Influence of Combustion Factors on Biomass Emissions

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Pollution from Wildland Fires

- Emissions from wildland fires, including wildfires and prescribed forest and agricultural fires, are recognized for their impact on
  - ambient air quality
  - respiratory health

Are Emissions Inevitable?

- Is there nothing we can do about emissions other than mapping the path of smoke and informing the impacted public about health risks?
- Or can we undertake land management processes to limit the impact of wildfires?
- And can we optimize conditions under which prescribed burns are done?

This will be the focus of this talk….

Emissions Vary

- The concentration and pollutant species vary as a function of
  - Fuel variables
    - Species
    - Moisture
    - Season
  - Burn variables
    - Fire intensity and combustion completeness
    - Stage of burn
  - Meteorology
    - Humidity
    - Wind
    - temperature

These effects have been minimally characterized, if at all.

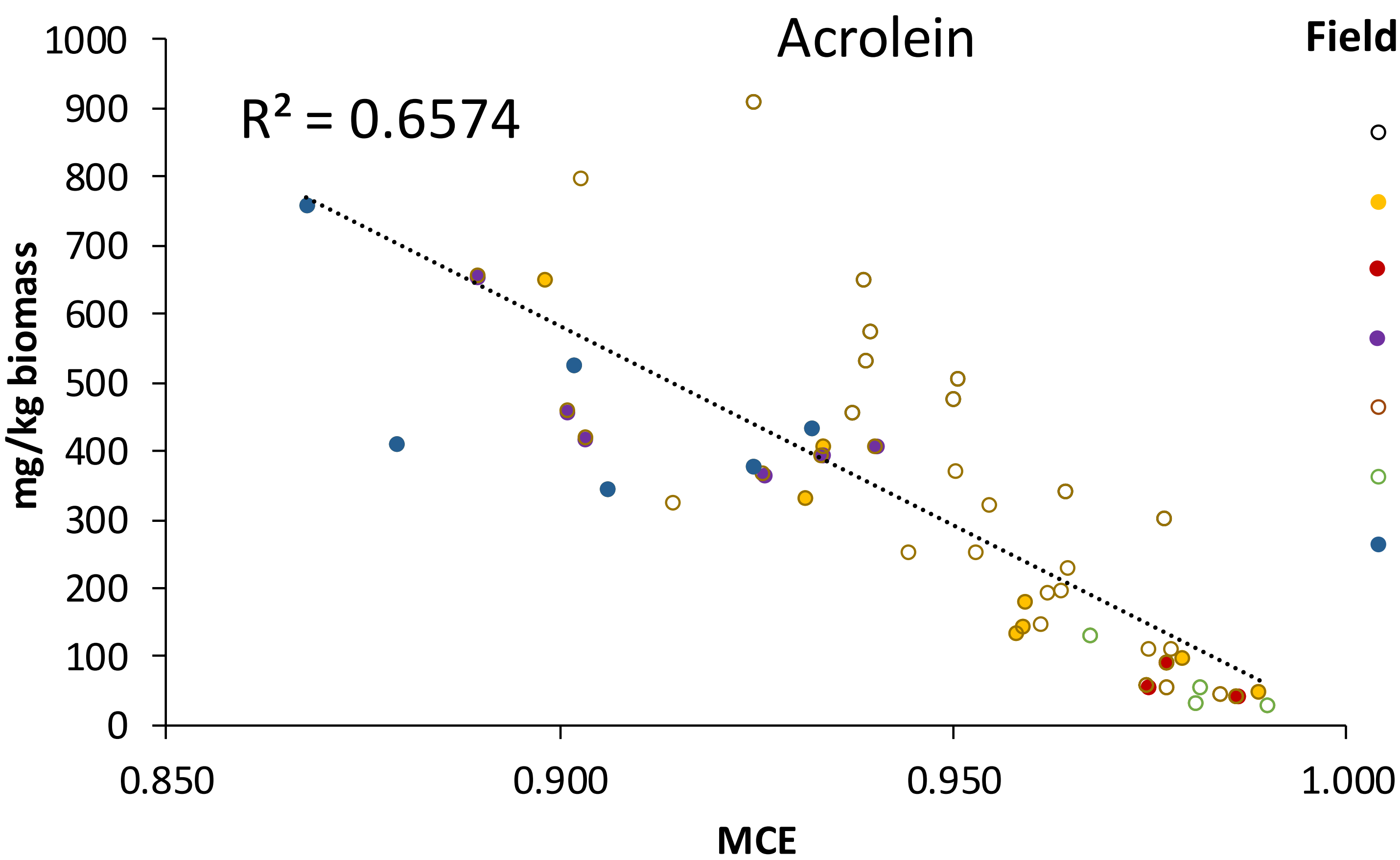
Definitions

- Quantification = Emission factor x Activity level
  - Emission factor = mass of pollutant/mass of fuel
  - Activity level = acres burned, mass combusted
- Modified Combustion Efficiency

$$MCE = \frac{\Delta CO_2}{\Delta CO_2 + \Delta CO}$$

  - Does not account for unburned carbon in PM
  - Does not account for unburned biomass

