Recreational Fire Pit Emissions Testing

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Motivation and Study Questions

Motivation

Initiated and Funded by the Minnesota Pollution Control Agency (MPCA)

Sales of woodburning outdoor recreational wood burning equipment (ORE) – fire pits – have increased significantly since COVID-19 pandemic

Anecdotal evidence of increased use of backyard fire pits in urban/suburban areas

Increased consumer demand for "smokeless" fire pits

Study Questions

Do "low-smoke" fire pits have lower $PM_{2.5}$ emission factors (EFPM) than traditional fire pits?

Provide data for estimating $PM_{2.5}$ emissions from "low-smoke" outdoor recreational fire pit use in Minnesota

What is effect of firewood moisture content (MC) on PM emissions?

Recreational Fire Pit Emissions Testing

$$\text{Emission Rate} = \text{Emission Factor} \times \text{Fuel Consumption}$$

$$\underset{(\text{g-PM}_{2.5}/\text{hour})}{\text{EPM}} = \underset{(\text{g-PM}_{2.5}/\text{kg-fuel consumed})}{\text{EFPM}} \times \underset{(\text{kg-fuel consumed/hour})}{\text{FC}}$$

Measure EFPM, FC and other factors to estimate EPM for firepit use

FC, a function of user behavior, will drive emissions

Need to: Standardize FC across tests
Extrapolate test results to real world use

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Fire Pits Tested

“Low-smoke” Fire Pits

Accessible Campground Fire Ring

Solo Yukon

- 304 stainless steel
- 38 pounds
- 27” diameter
- 17” height

Breeo

- 304 stainless steel
- 62 pounds
- 24” diameter
- 16” height

Pilot Rock

- 3/16” thick steel
- 8” high heat shield with cooling air gap.
- 32” diameter

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Fuels

Split firewood, red oak, maple, and birch, from Minnesota

Round 1	Round 2	Round 3
May 2019	December 2019	June 2021
Moderate to low moisture content (MC)	Same fuel as round 1, cured for 9 months	New pallet of wood, uncured
MC 20-27%	MC 6-9%	MC 14-35%

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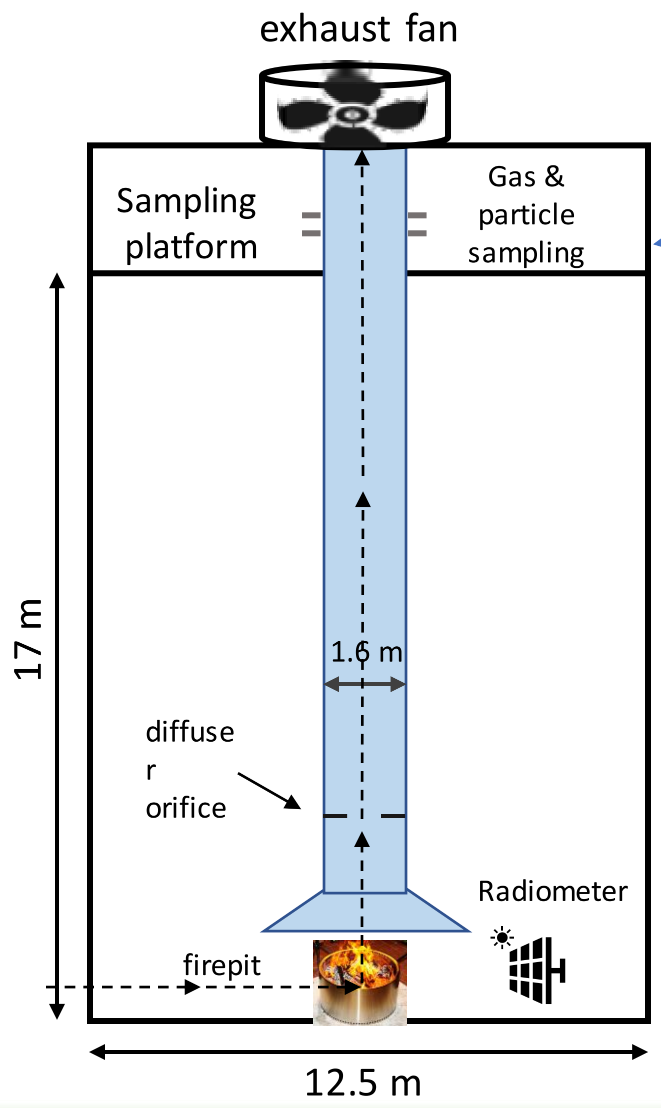

