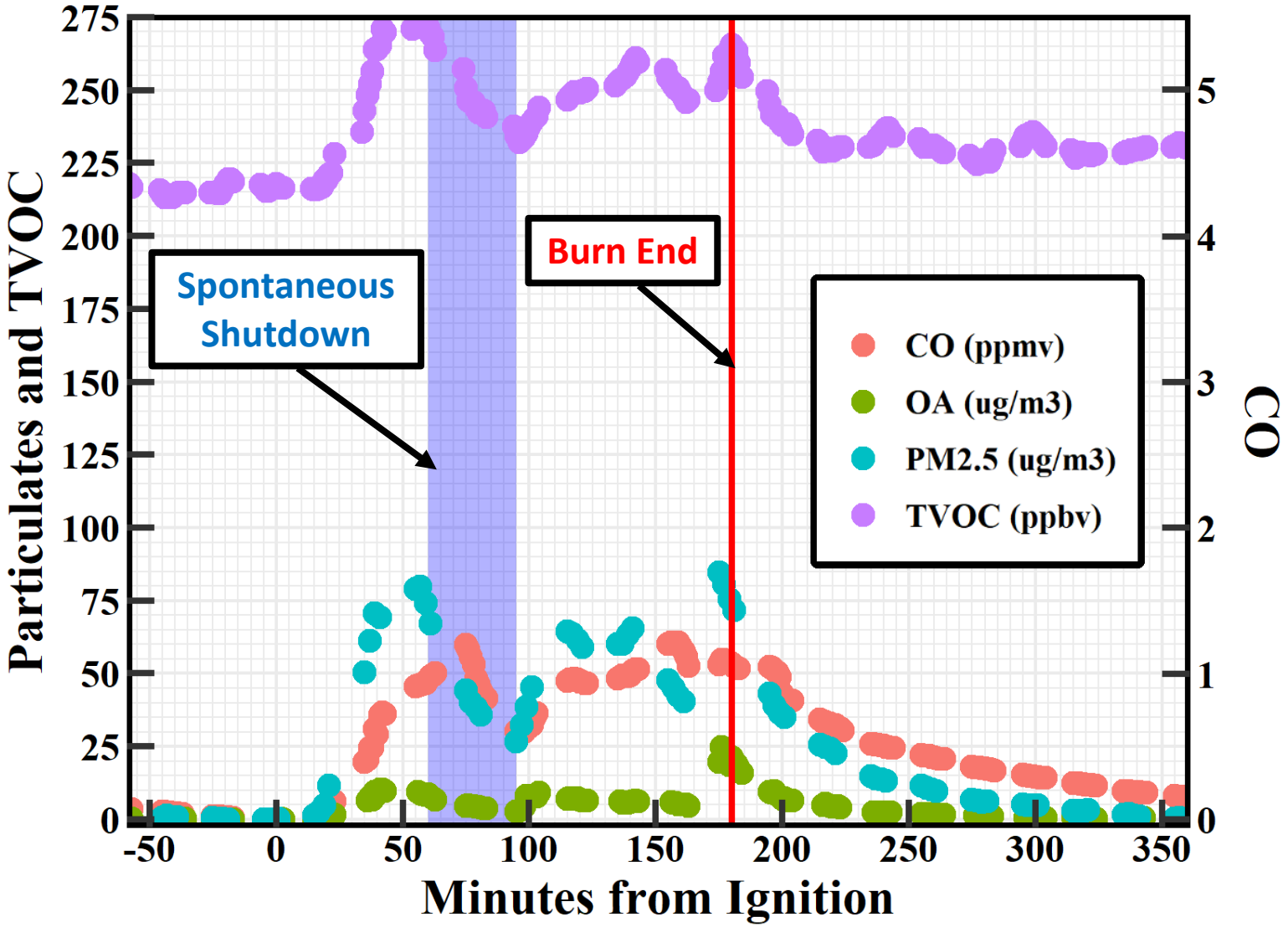
$$EF_X = F_C * \frac{MW_X}{MW_C} * \frac{\frac{\Delta X}{\Delta CO}}{\sum_{x=1}^{n}\left(N_C * \frac{\Delta C_x}{\Delta CO}\right)}$$





Our pellet stove was “leaky”!