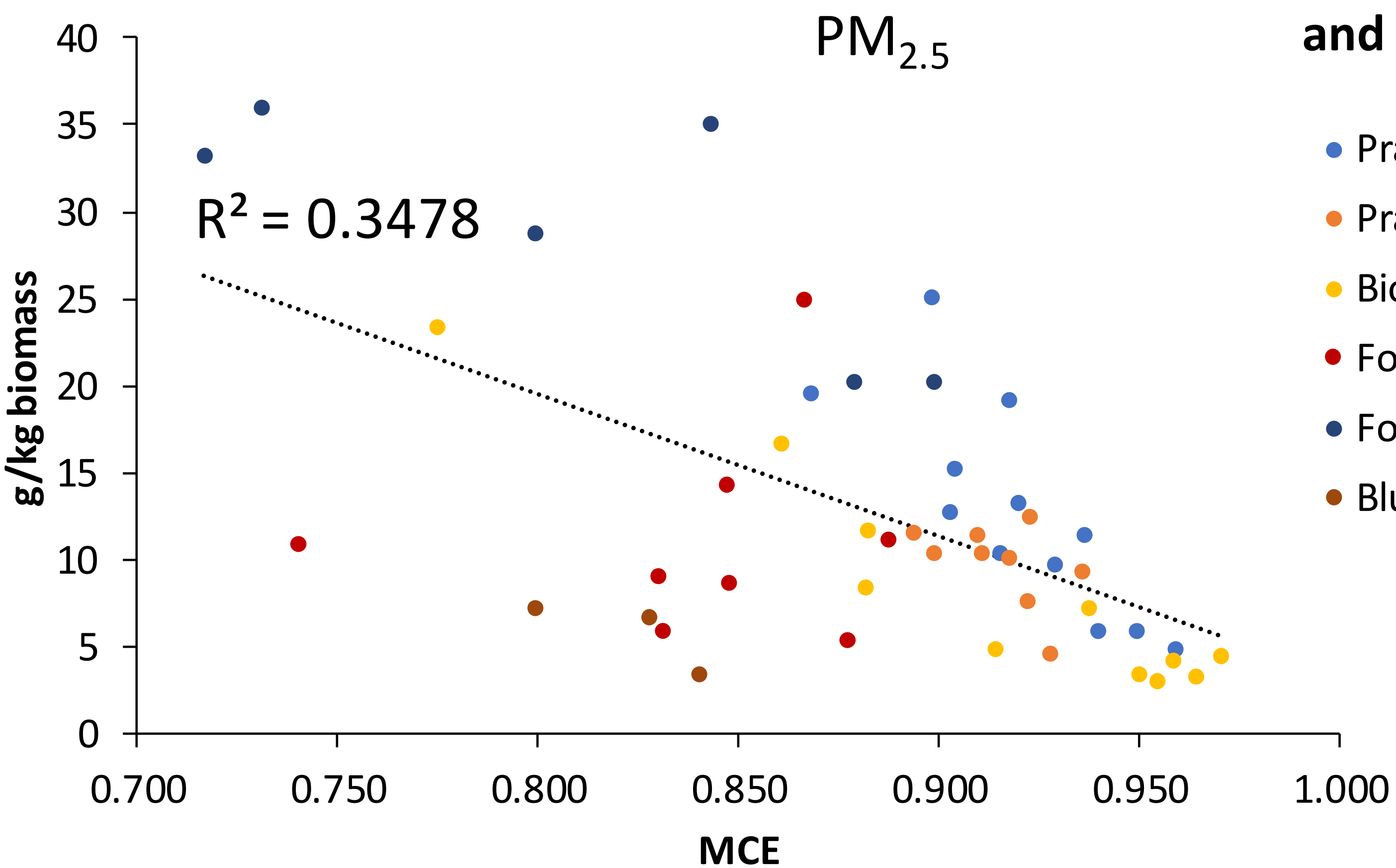
VOC vs MCE



Seven Sources, Field and Laboratory

- Prairie, KS - Spring
- Biomass piles, OR
- Forest, FL - OBTF
- Forest, FL - Field
- Bluegrass, ID - OBTF
- Wheat, WA
- Forest, SC - Field

$PM_{2.5}$ vs MCE



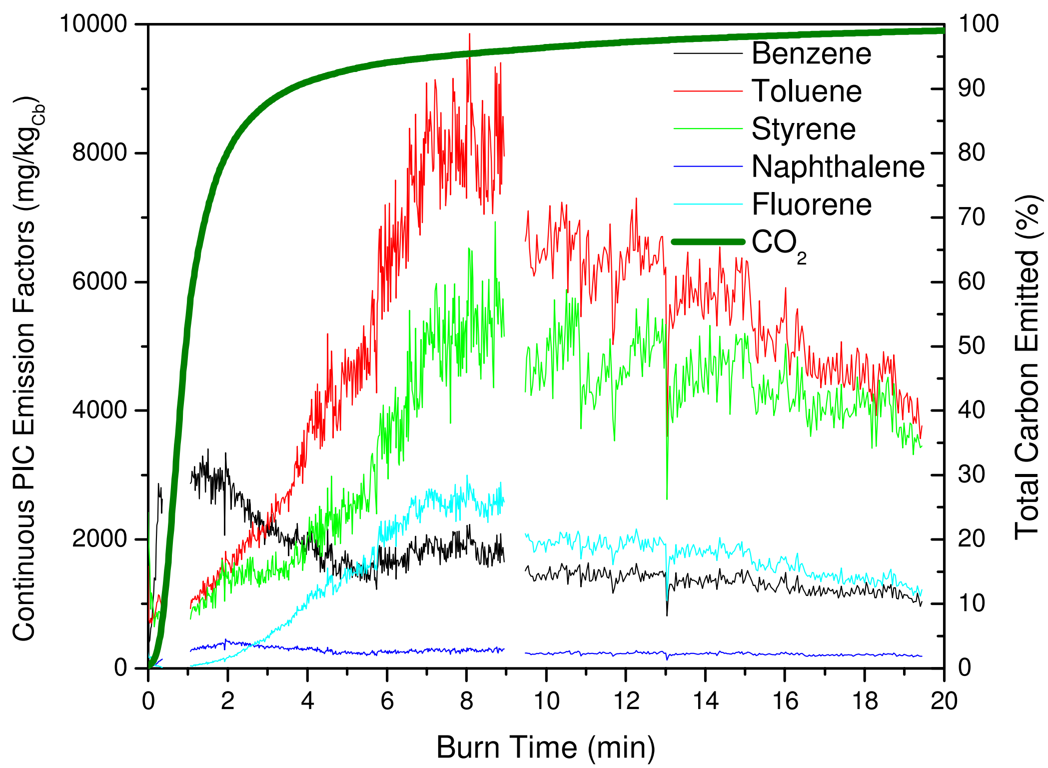
Six Sources, Field and Laboratory:

- Prairie, KS - Fall
- Prairie, KS - Spring
- Biomass piles, OR
- Forest, FL - OBTF
- Forest, FL - Field
- Bluegrass, ID - OBTF

Carbon Oxidation and Pollutant Concentration

Real time measurements on biomsss

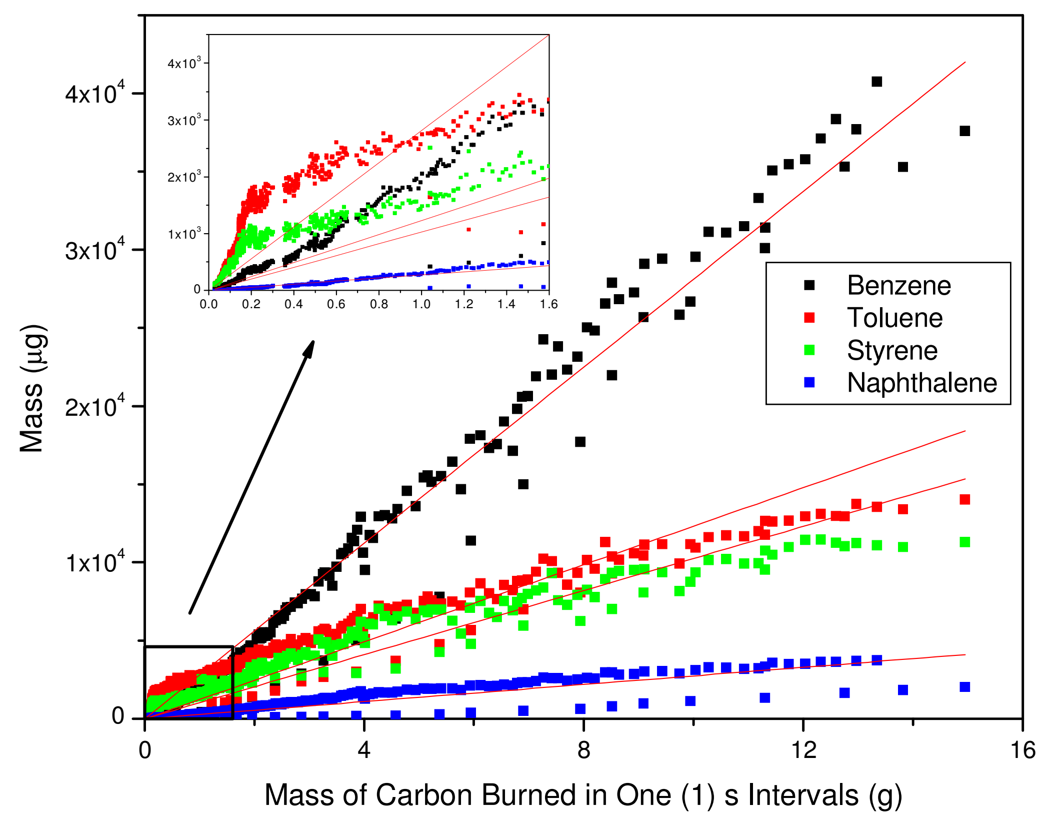
- Real time measurements during combustion