Gas & aerosol instruments sample emissions + ambient air

USDA Forest Service Combustion Facility

Mixing ratio & T uniform across the width of the stack

Outdoor air into chamber at floor along the walls and exhausted through stack

Firepit centered under intake funnel of exhaust stack

Diffuser ring mixes the air and entrained emissions

Instruments on chamber floor measure radiant heat flux, T, RH, CO_2

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Setup

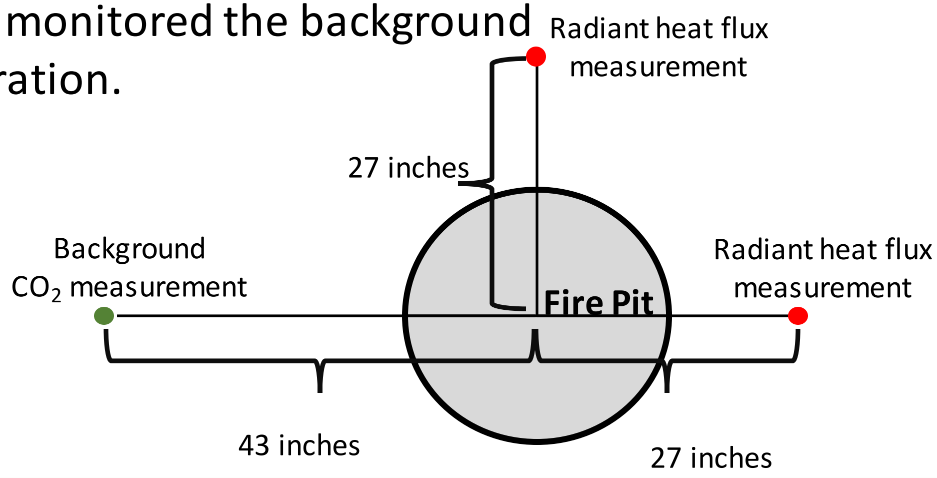
Sampling Platform

- Emissions instrumentation on the sampling platform
- Measure PM, CO_2, CO, CH_4

Continuous measurement
CO2, CO, CH4 via
Cavity Ring-down Spectroscopy

Combustion Chamber Floor

- The firepit under the center of the exhaust stack
- Radiant heat sensors on two sides
- Gas analyzer monitored the background CO_2 concentration.



