Quantification of Firebrand Production from WUI fuels for Model Development

Michael J. Gollner

Associate Professor and Deb Faculty Fellow

Department of Mechanical Engineering

University of California, Berkeley

Mohammadhadi Hajilou

Postdoctoral Scholar

University of California, Berkeley

Incoming Assistant Professor

University of Portland

firelab.berkeley.edu

GORDON AND BETTY MOORE FOUNDATION

NSF

JOINT FIRE SCIENCE PROGRAM

NIST National Institute of Standards and Technology U.S. Department of Commerce

FEMA

Berkeley UNIVERSITY OF CALIFORNIA Fire Research Lab MECHANICAL ENGINEERING

Photo Credit: Melia Robbinson

Berkeley Fire Lab Research

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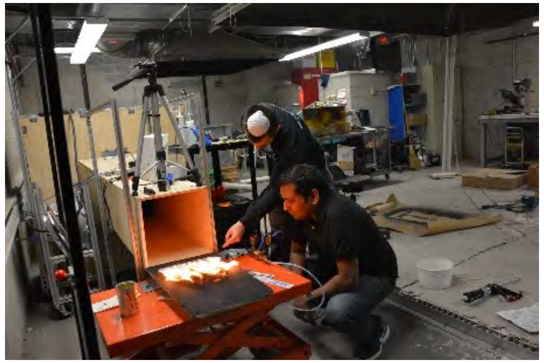
Gollner ad Fernandez-Pello



How do Wildfires Spread?
- Fluid dynamics & heat transfer

How do Fires Ignite Communities?
- Embers (laboratory)
- WUI risk/spread modeling

Fire Emissions & Health Effects
- Fuel/fire effects
- Risk to firefighters

Fire Whirls
- Efficient Multi-Fuel Combustion
- Oil Spill Cleanup

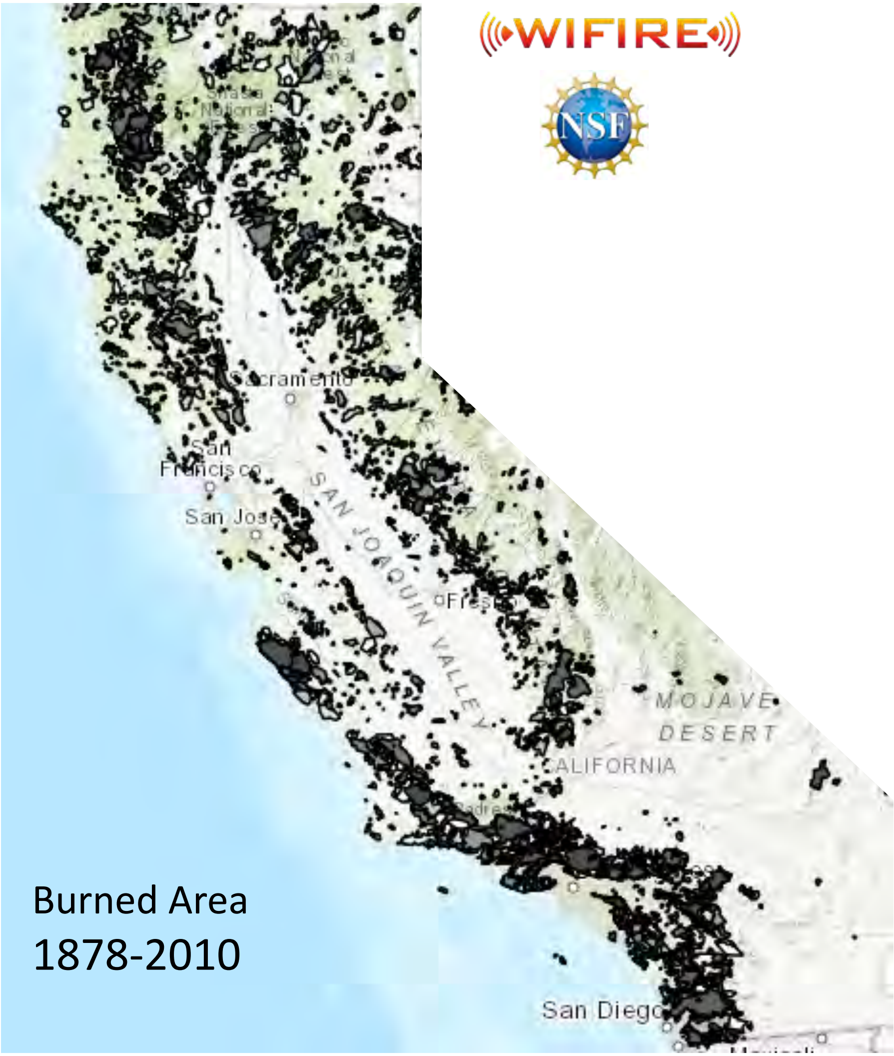
Spacecraft Fire Safety
- Flammability, batteries

https://firelab.berkeley.edu

Outline

- WUI Fire Problem
- Firebrand Ignition Studies
- Firebrand Generation – Completed Work
- Future work on Firebrand Generation