Operation of the leaky pellet stove resulted in substantial fugitive emissions of both gas- and particle-phase species.



- Background levels for CO, OA, and $PM_{2.5}$ are near zero
- Total Measured VOC (TVOC) background mixing ratios are ~215 ppbv
- Background indoor mixing ratios for VOCs are generally much higher than outdoors, highlighting indoor sources

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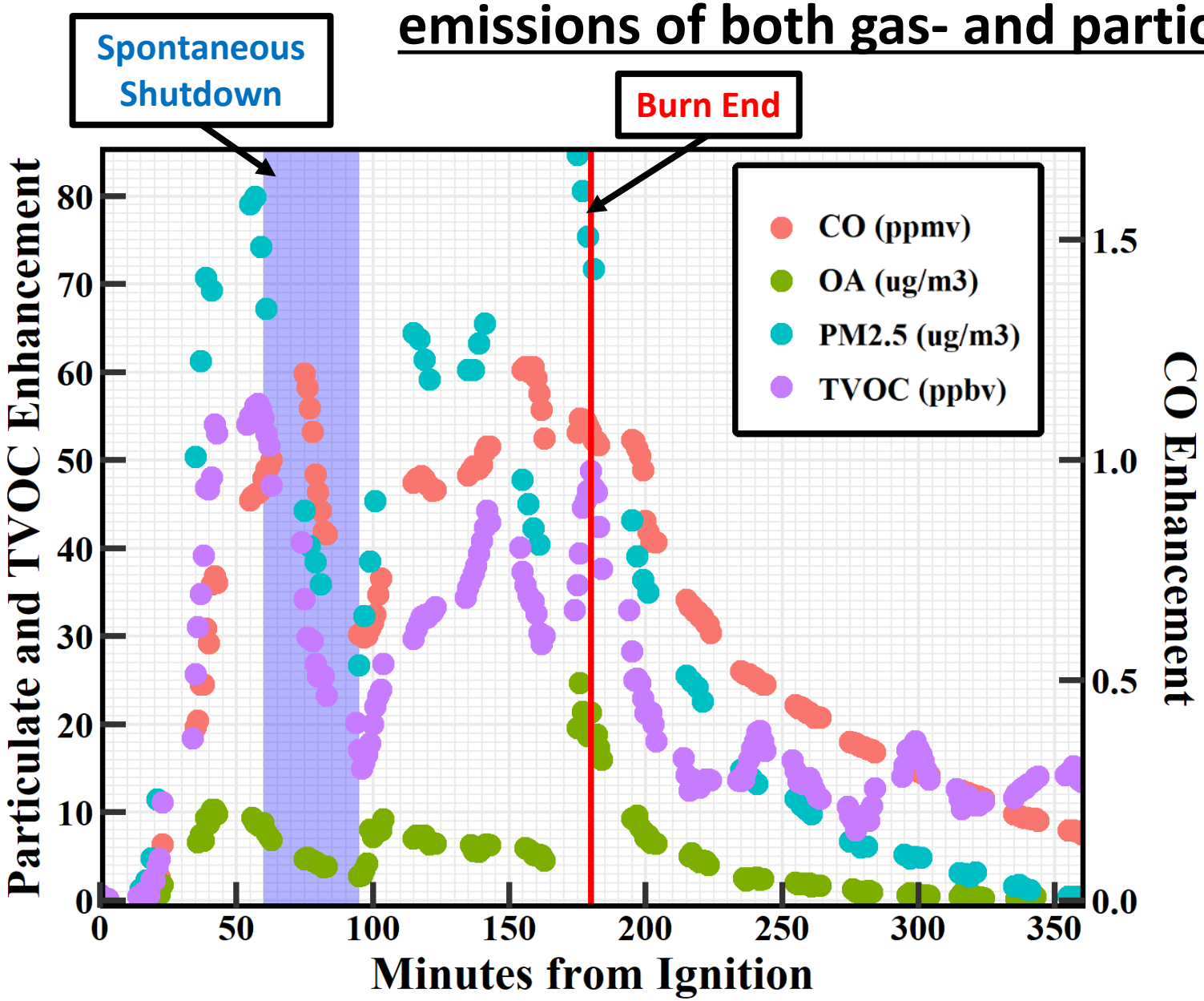
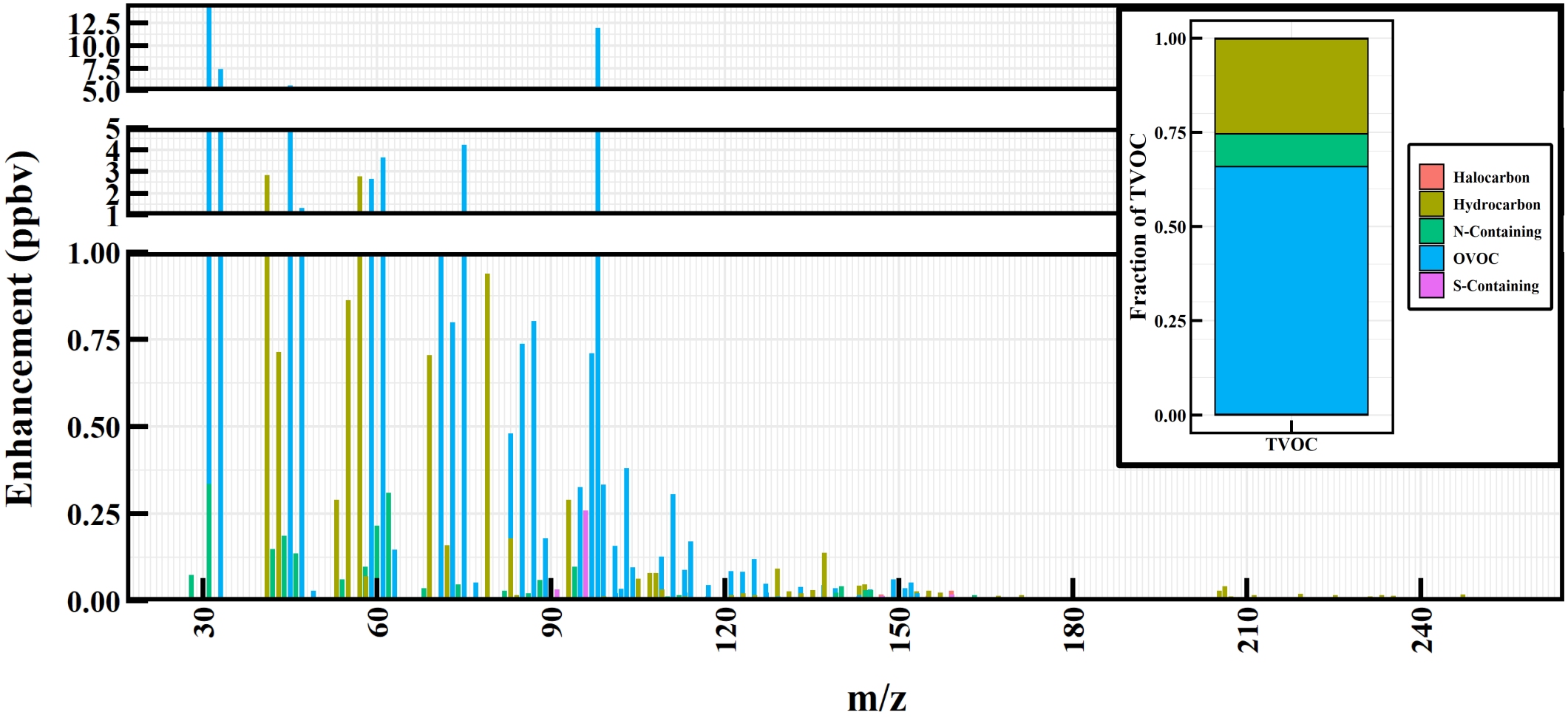