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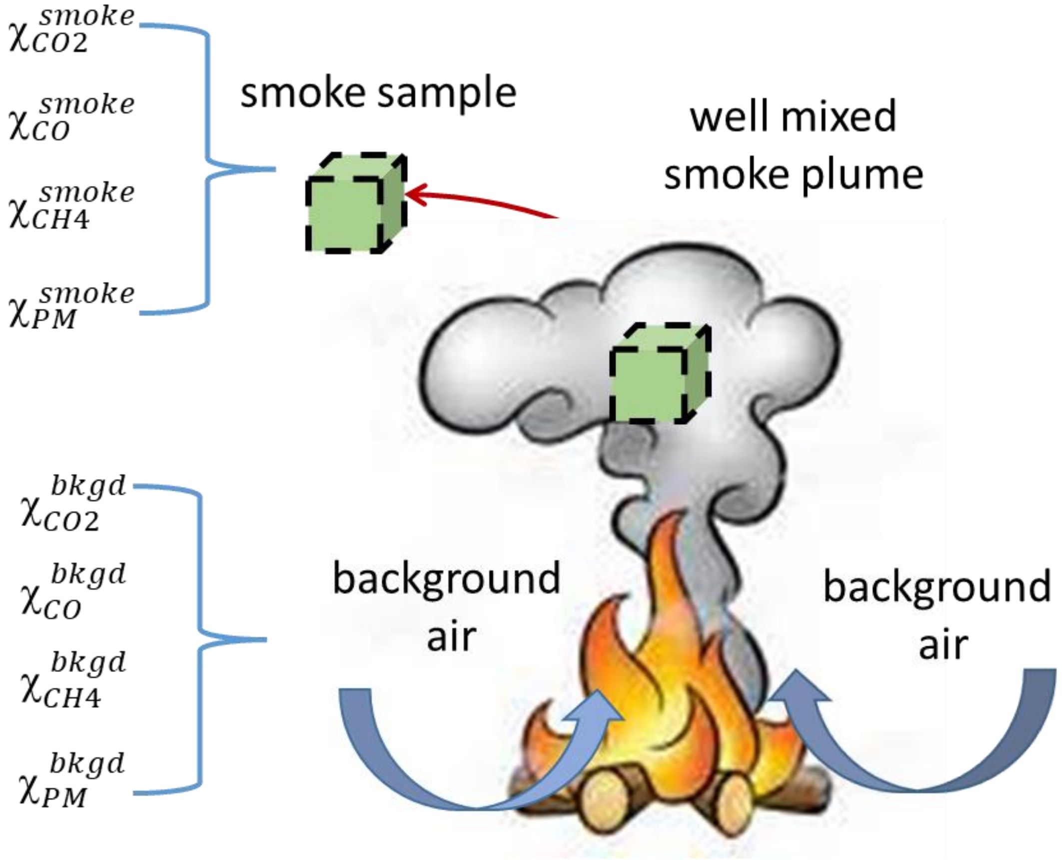
Quantifying EF



Carbon Mass Balance Method

- *All volatilized carbon species measured*
- *Emissions are well mixed*
- *volatilized fuel C% = unburnt fuel C%*

Excess mixing ratio = Emissions

$$\Delta\chi_i = \chi_i^{emitted} = \chi_i^{smoke} - \chi_i^{bkgd}$$

$$EF_X = F_C \times 1000\ (g\ kg^{-1}) \times \frac{MM_X}{12} \times \frac{\Delta X}{C_T}$$

C_T = Sum of volatilized carbon

F_c = Fuel carbon fraction (C%)

> 90% of volatilized C in CO_2, CO, and CH_4

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Burn cycle

Burnup Stage

Achieve steady fire

Fuel additions ~5 min.
Duration ~25 min.
Fuel added ~15 kg

Steady Burn Stage

Typical recreational use

Fuel additions ~10 min.
Duration ~55 min.
Fuel added ~11 kg

Burndown Stage

Smoldering

Begins 10 min. after last steady stage fueling
Duration ~25 min.

Fuel additions weighed. Periodically reserve fuel for moisture content. Extinguish to preserve charcoal & unburnt fuel