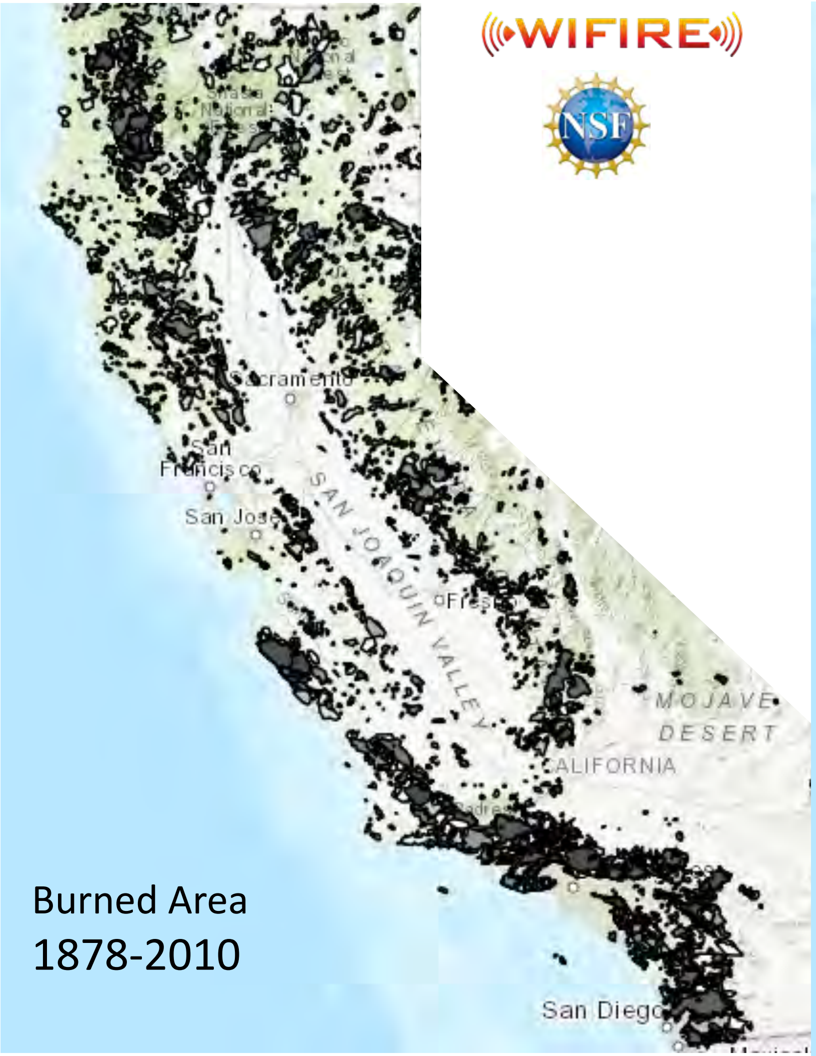
California – A History of Fire



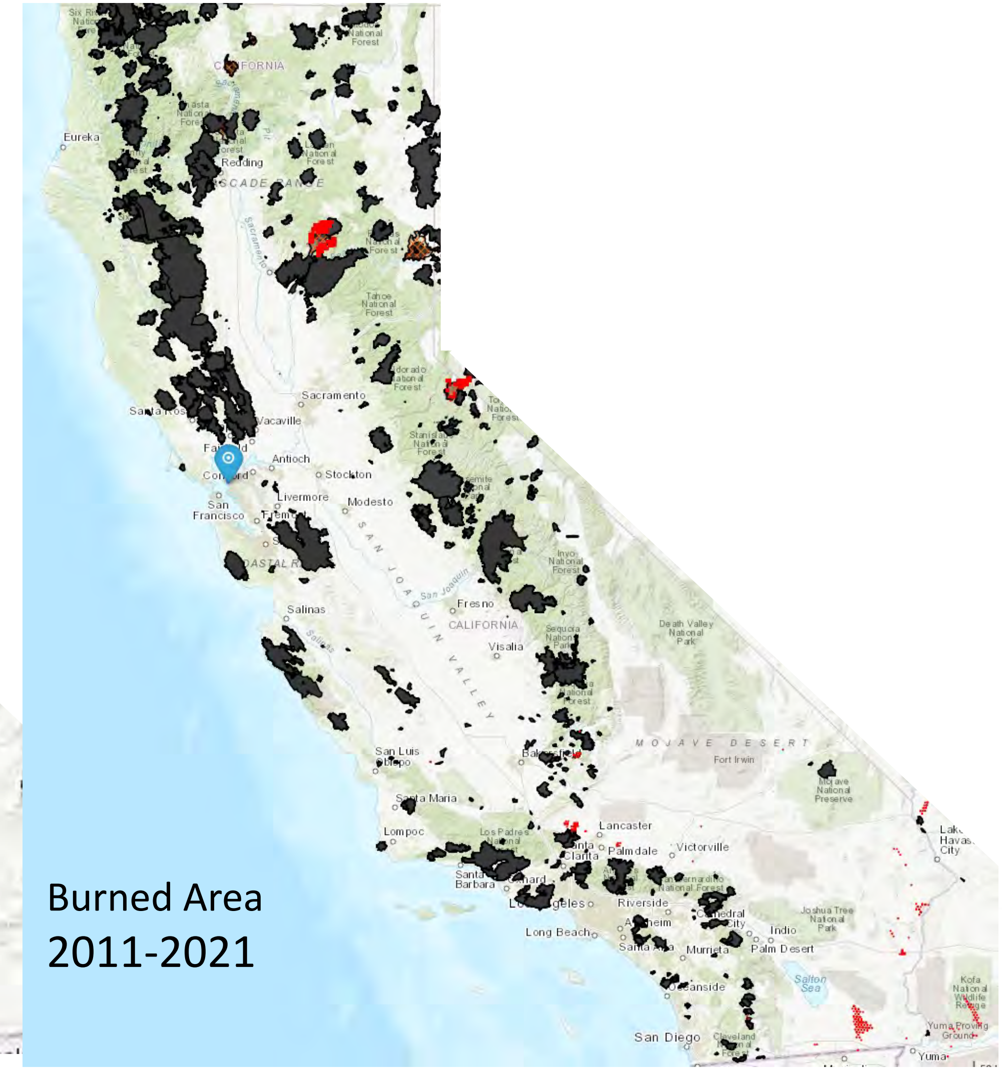
WIFIRE

NSF

California – A History of Fire

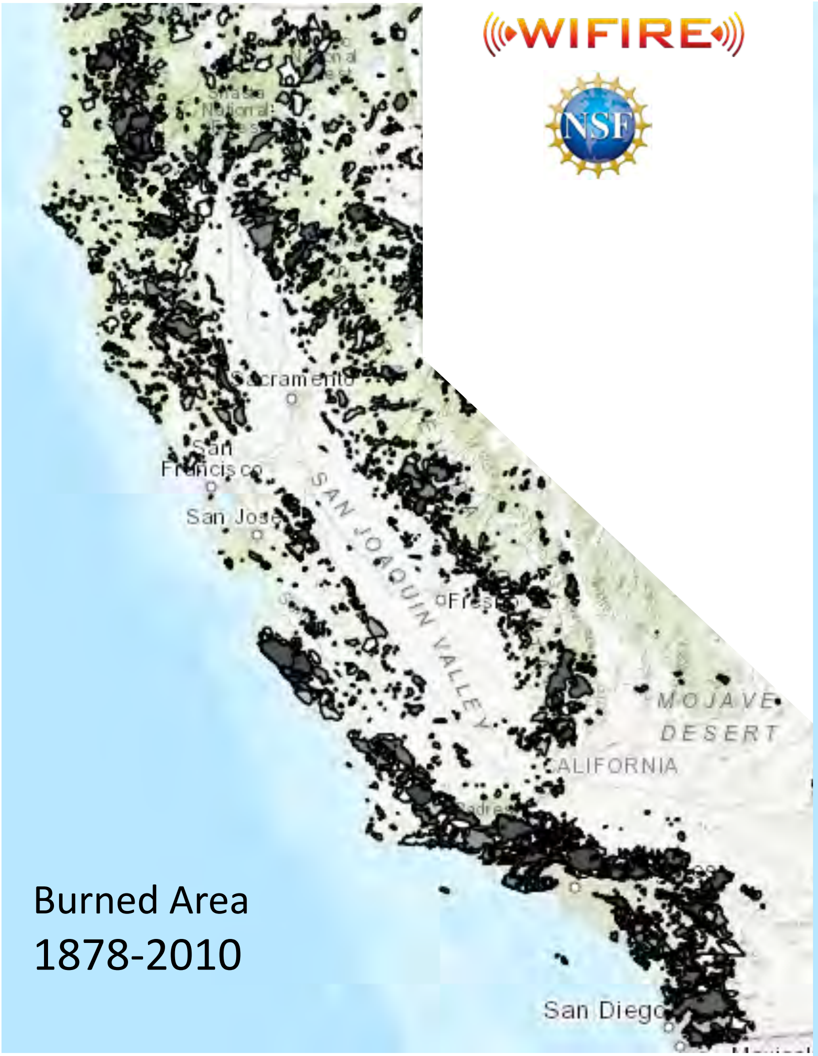