Carbon Oxidation and Pollutant Concentration

- Pollutant concentrations parallel carbon oxidation rate. High conversion rate of C to CO2 = high pollutant concentration, first order.

Real time measurements on biomass



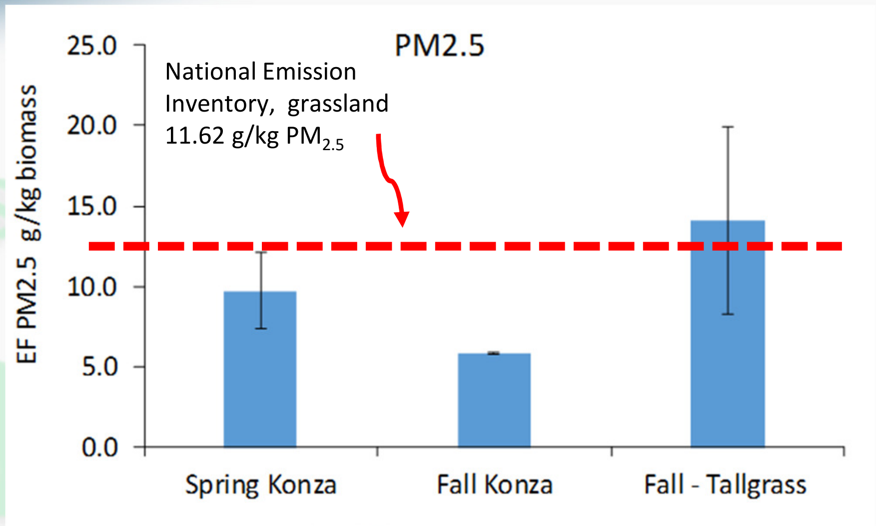
Emissions and Combustion Quality

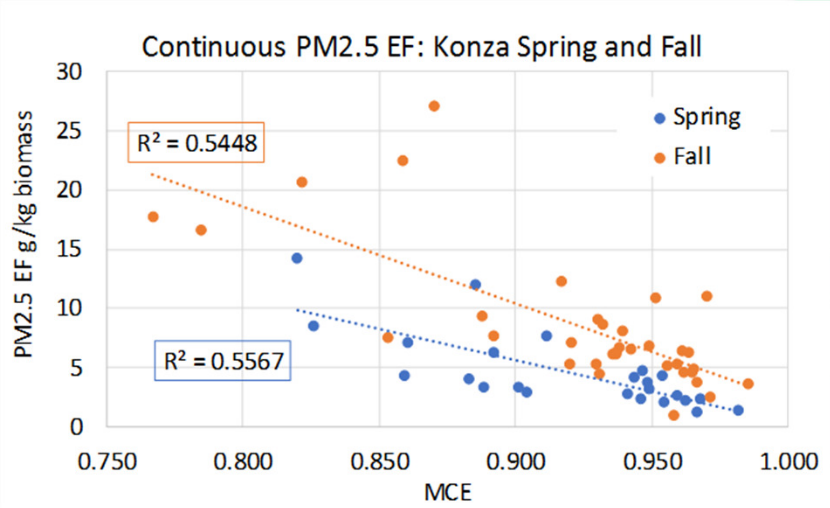
Emission factors are now being categorized as either “Flaming” or “Smoldering”

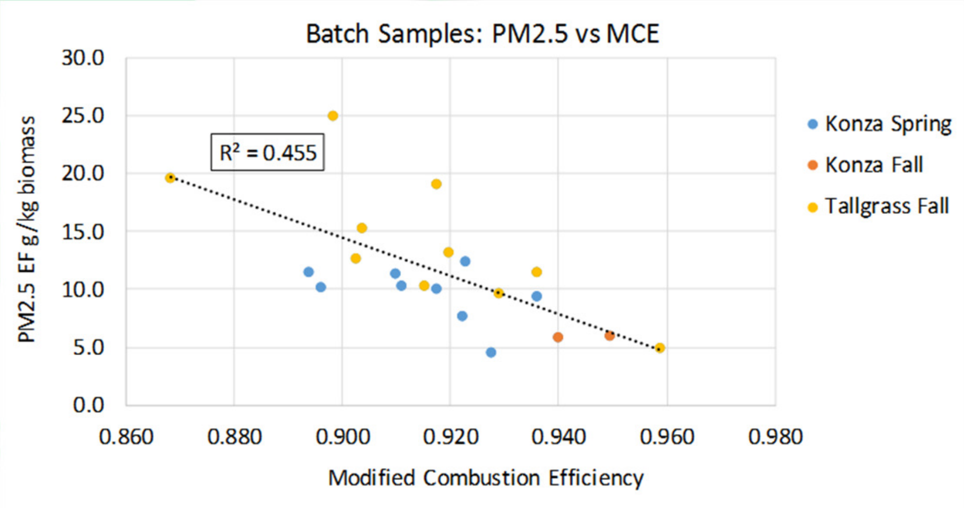
- A semi-arbitrary designation of MCE < 0.84≡ Smoldering, MCE > 0.95 ≡ Flaming
- However, fires are a continuum between flaming and smoldering with all fire conditions occurring simultaneously across the burn area

$PM_{2.5}$ Results in the Flint Hills, KS

- Seasonal differences in particulate matter ($PM_{2.5}$) emissions?
- $PM_{2.5}$ MCE relationship, Continuous and Batch samples