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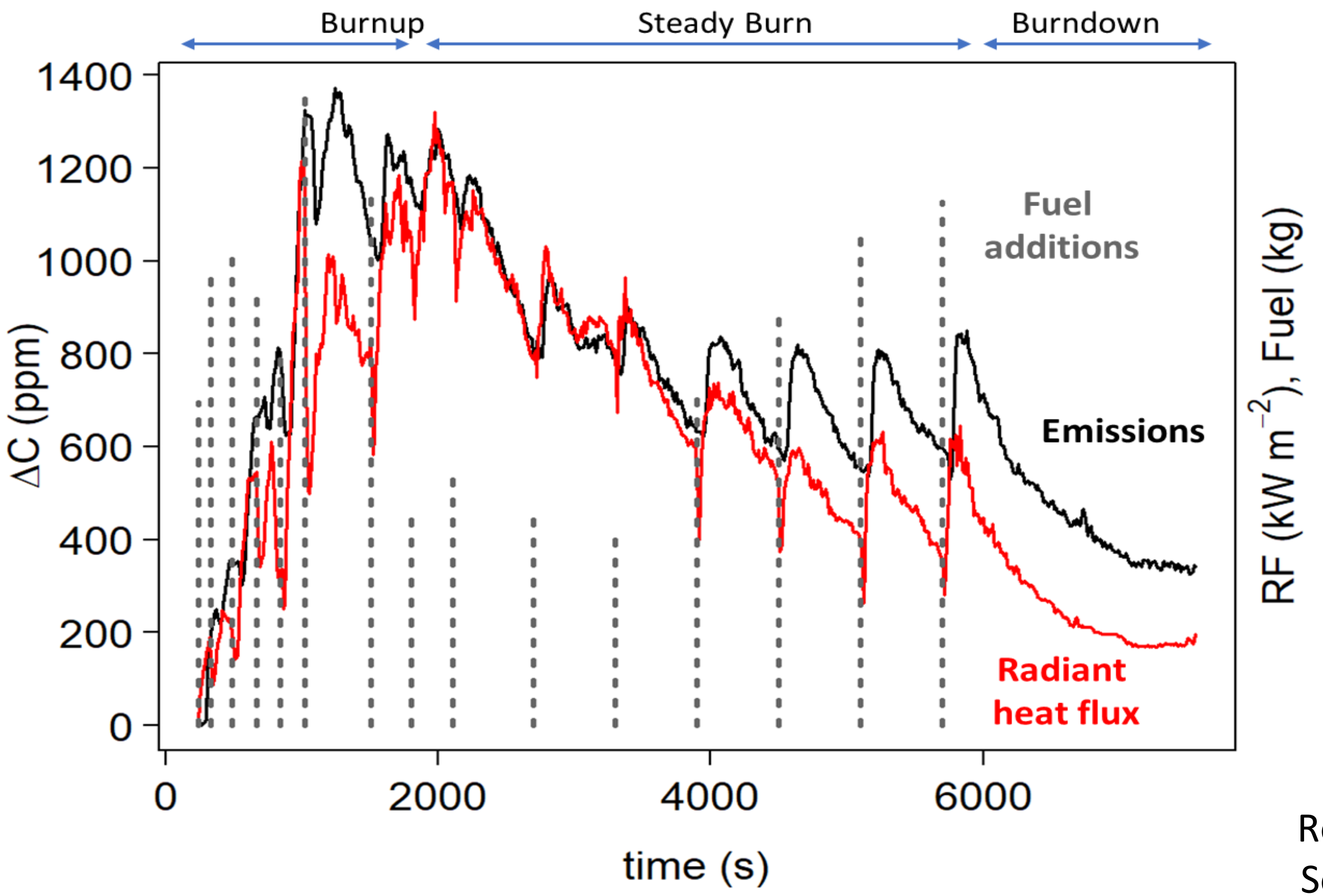
Typical burn profile



Round 1, May 10, 2019
Solo Firepit (MC = 14%)