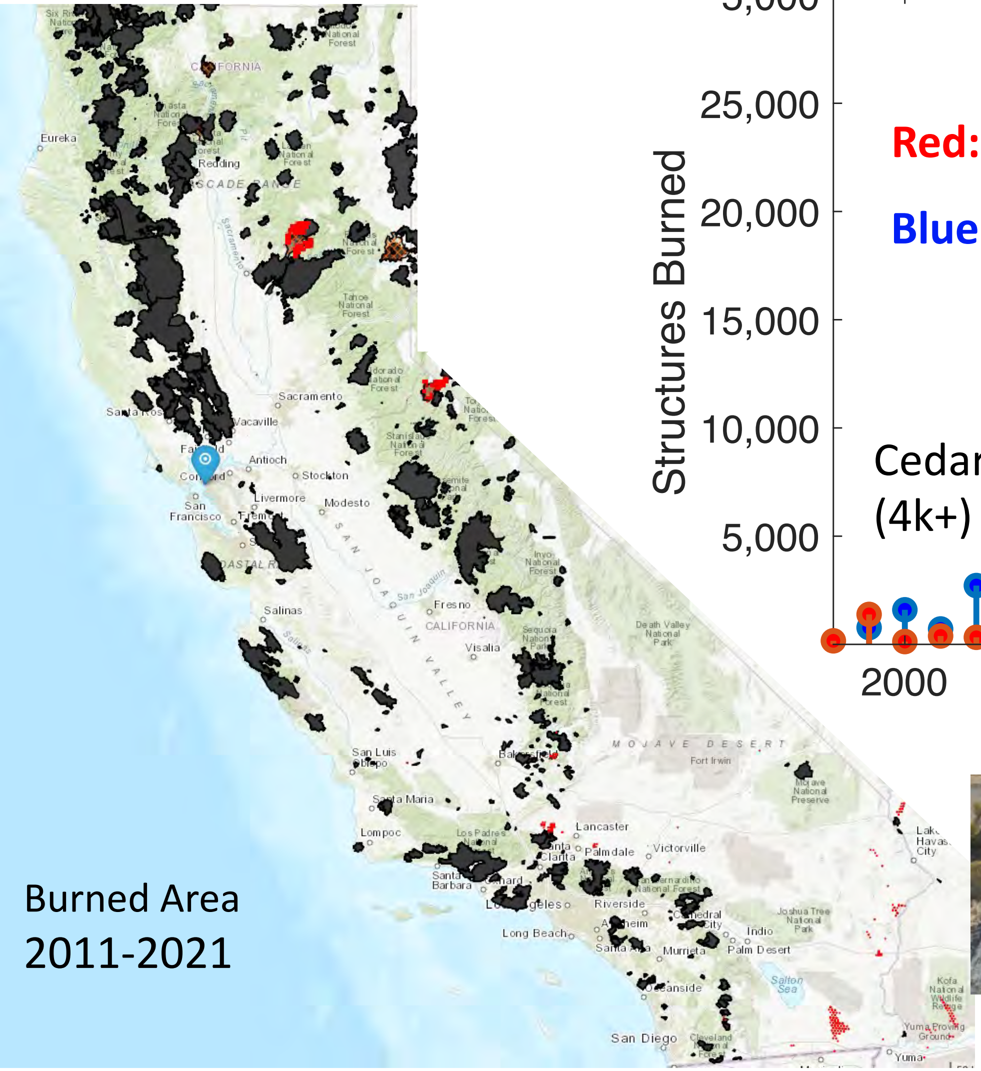
Burned Area
1878-2010

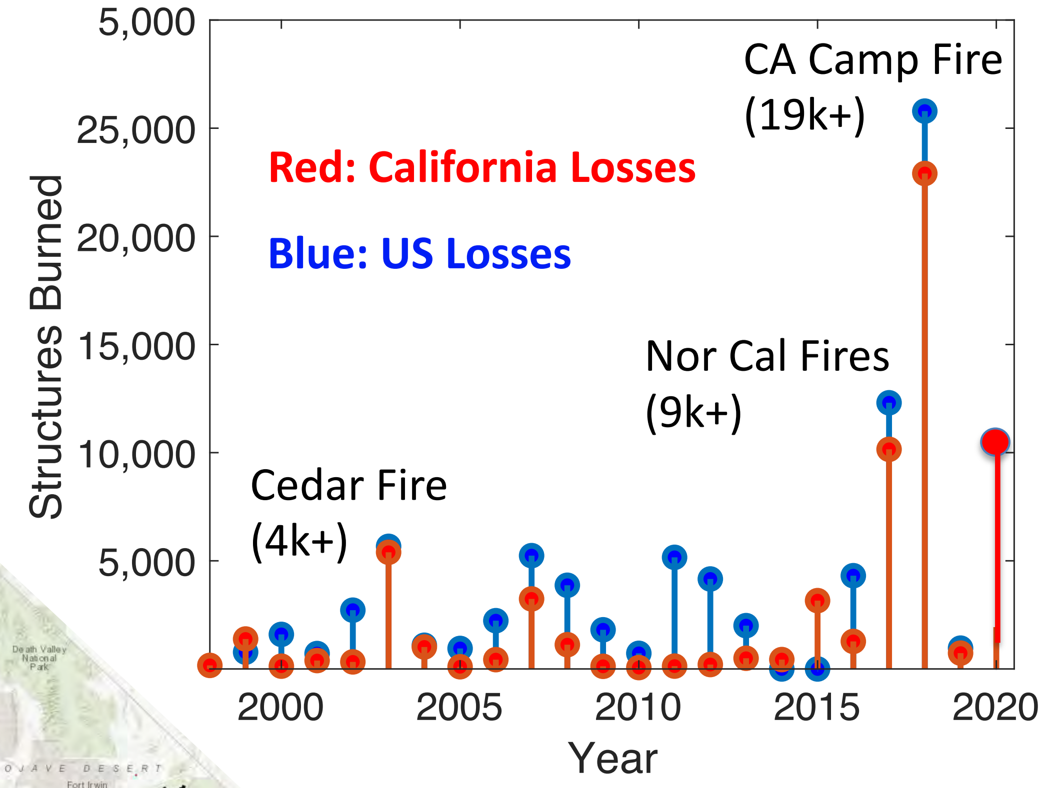


Burned Area
2011-2021

California – A History of Fire

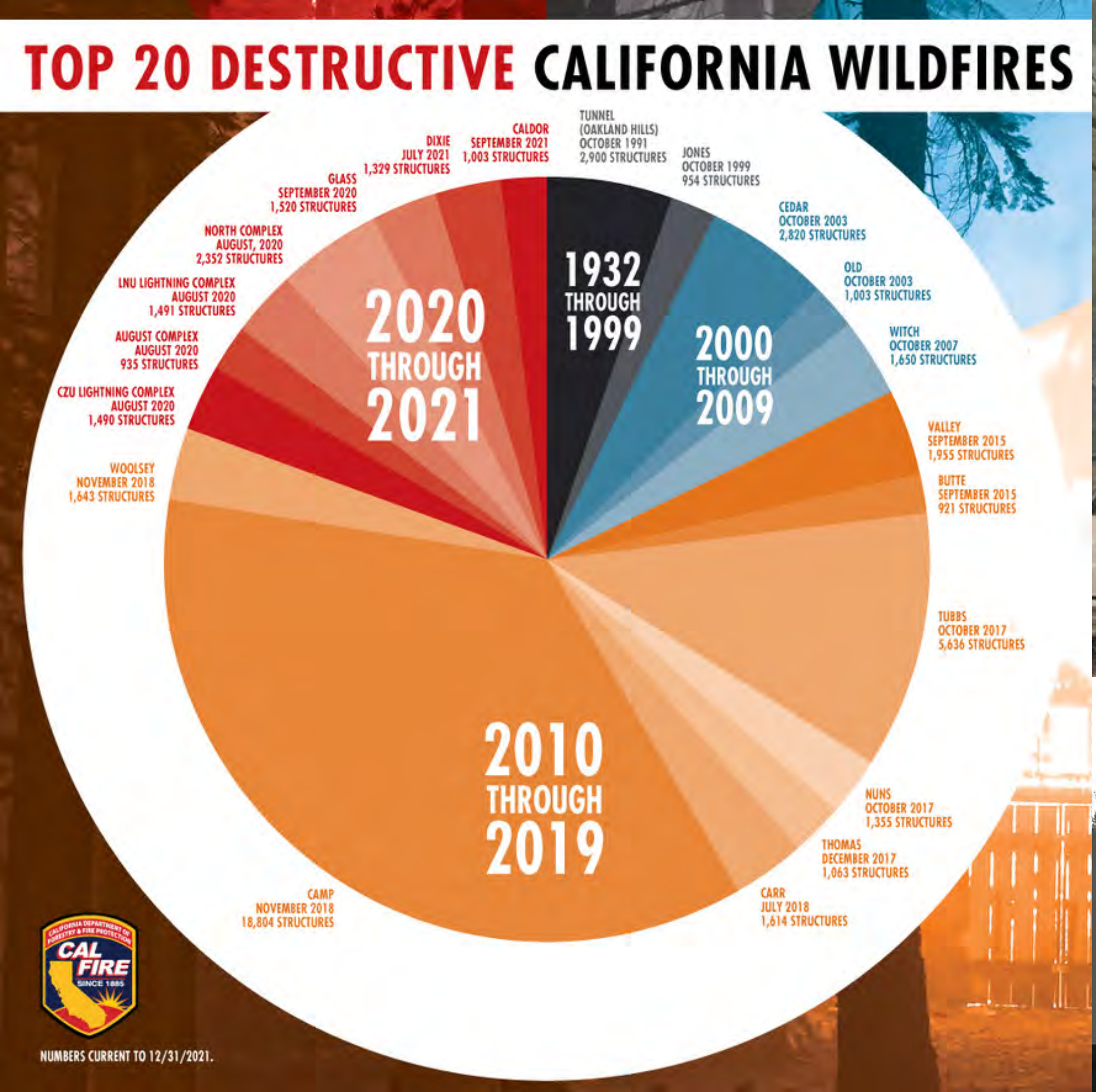