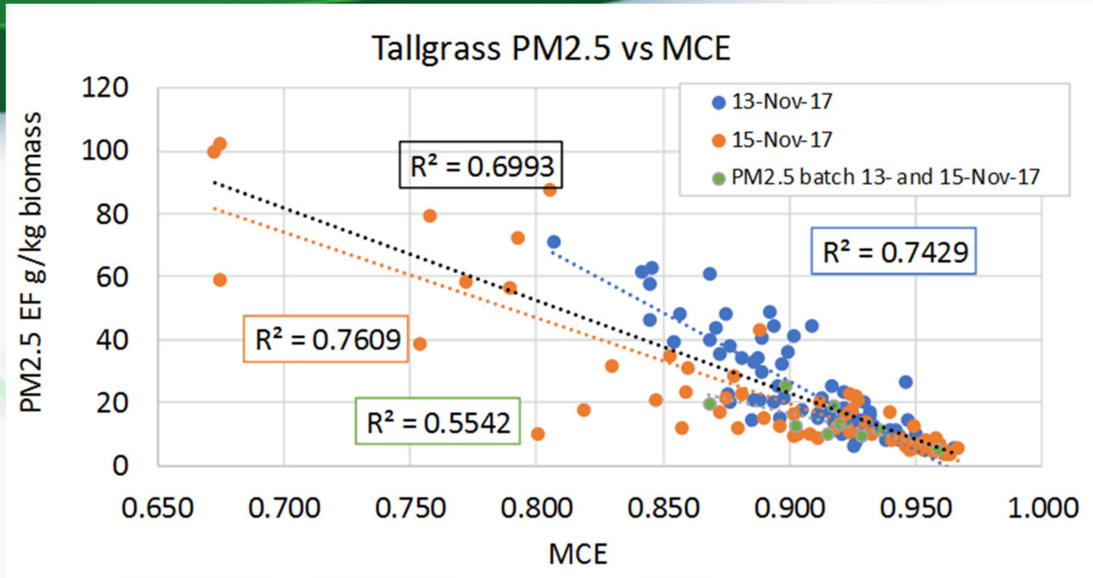


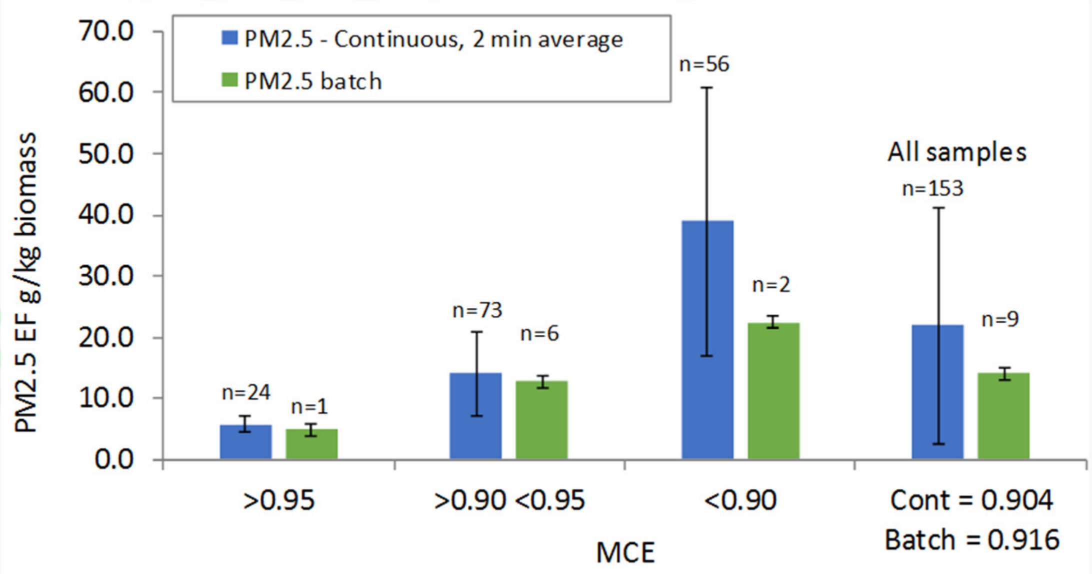




$PM_{2.5}$

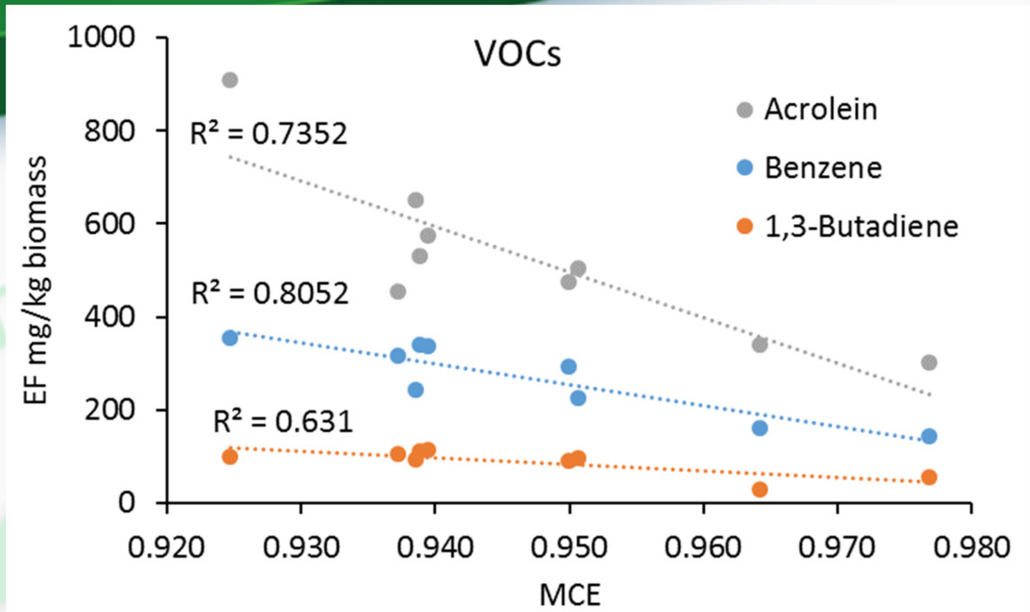
- Good relationship between particulate matter (PM) and combustion efficiency, MCE.
- Better combustion (higher MCE) = less PM