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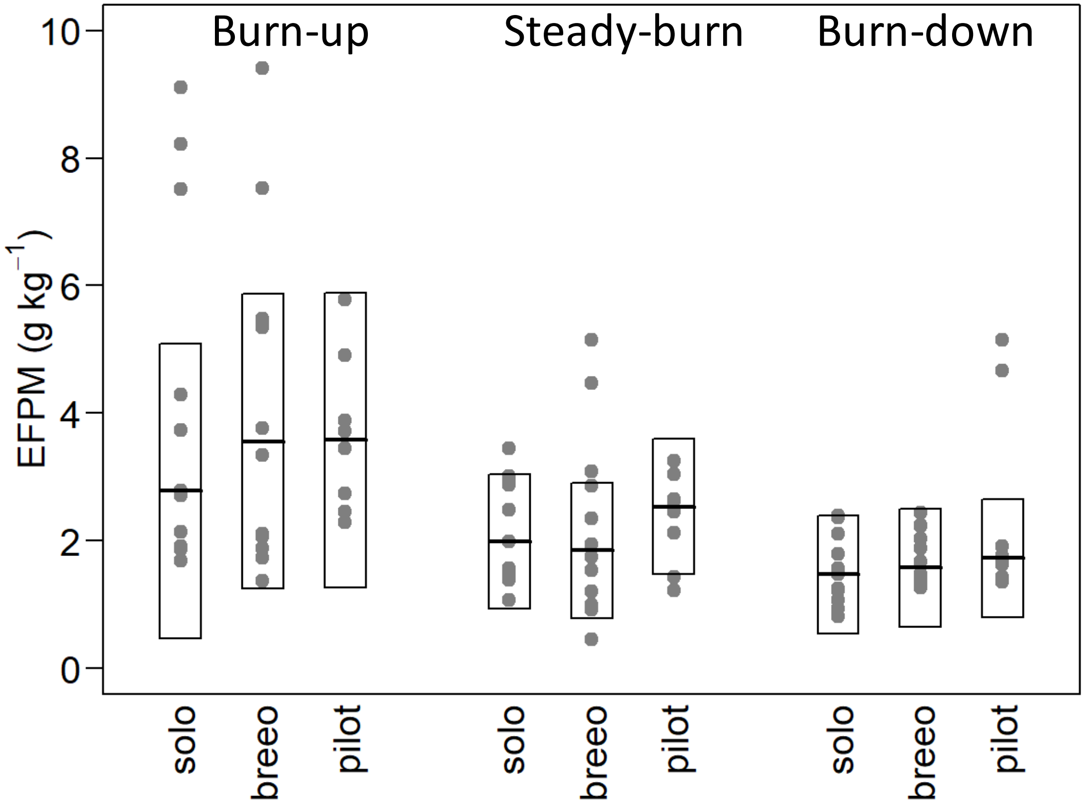
$PM_{2.5}$ Emission Factors



	Burn-up	Steady-burn	Burn-down
EFPM (g kg^{-1})			
Solo	2.8	2.0	1.5
Breeo	3.6	1.8	1.6
Pilot	3.6	2.5	1.7
All	3.4	2.1	1.6

No. tests = 31, Moisture Content: 6 – 35%

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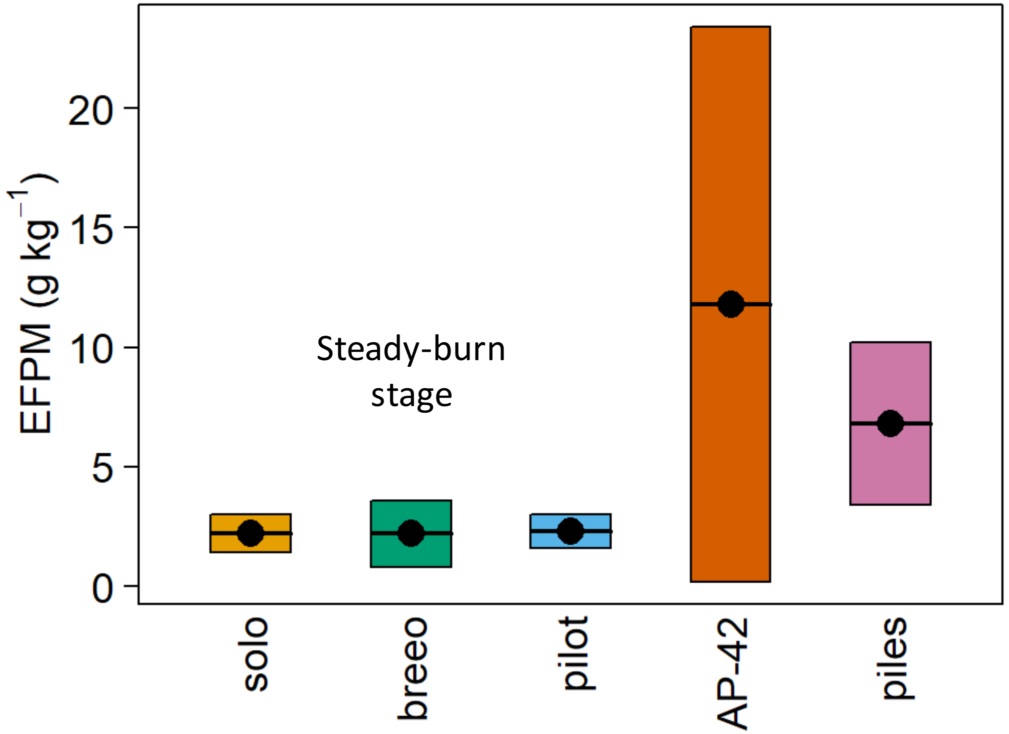
$EFPM_{2.5}$: "low-smoke"/barrel design fire pits *versus* AP-42 and pile burns of logging slash