2017 Nor Cal Fires Loss ~$14.5B, 22 deaths

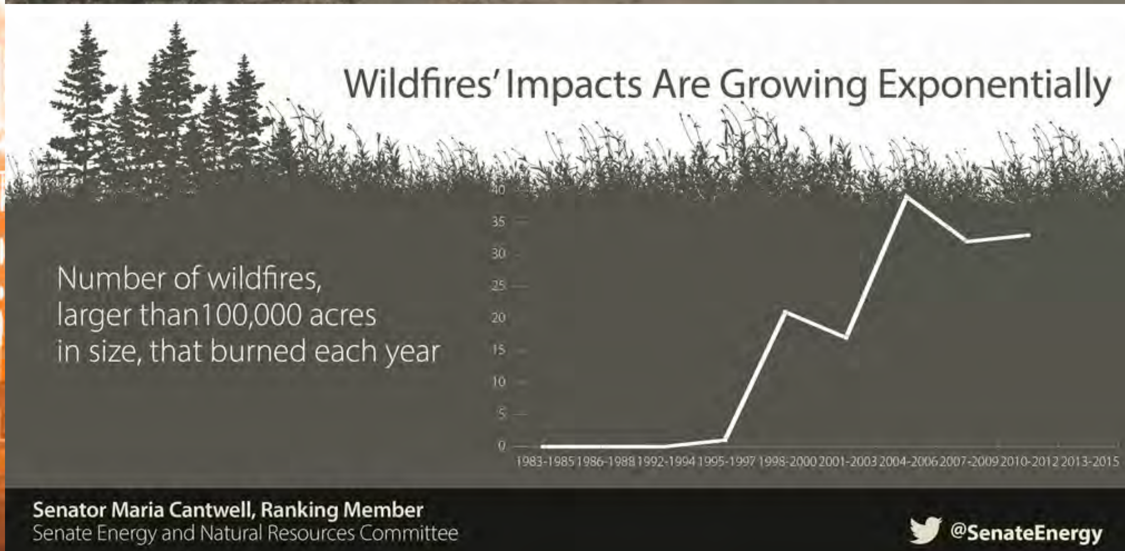
2018 Camp Fire Loss ~$16.5B, 85 deaths



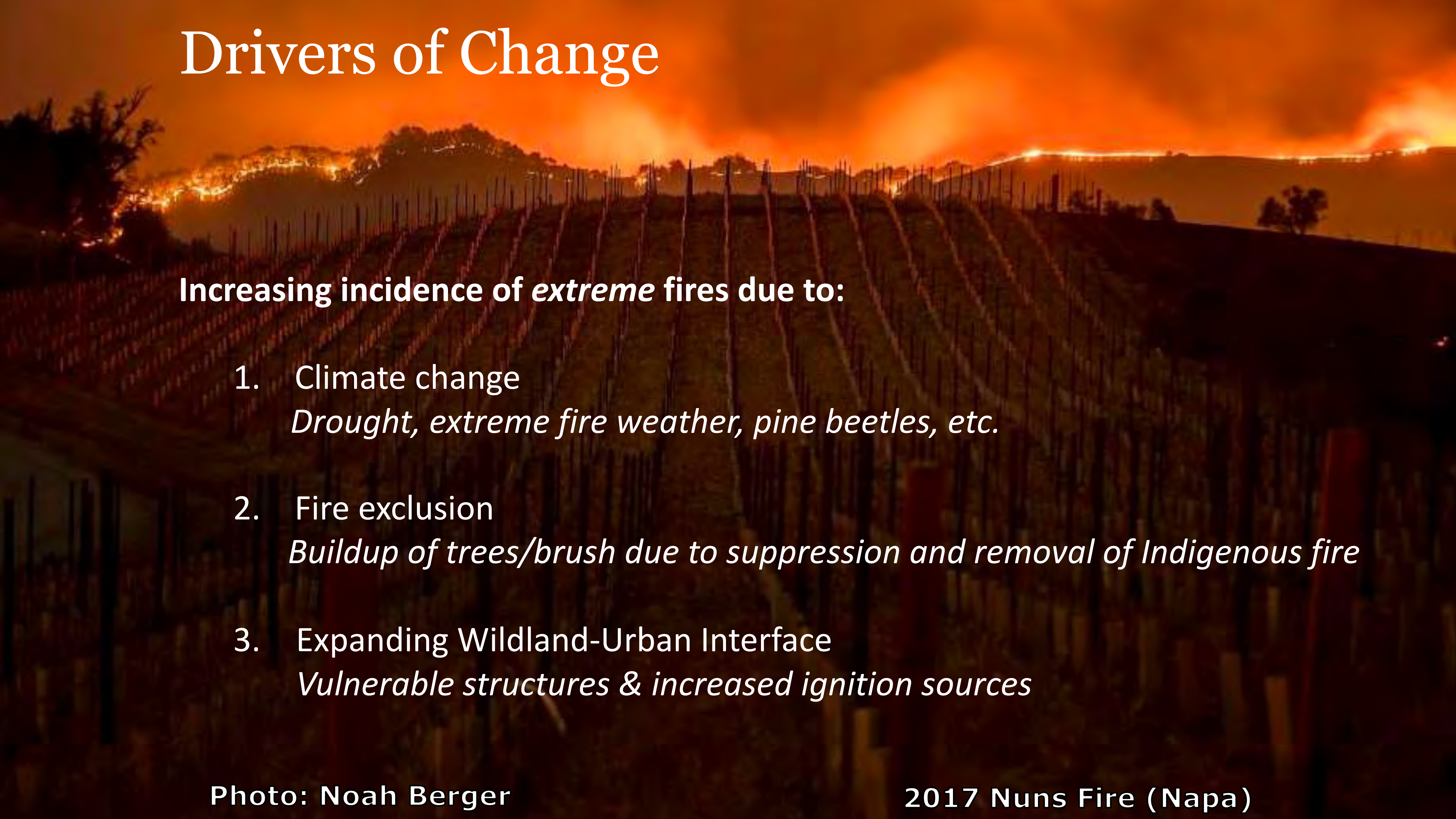
NIFC now has officially adopted the term "Megafires"