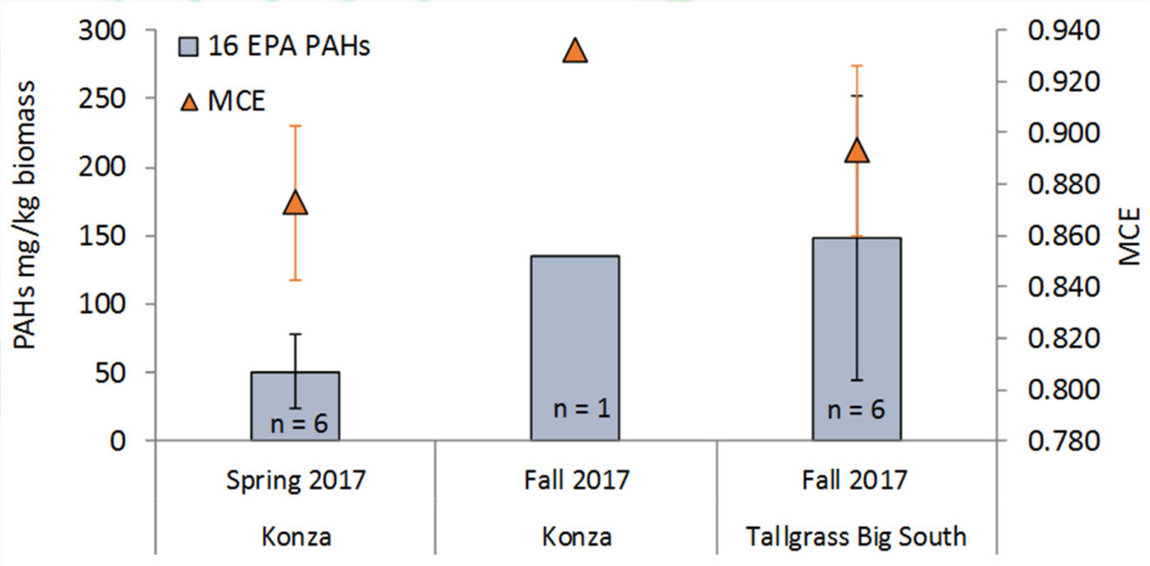




Effect of Combustion Efficiency and Season on Emissions

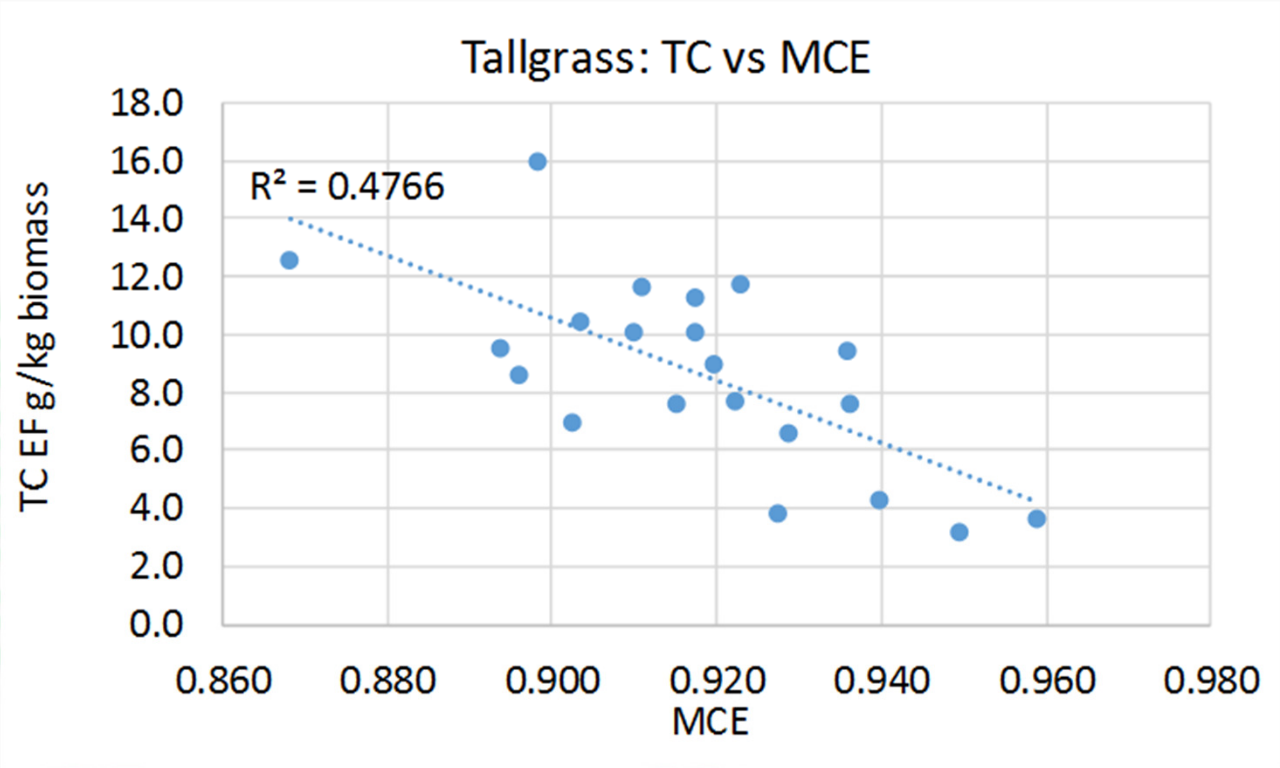
- Volatile organic compounds (VOCs) also show decreasing concentrations with improved combustion efficiency (MCE)
- Polycyclic aromatic hydrocarbons (PAHs) <u>may</u> show slight fall decrease, but statistically indistinct





Carbon Emissions

Carbon in $PM_{2.5}$ increases as combustion efficiency, MCE, declines.



Study Objective

- In general, emissions drop as combustion efficiency improves.
- Can we relate fire dynamics, or how things burn, to combustion efficiency and then to emissions?

Combining Fire Science and Emission Science

- Many variables are believed to determine fire emissions
  - Fuel variables
    - Species
    - Density (area and volume)
    - Moisture
  - Meteorological
    - Relative humidity
    - Wind speed
  - Fire dynamics (including combustion efficiency, MCE)
    - Fire intensity
    - Ignition pattern