"low-smoke" / barrel design fire pits ~ 2.2 g kg^{-1}

AP-42 (outdoor woodburning device) = 11.8 g kg^{-1}

Pile burn of logging slash = 6.8 g kg^{-1}

AP-42 from Houck et al. (2001)
Pile burns from Wright et al. (2010)

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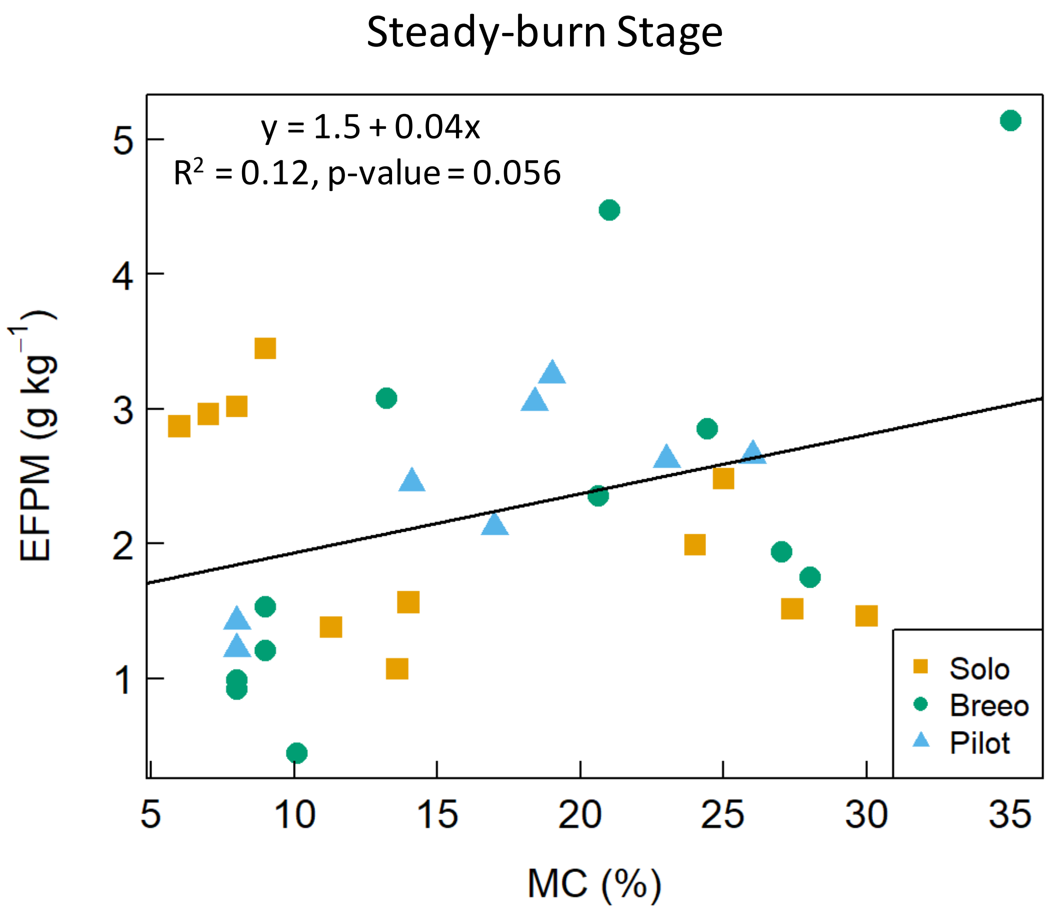
Does firewood moisture content influence EFPM?