Over 100,000 acres

Hung T. Vu/Record Searchlight



Drivers of Change



Increasing incidence of *extreme* fires due to:

1. Climate change
   Drought, extreme fire weather, pine beetles, etc.

2. Fire exclusion
   Buildup of trees/brush due to suppression and removal of Indigenous fire

3. Expanding Wildland-Urban Interface
   Vulnerable structures & increased ignition sources

Photo: Noah Berger

2017 Nuns Fire (Napa)


Why are our communities burning?
Coffey Park
Santa Rosa, CA
Tubbs Fire – previously most destructive in CA history

Pathways to Fire Spread

Radiation

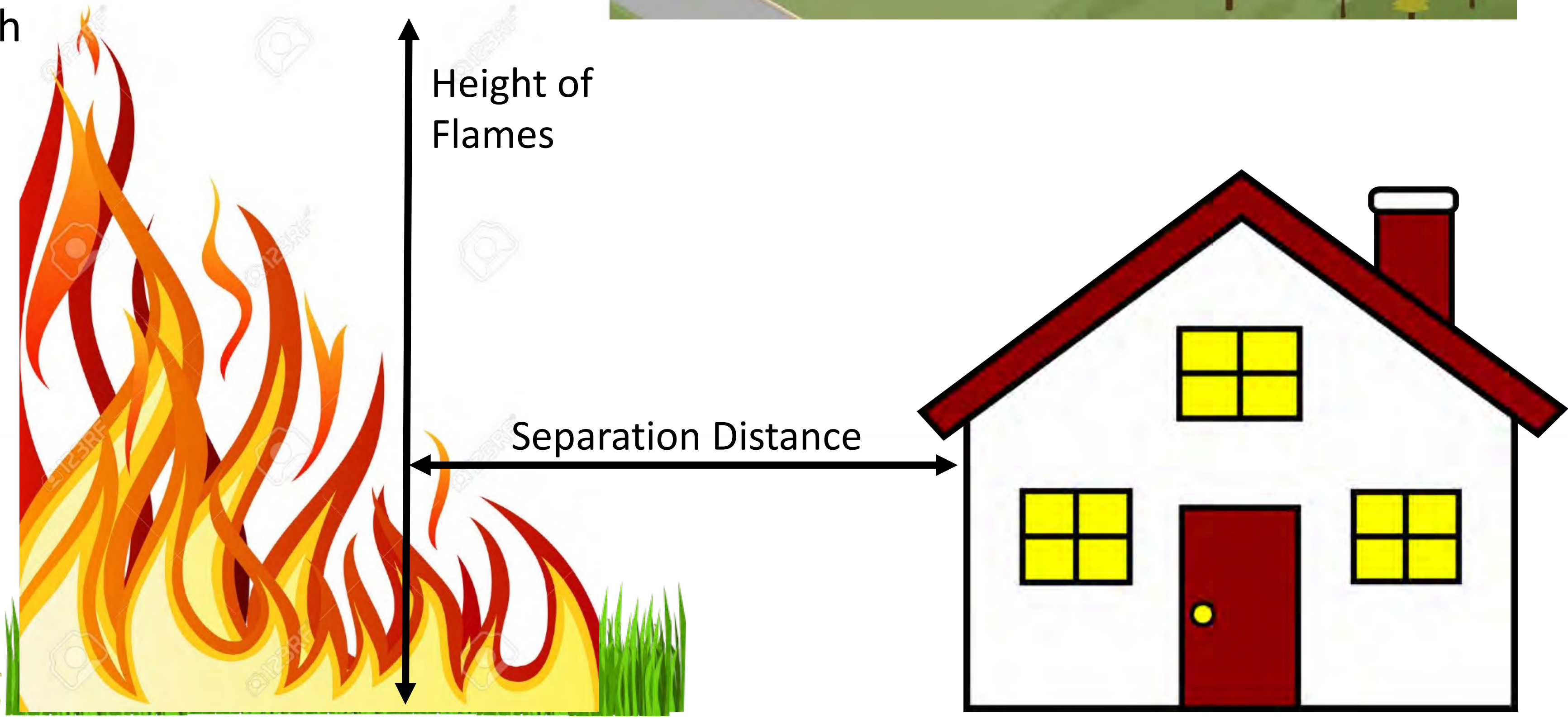
Originally thought to be responsible for most/all ignitions

Direct Flame Contact

Smaller flames from nearby sources

Embers or Firebrands

Small burning particles which



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Small burning particles which cause spot ignitions

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Nathan Trauernicht, UC Davis Fire @ Tamarack Fire

Firebrand Ignitions

Most homes at the Wildland-Urban Interface ignite due to small, flying embers, not the main fire

Maranghides, Mell, 2009, A Case Study of a Community Affected by the Witch and Guejito Fires (NIST TN 1635)

Union Tribune

WUI Disaster Sequence

Severe Wildfire Conditions

High winds, dry fuels

Adapted from *Calkin, et al., 2014. PNAS. 111, 746–51.*

WUI Disaster Sequence

Hardening Structures/Communities

- Codes & Standards (e.g. CBC Chp. 7A)
- Community Programs (e.g. Firewise)
- Defensible Space