- $PM_{2.5}$ reached up to 80 µg/m^3
- CO was enhanced over 1 ppmv
- VOCs enhanced by up to 57 ppbv
- Particulates decreased rapidly after shutting down the stove, while gas-phase species remained elevated
  - Deposition/Air Exchange
  - HEPA Filtration
  - Surface film partitioning

Oxygenated VOCs make up over 50% of fugitive pellet stoves emissions



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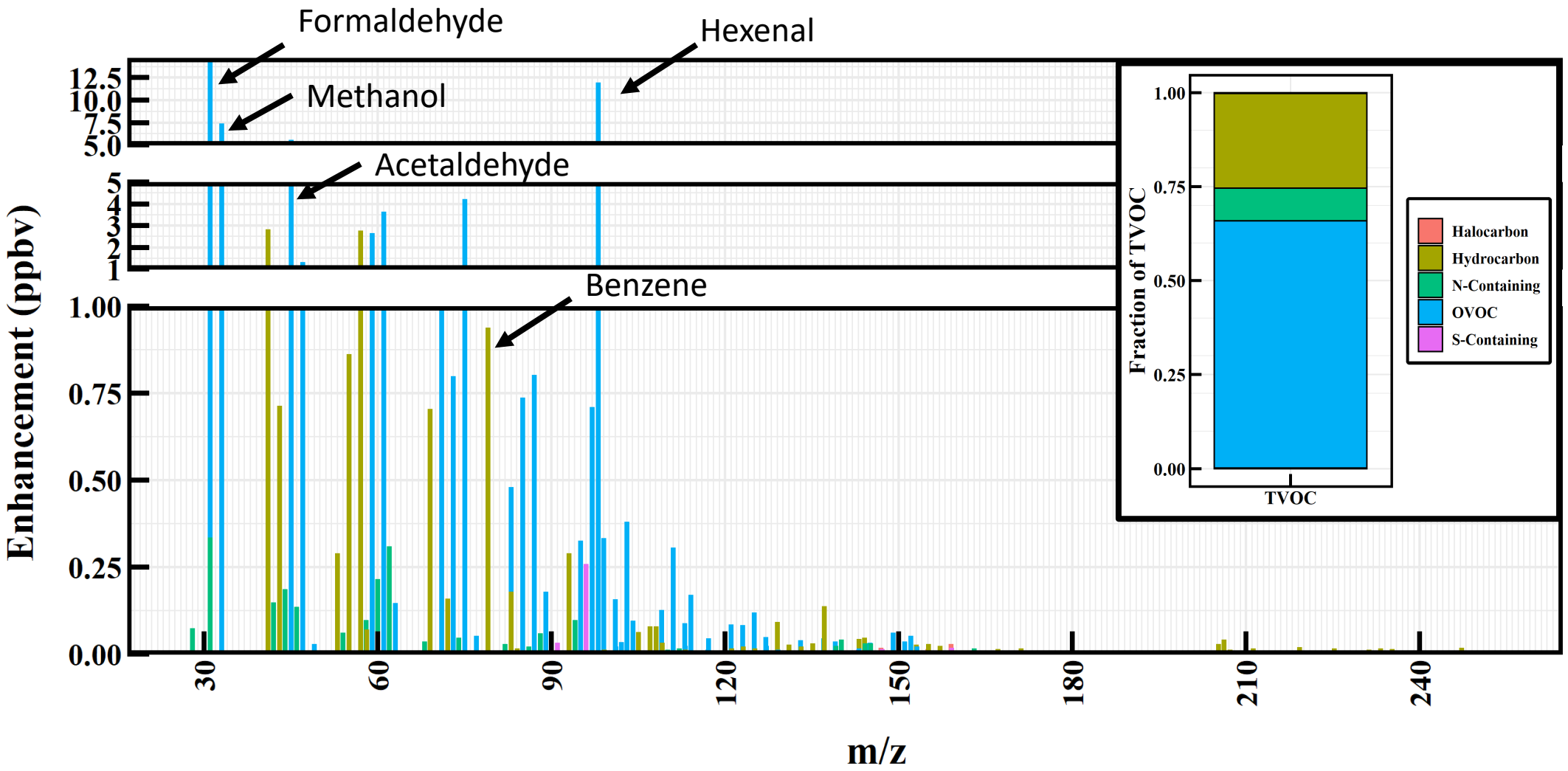
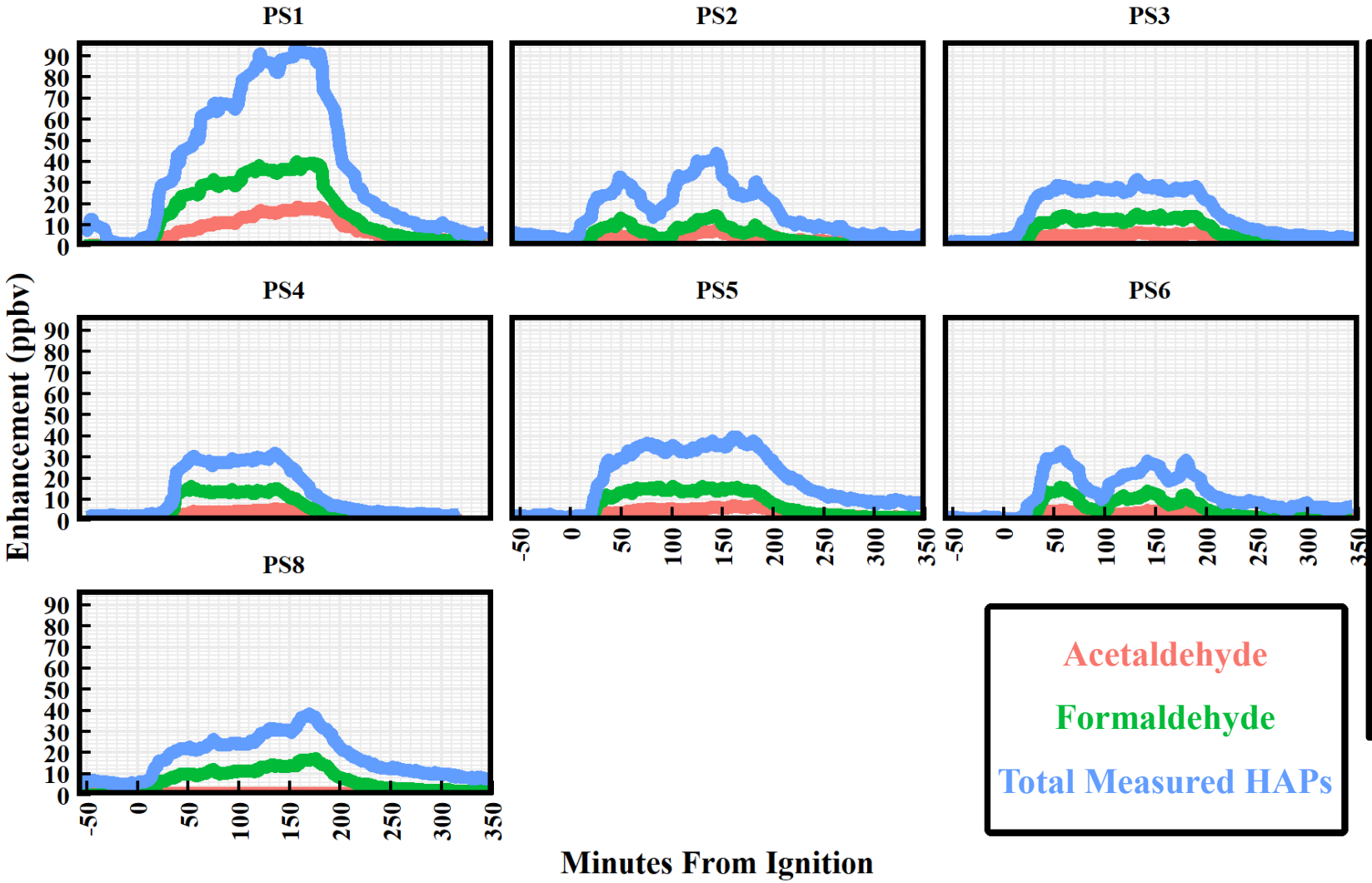
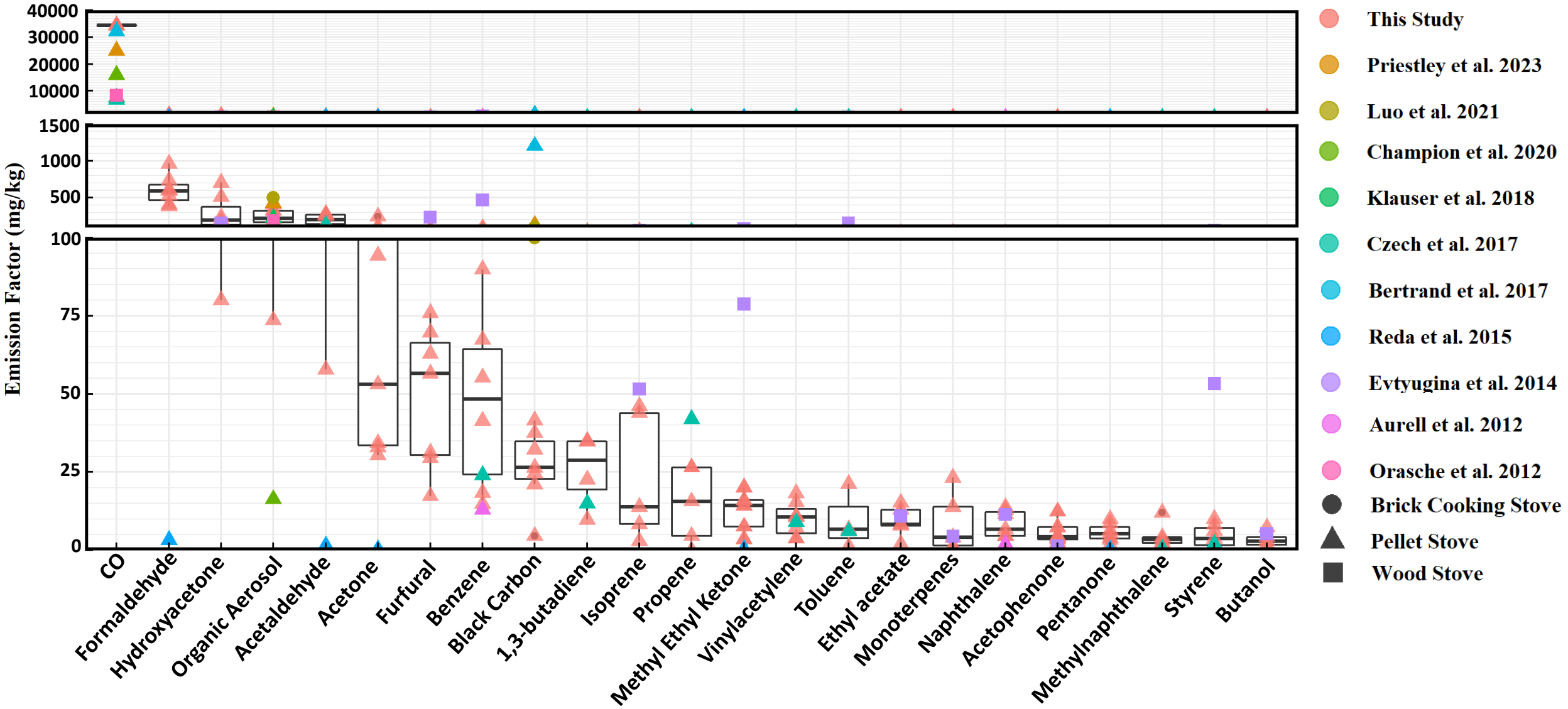