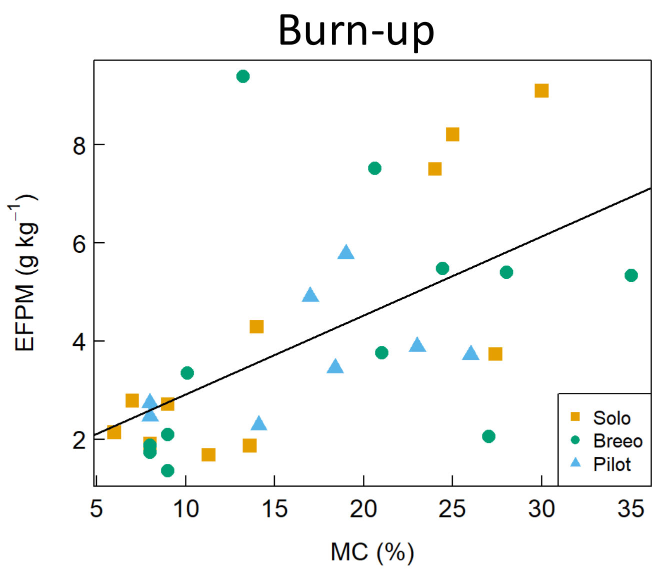


No strong influence for steady-burn stage

Not enough tests to sort fire pit/MC effects

MC does impact burn-up stage:

EFPM increases with MC



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Weighting combustion phases for single EF based on firewood *input*

Weighted EF = 2.0 g kg^{-1} (4.0 lb ton^{-1})

Create model of typical burn:

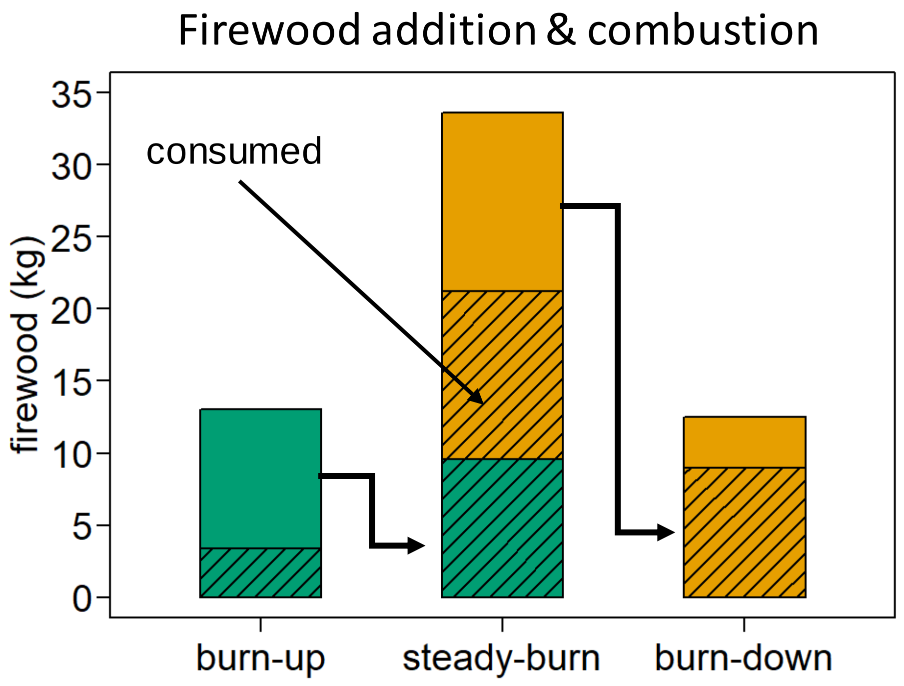
Test data – EF, firewood addition rate, combustion completeness