WUI Fire Disaster

Potentially 100's + homes destroyed

Fire Protection Resources

Overwhelmed resources diminish in effectiveness

Residential Fires

Many home ignitions

Extreme Fire Behavior

High fire intensity & growth rates

Severe Wildfire Conditions

High winds, dry fuels

Reducing Exposure

- Community Design
- Fuel Reduction
- Prescribed Fire

Improve Response

- Notification
- Evacuation
- Response Coordination
- Planning & Communication

Adapted from *Calkin, et al., 2014. PNAS. 111, 746–51.*

Firebrand Generation and Transport

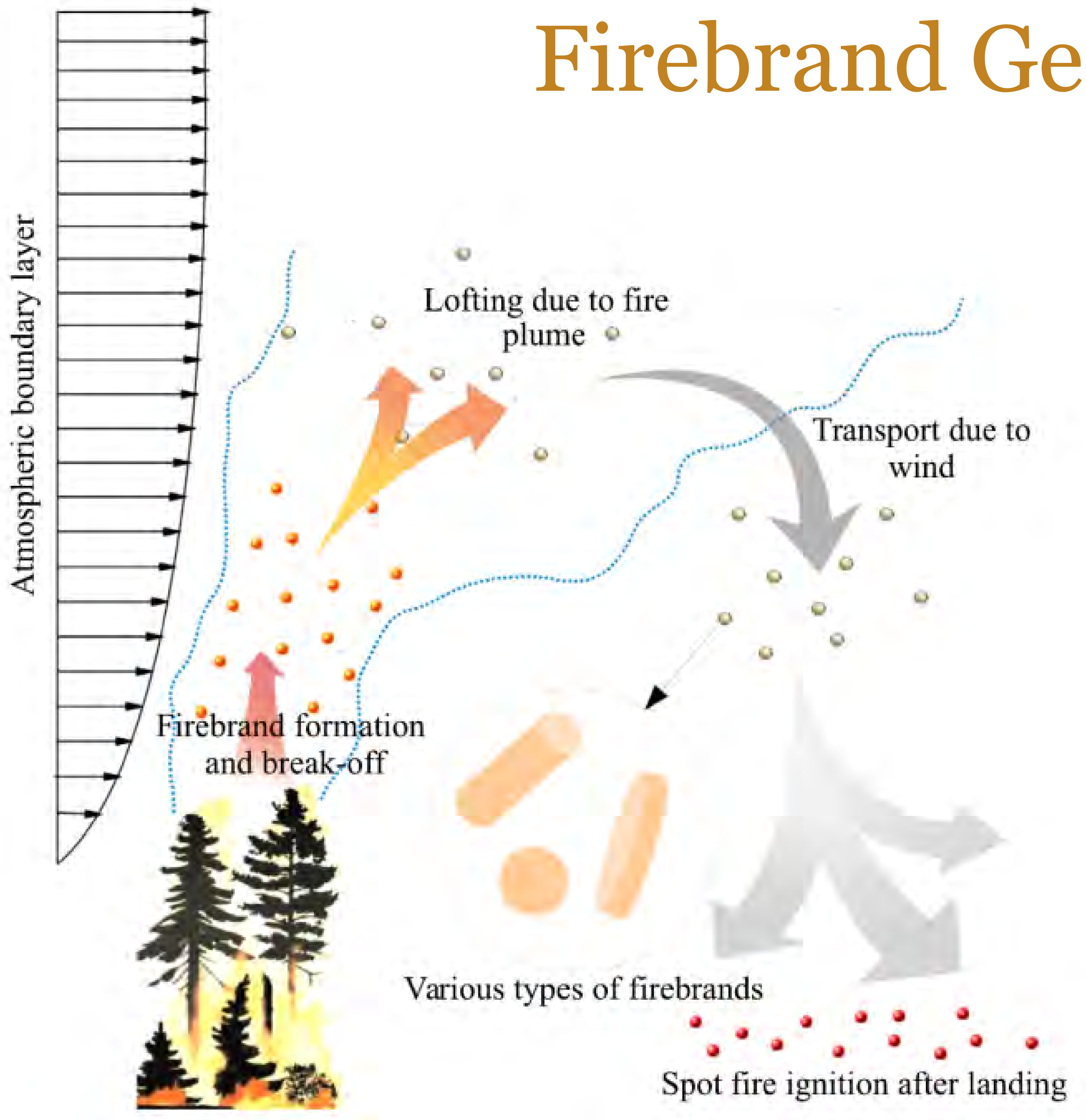


Figure by Tohidi et al., 2015

Firebrand Generation and Transport

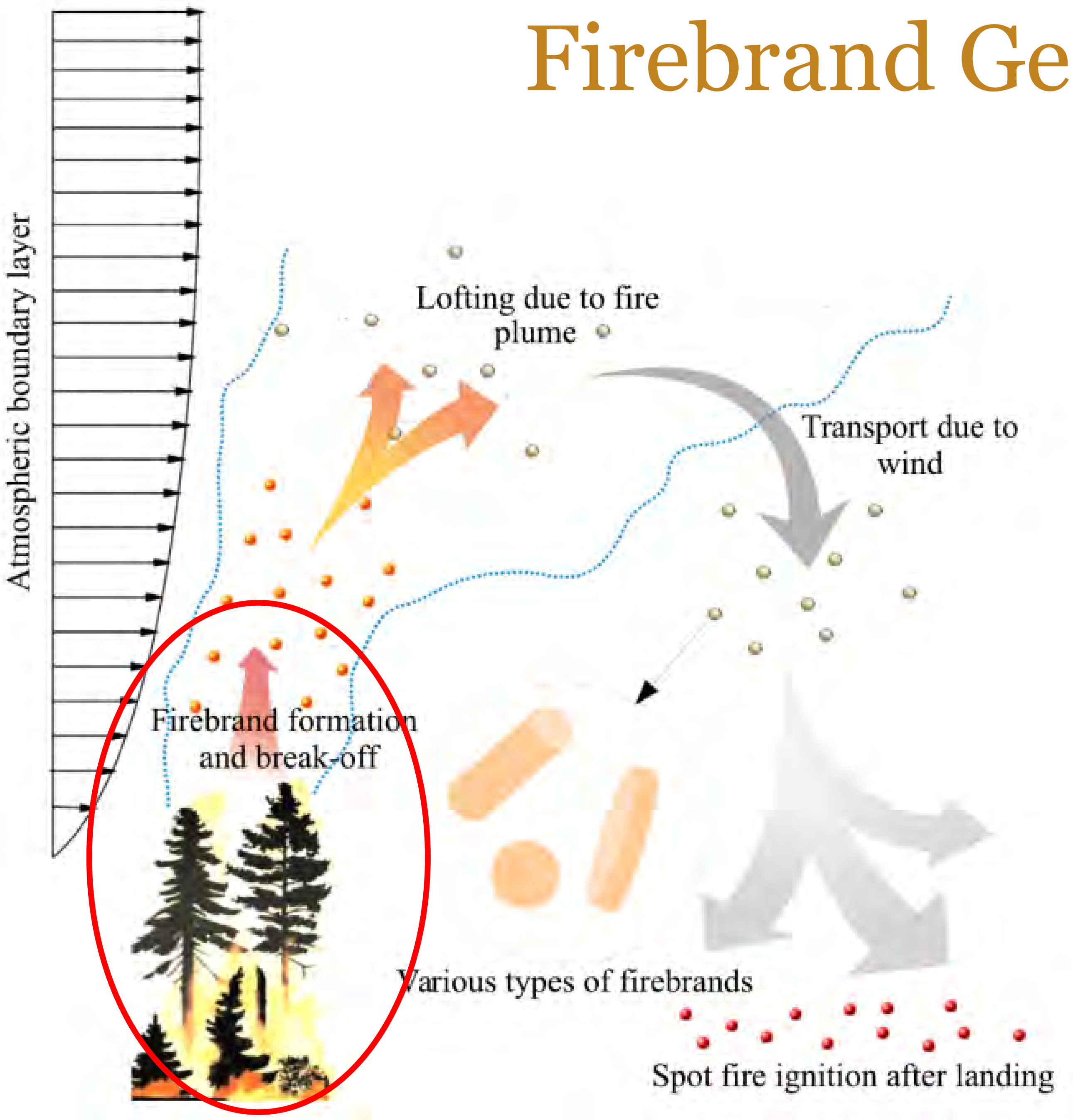
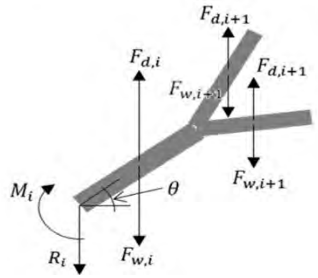


Figure by Tohidi et al., 2015

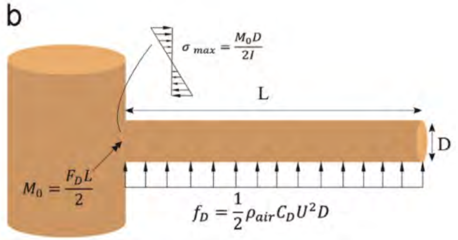
Firebrand Formation and Break-off

Only 2 models:

Barr & Ezekoye

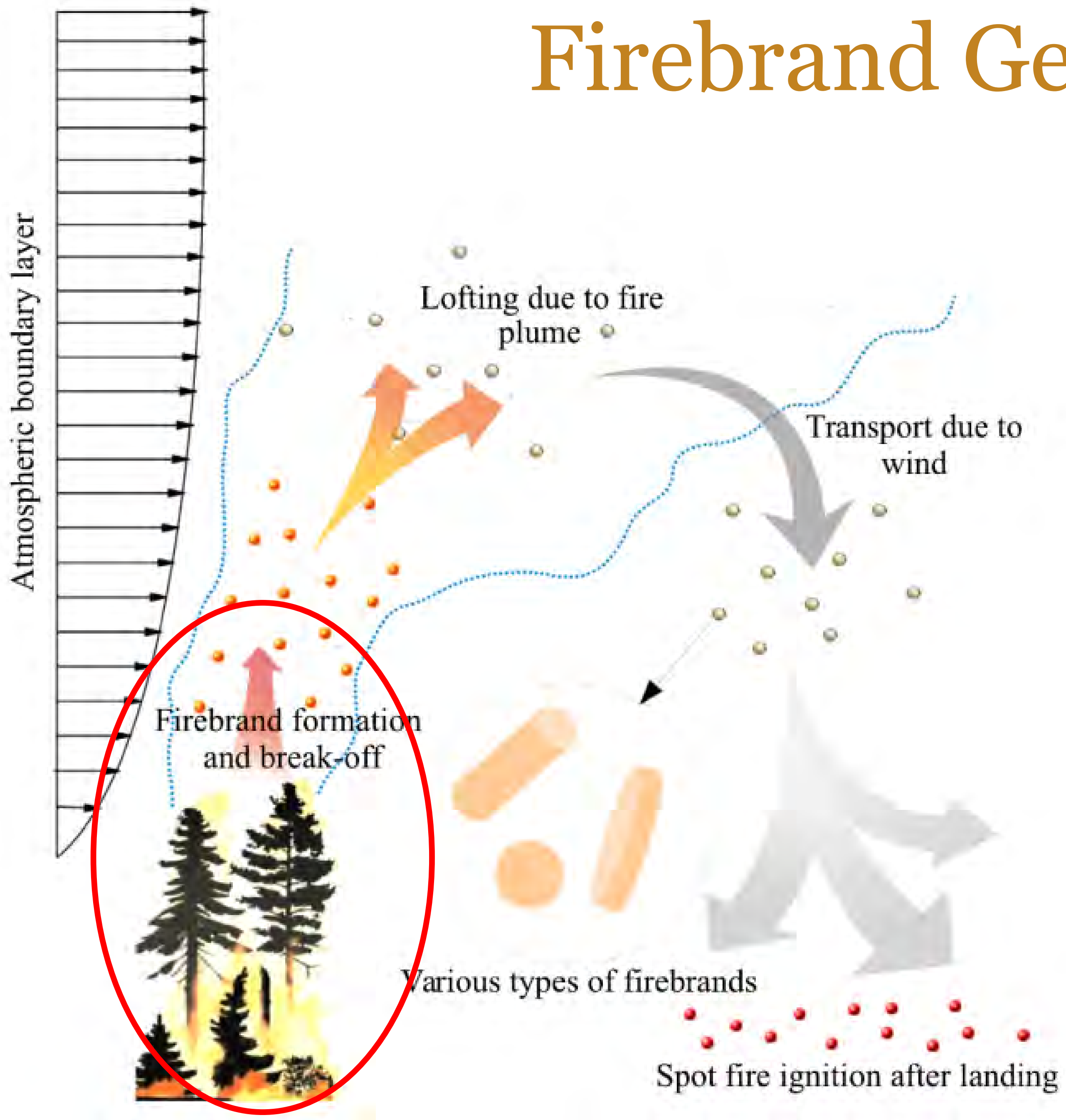


Tohidi et al.



Still not complete

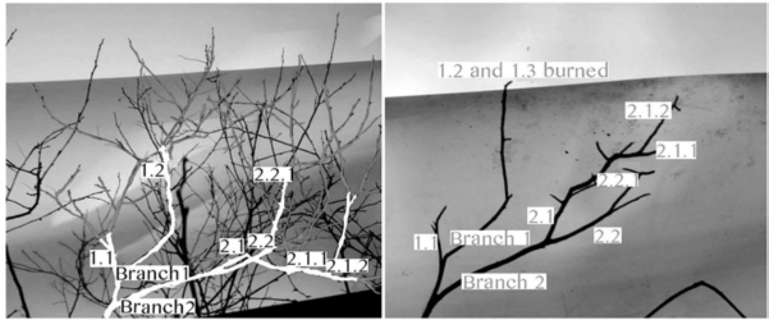
Firebrand Generation and Transport



Generation Measurements

Trees: Lab, no wind
Manzello et al.

Field Measurments

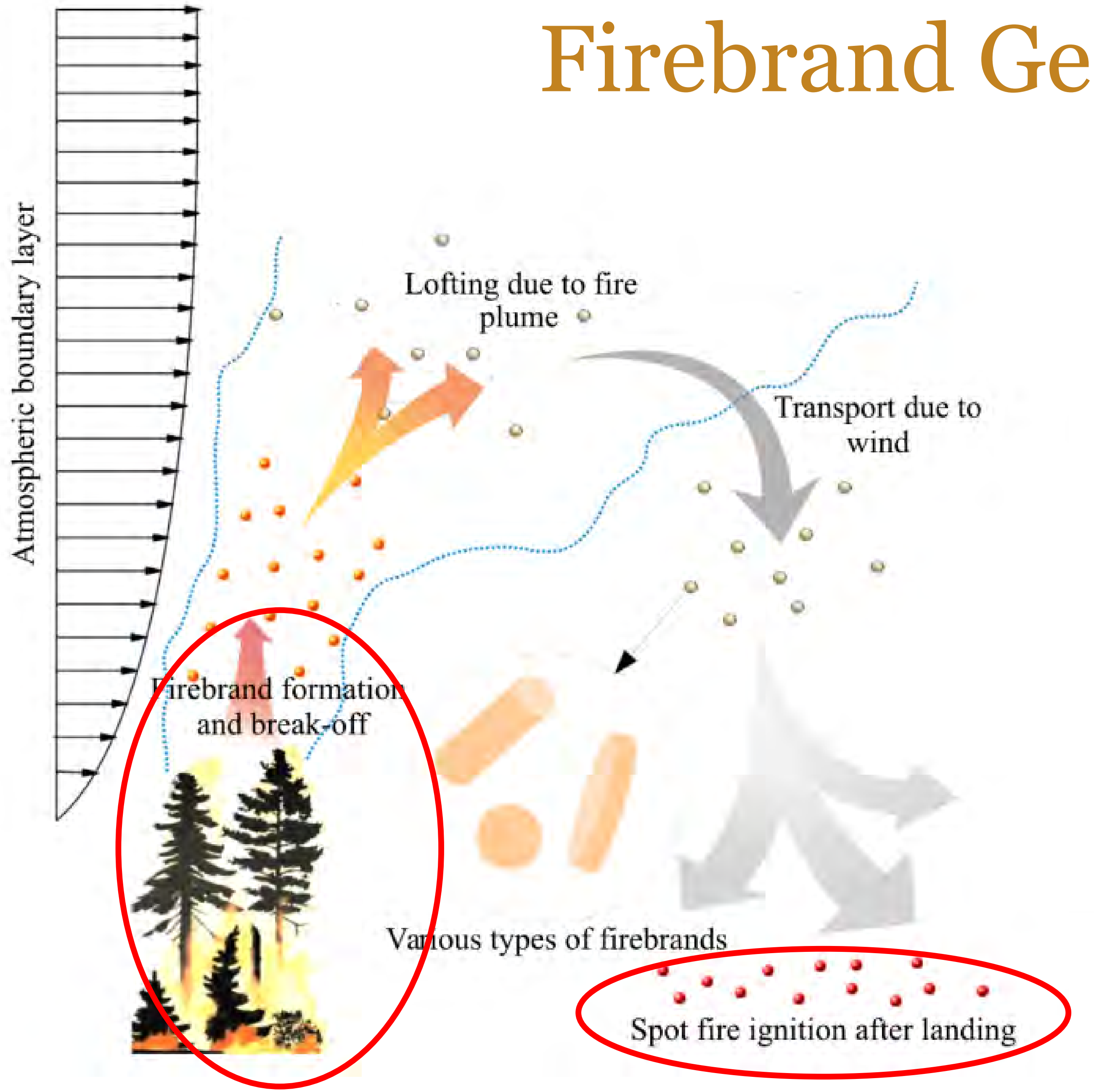


Generation Under Wind
(IBHS - Farahani, Tohidi)