HAPs account for ~50% (30 ppbv) of VOC enhancements for a typical burn!



- The first burn emitted substantially more HAPs than subsequent experiments
- Most Abundant HAPs (excluding CO): Formaldehyde, Acetaldehyde, Methanol, Acetone, 2,3-butanedione, Methyl Glyoxal, Benzene, C8 Aromatics, Toluene, Phenol/Vinylfuran
- The indoor acetaldehyde background in PS8 was so large that no enhancement was observed.

EFs vary in comparison with literature values



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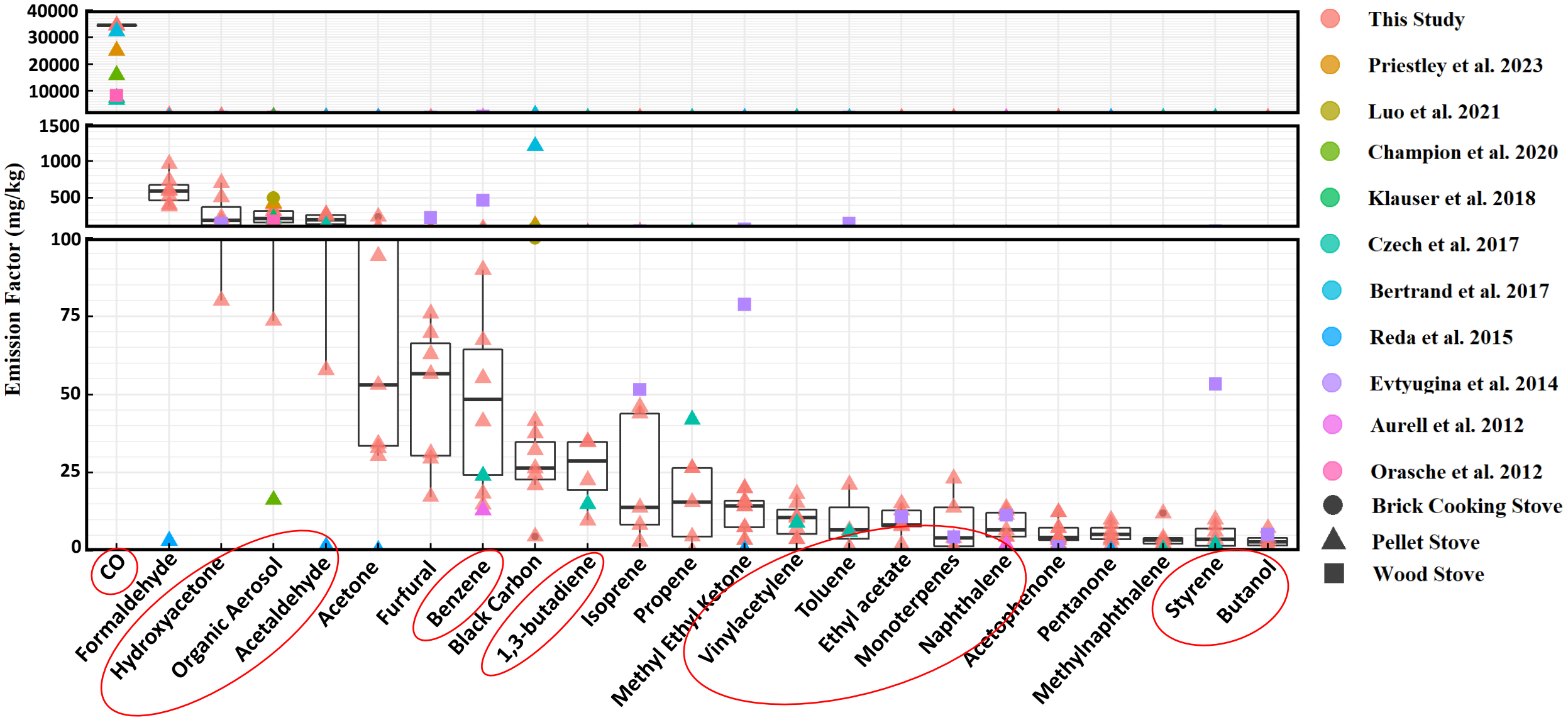