Open Burn Test Facility

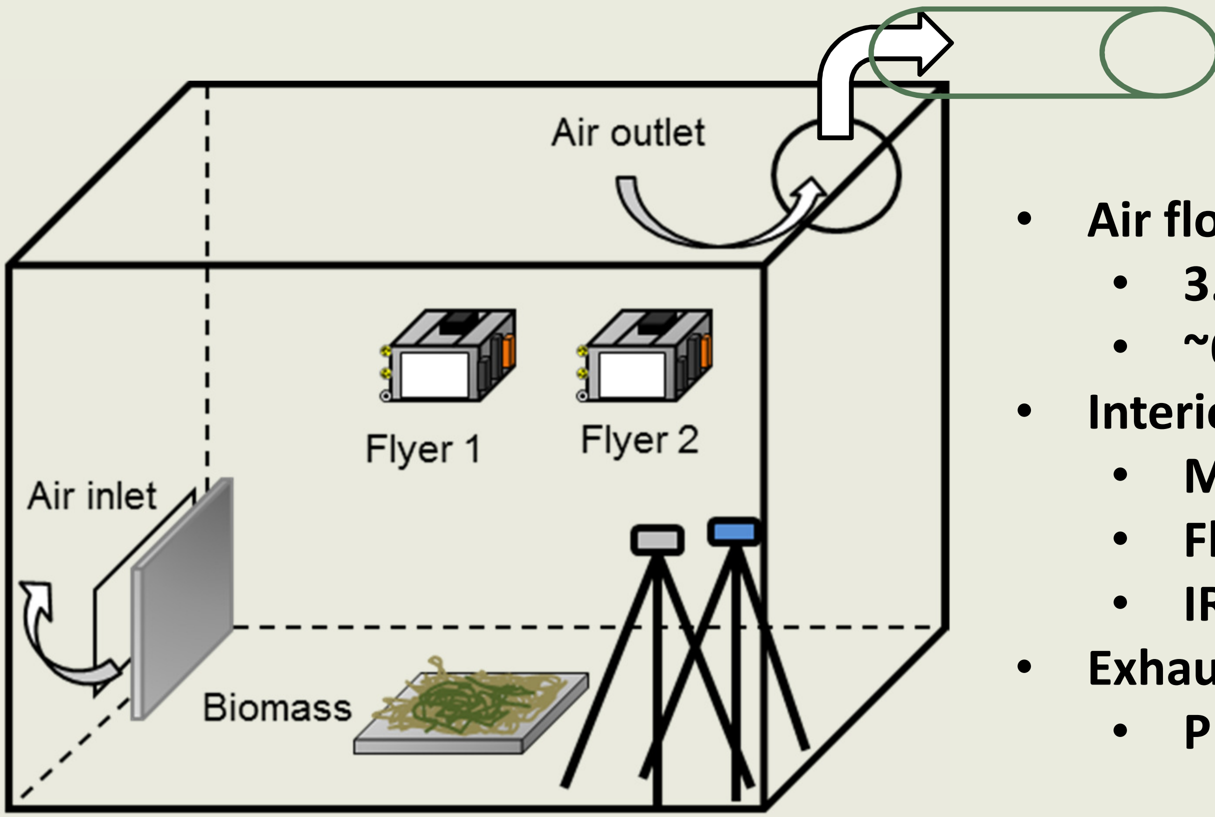
The unimpressive-looking OBTF

Field collection of biomass

Combustion testing and emission sampling

Open Burn Test Facility

Exhaust Duct, 40.6 cm diameter



Schematic

- **Air flow through facility**
  - **3.9 × 3.9 × 4.6 m**
  - **~60 second air turnover**
- **Interior measurements**
  - **Mass loss scale**
  - **Flyer 1, 2**
  - **IR and video cameras**
- **Exhaust duct measurements**
  - **PM(t)**

Open Burn Experiments

Methods

- Pine straw
- 2.42 lb (1.1 kg) pine straw
- ~1 m^2 burn pan
- On aluminum foil
- Ignited with butane burner

Variables

- "Baseline" = Field-collected density
- "High Fuel Density" = 2x area density
- "High Burn Intensity" = pine straw spread out on 3 shelves

Baseline

High Density

High Intensity

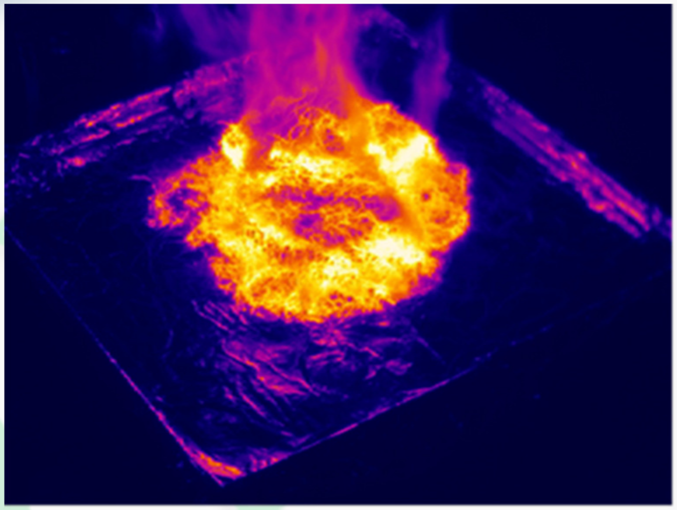
Measurements

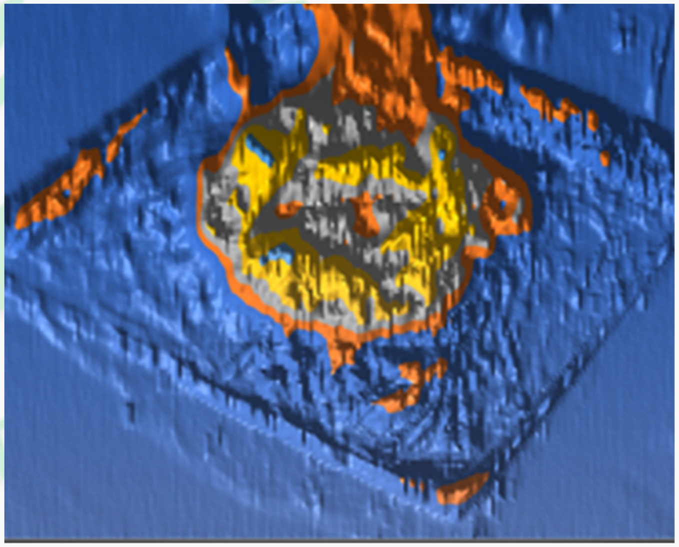
- $CO(t)$
- $CO2(2)$
- PM2.5(t)
- VOCs batch
- BC/EC/OC/TC
- Carbonyls
- PAHs
- T (IR)

Flaming (left) and Smoldering (right)

Studying Fire Intensity – IR Measurements

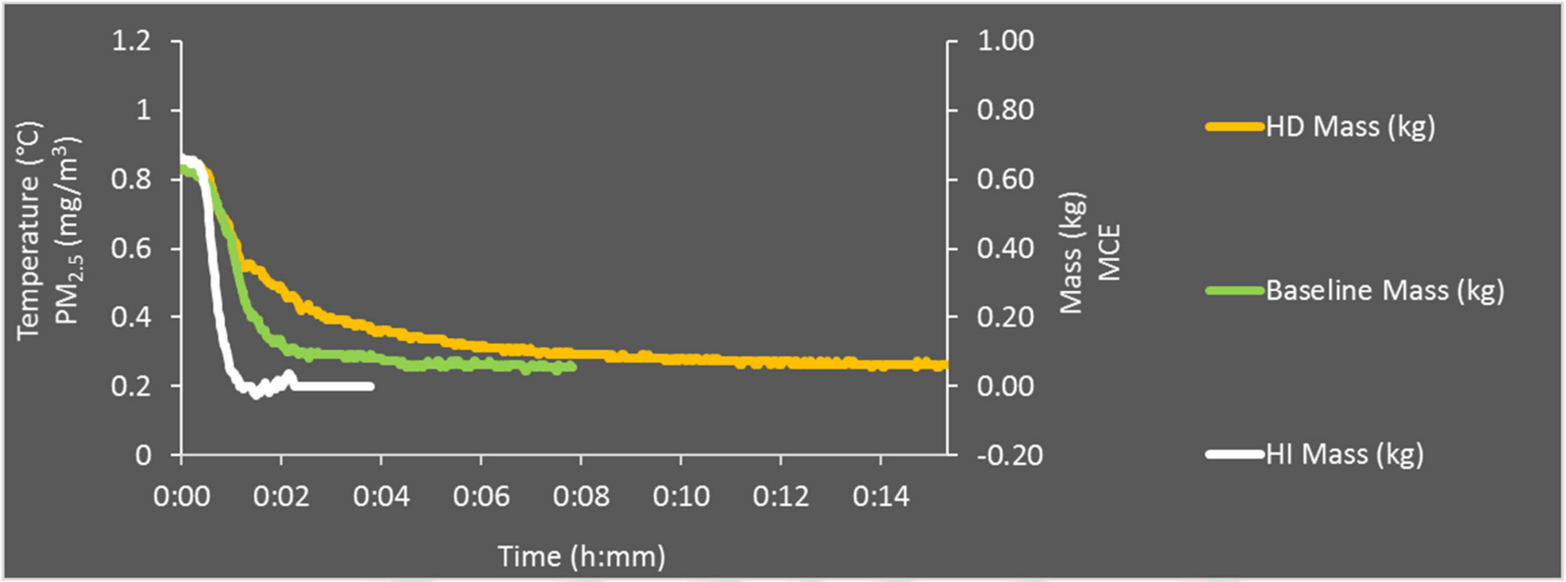
Thermal
IR camera.