Assumptions for typical burn –

- Similar fueling approach and appliance
- Split hardwood at MC = 15%

Burn stage durations (minutes) –

- Burn-up = 20, Steady-burn = 120, Burn-down = 60



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Emission Inventory Impact

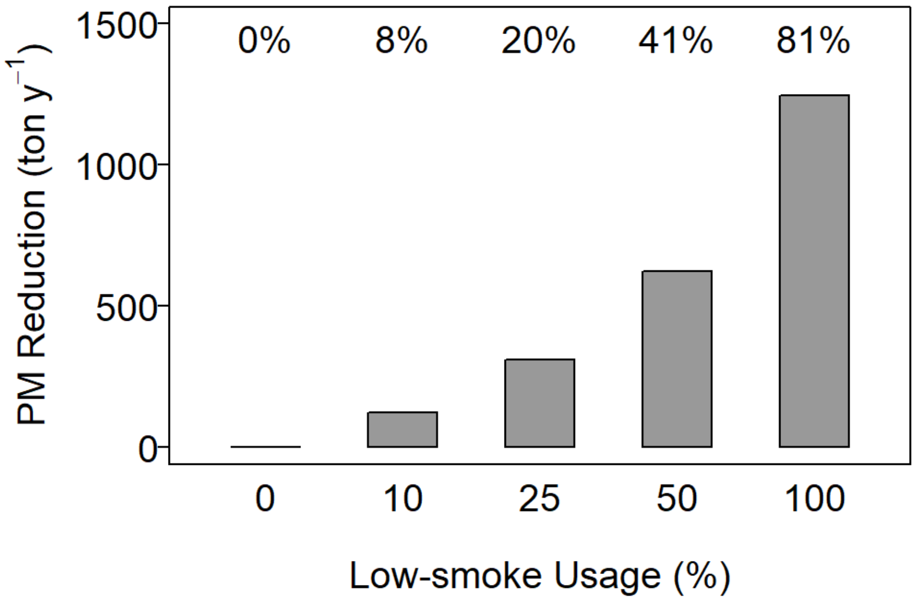
Minnesota residential wood combustion survey
MSP Metro region estimates for 2018:

Outdoor Recreational Equipment (ORE) = 358,371

Annual wood use = 0.25 cord/piece = 0.363 ton/piece

Annual PM2.5 = 1533 ton (EFPM = 23.6 lb/ton)

Our ‘typical burn’ implies
~ 9 burns / year/ ORE



Replacing 1 fire pit provides ~ 7 lb y^{-1} reduction in PM

1 pp increase ‘low-smoke’ ORE = 1.24% reduction in emissions

Conclusions

EFPM for “low-smoke”/barrel design fire pits 80% lower than AP-42

PM emissions normalized to radiant heat flux increase with MC

Higher MC → lower radiant heat yield → greater firewood use → more emissions

Improved MC handling and increased test number would have reduced uncertainty in emissions prediction

Additional Questions

How does real world fire pit activity compare with standardized fueling used in testing?

How do fire pits used in testing compare versus other designs?

Small EFPM difference between “low smoke” & Pilot suggests physical dimensions are important factor

THANK YOU

QUESTIONS?