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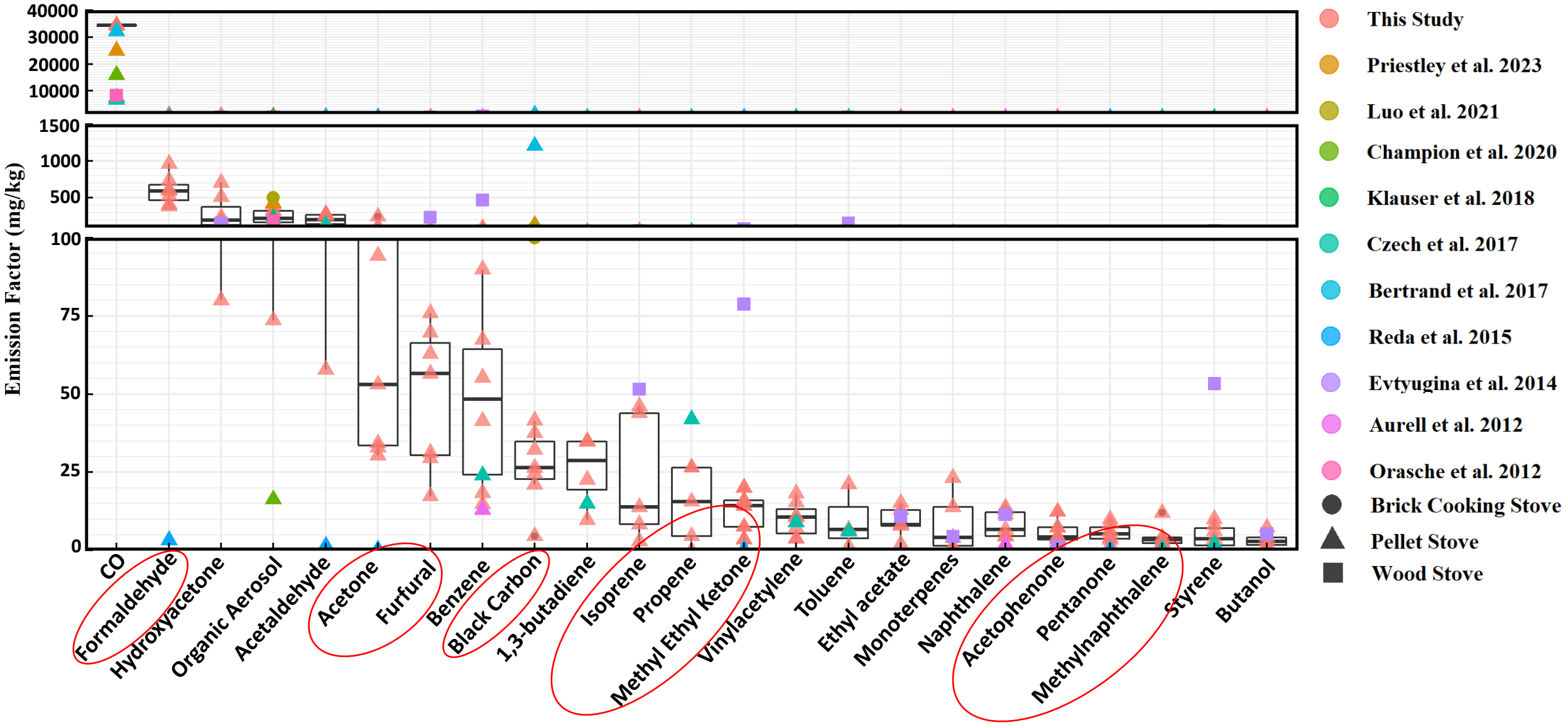

Take Home Messages

- Pellet stoves have the potential to be a major indoor source of OVOCs and HAPs
  - When 'fixed', particle-phase emissions decreased, but gas phase emissions did not change
- Emission factors for fugitive pellet stove emissions have been calculated
  - Small oxygenates dominate fugitive VOC emissions from pellet stove inserts
- If you smell smoke, ***even if you can't see it***, you are being exposed to fugitive emissions of many hazardous air pollutants.
- These were 3-hour burns for one stove in one house, more work needs to be done to assess fugitive emissions and exposure to HAPs for long-term use of RWC devices.

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