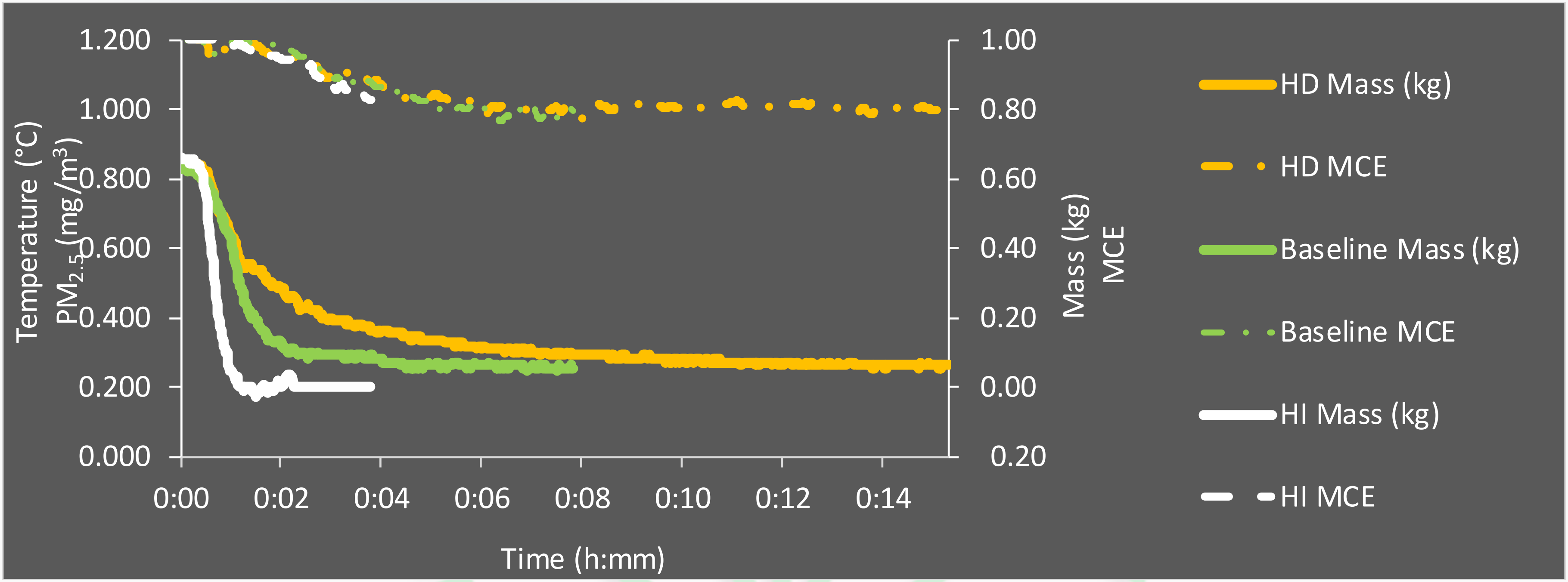
Camera: 382 x 288 pixels
Spectral Range: 7.5 to 13 microns
Thermal Sensitivity: 0.08K
System Accuracy: +/- 2ºC

Mass: Baseline, HI, HD



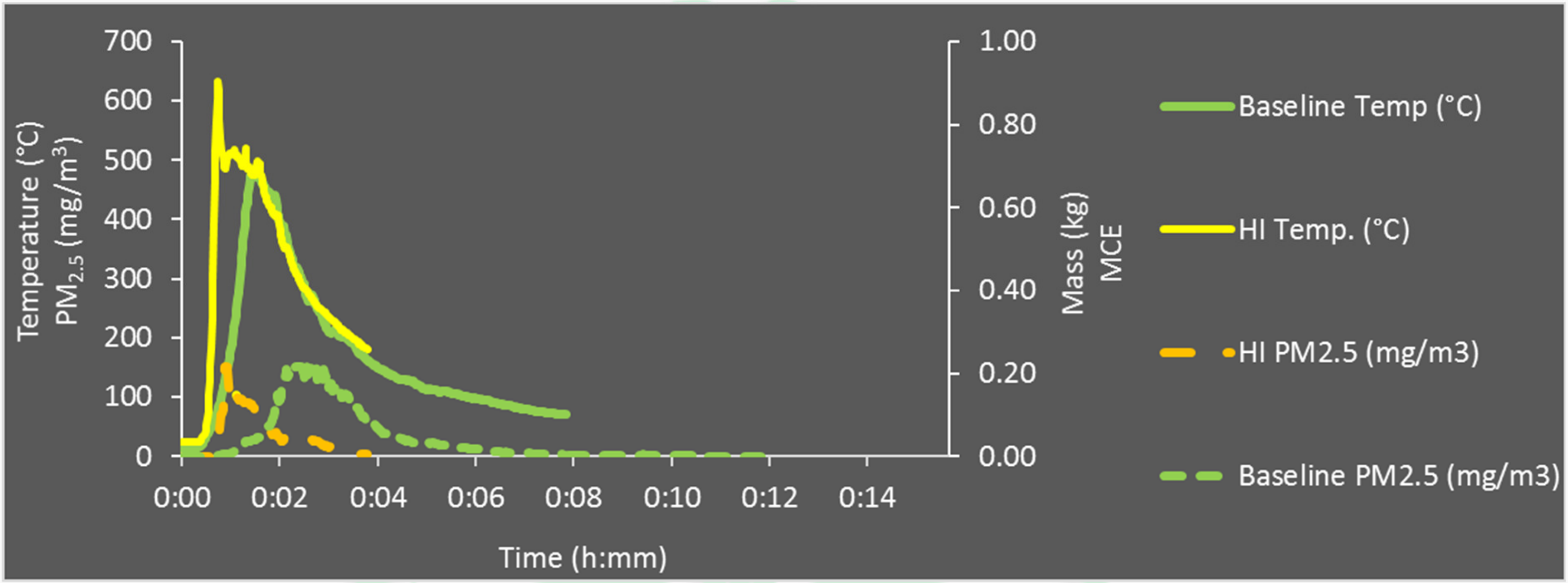
- **High Intensity (HI) burns lose weight faster than the Baseline burns and faster than the High Density (HD) burns. Our conditions appear to have defined three different burn intensities for which we can determine potential effects on emission factors.**

Baseline, HI, HD: Mass and MCE



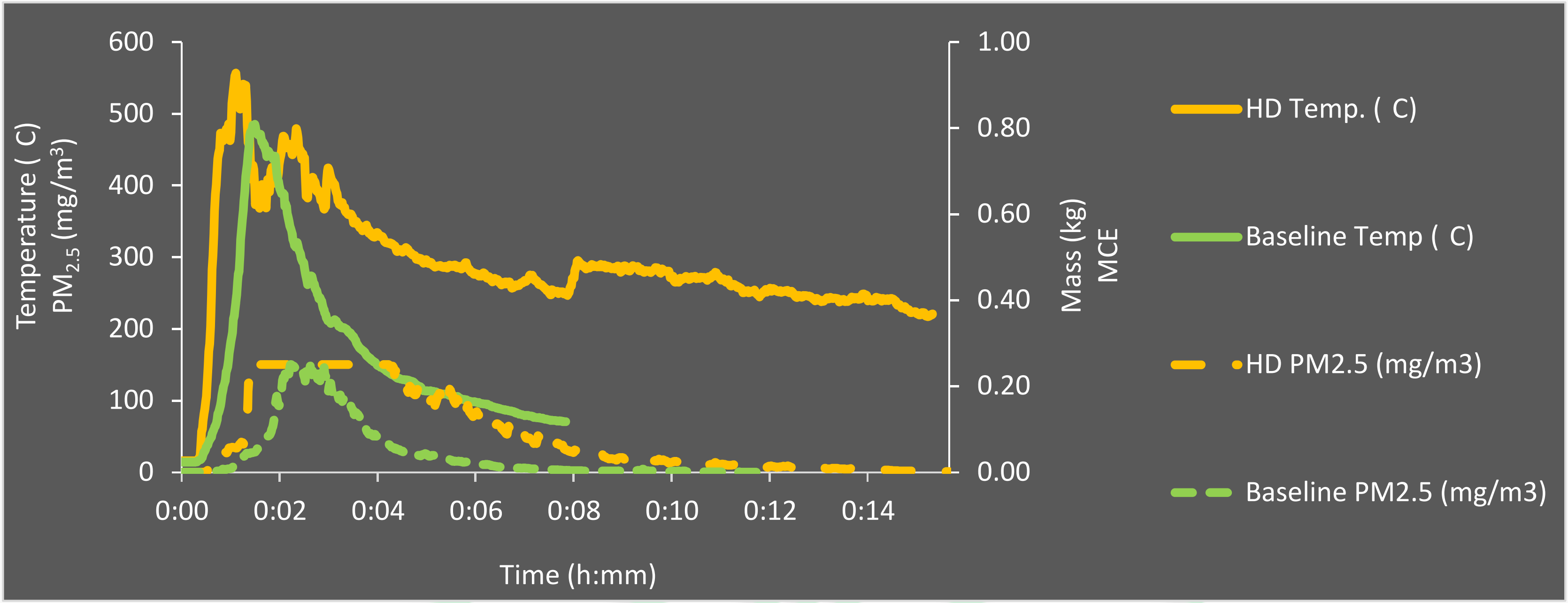
MCE is consistent (although burn have different durations) while mass loss profile changes

Baseline and HI: Temp., PM2.5



- **High Intensity burns reach high temperatures quickly and this is associated with quicker PM2.5 peaks.**

Baseline and HD: Temp., PM2.5

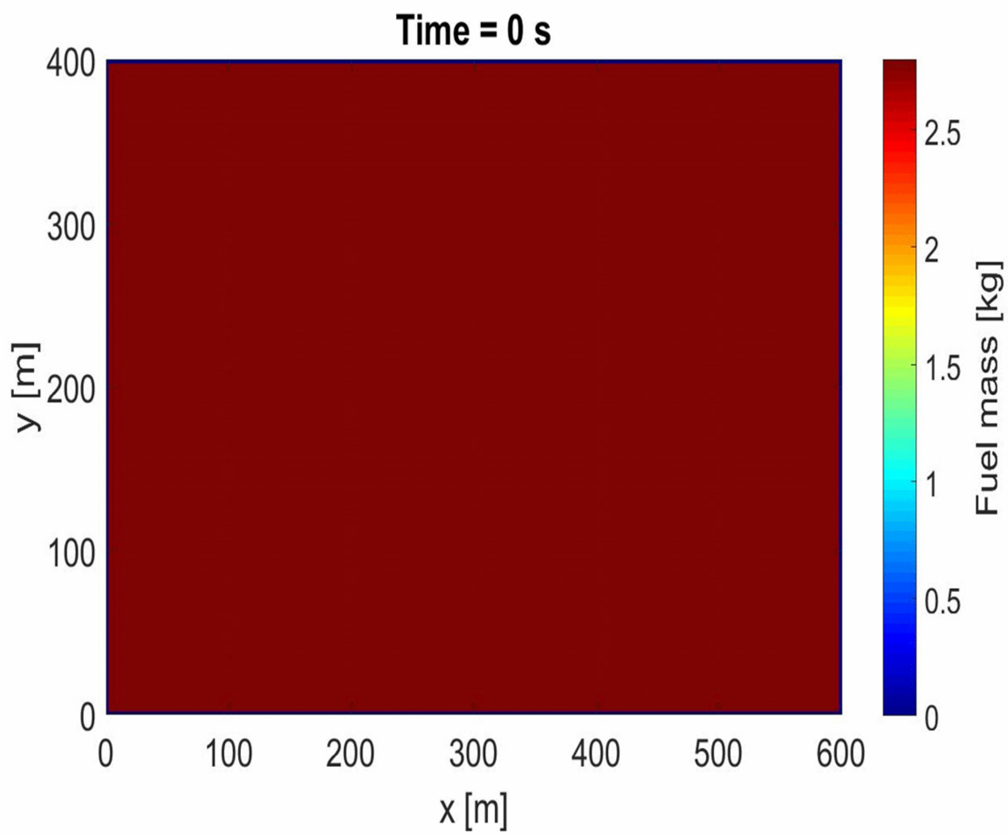


- **High Density burns saturated optical detector and have higher burn temperatures that persist.**

Modeling a Multi-Fireline Ignition Pattern

During a prescribed fire, multiple drip lines are being ignited in a staggered fashion. The model shows the effect on downwind fuel consumption/fire spread.

Coupling fire spread/dynamics with fuel emissions can provide us with means to minimize emissions.



Density = 4.5 tons/ac
Wind speed = 13.5 MPH

Courtesy of Rod Linn, Los Alamos National Security, LLC

What is the practical impact?

- If we can tie fire dynamics to emissions amount and composition, this will enable us to improve fire prescriptions (e.g., how and when is the best time to burn):
  - Optimum frequency for prescribed burns
  - Assessment of health impacts
  - How the fire is conducted (e.g., head fire, flanking fire) affects emissions
  - Moisture, humidity, wind prescription for fire

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