gure by Tohidi et al., 2015

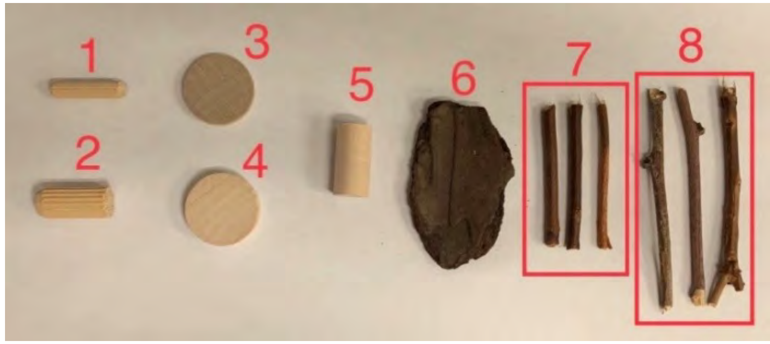
Manzello, Maranghides, Mell, IJWF, 2007, 16, 458–462; El Houssami et al., Fire Technology 2016

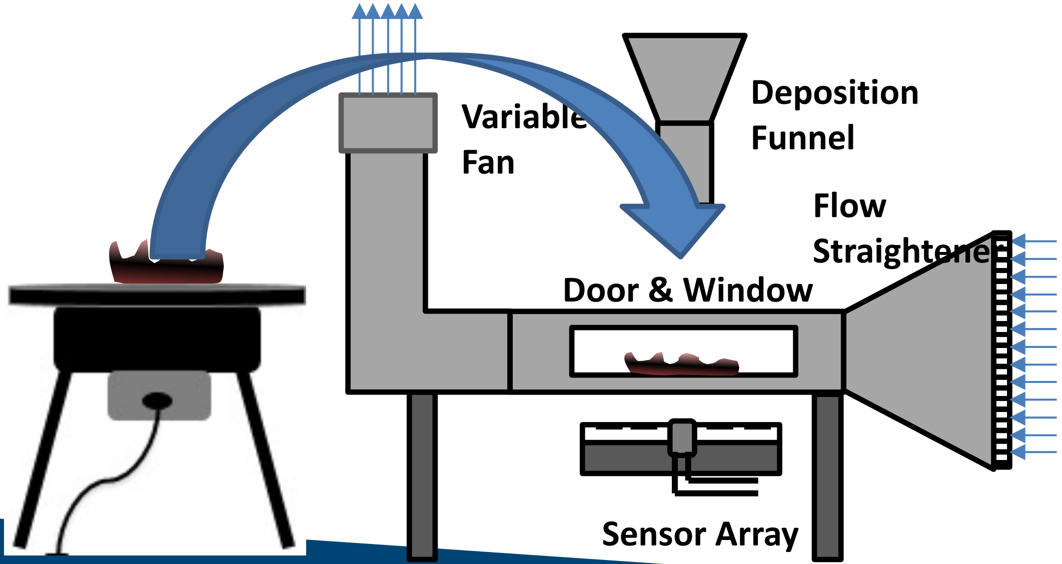
Firebrand Generation and Transport

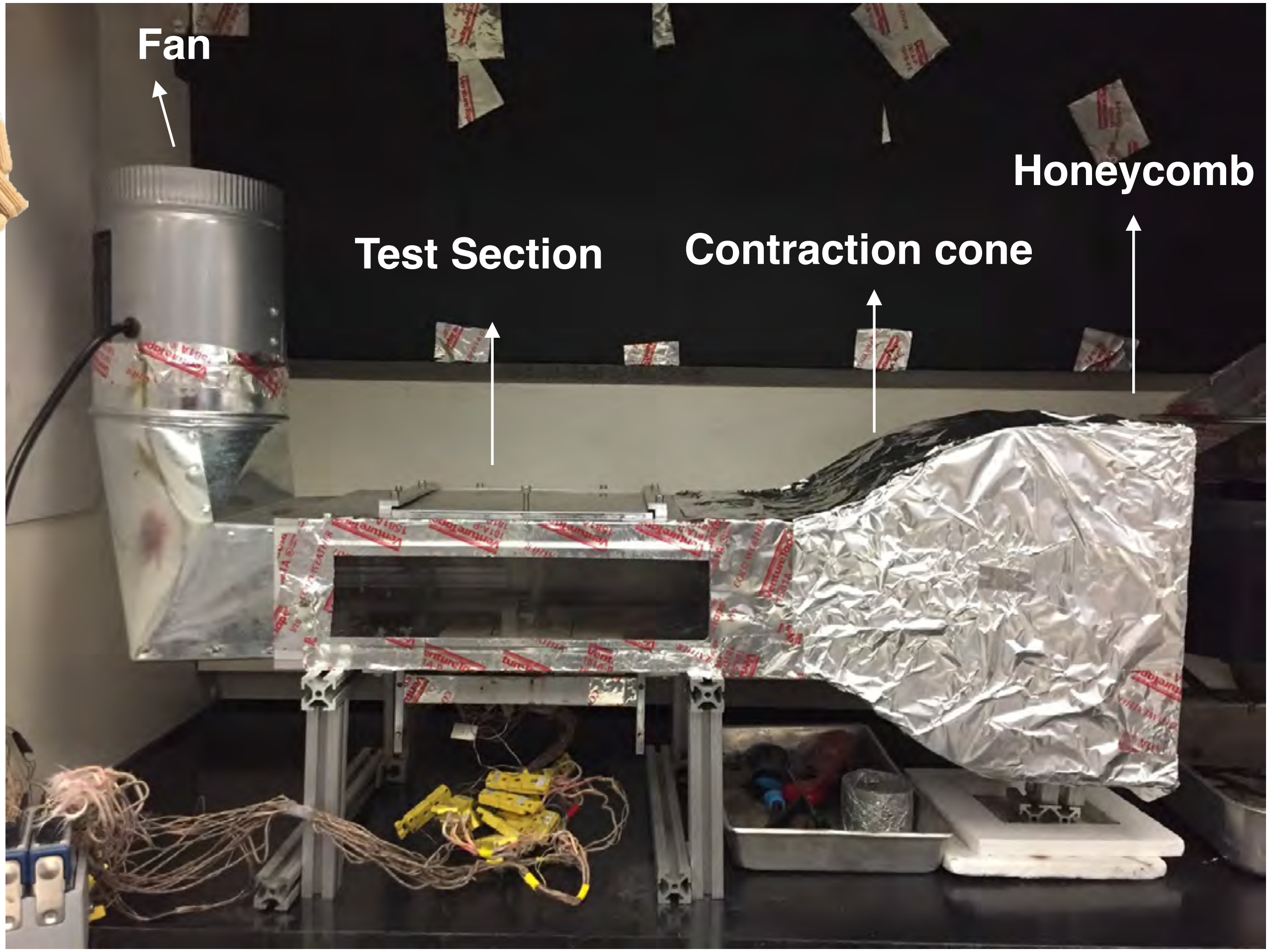


Firebrand Ignition Studies – Past Work


Hamed Salehizadeh
Raquel Hakes Weston-Dawkes





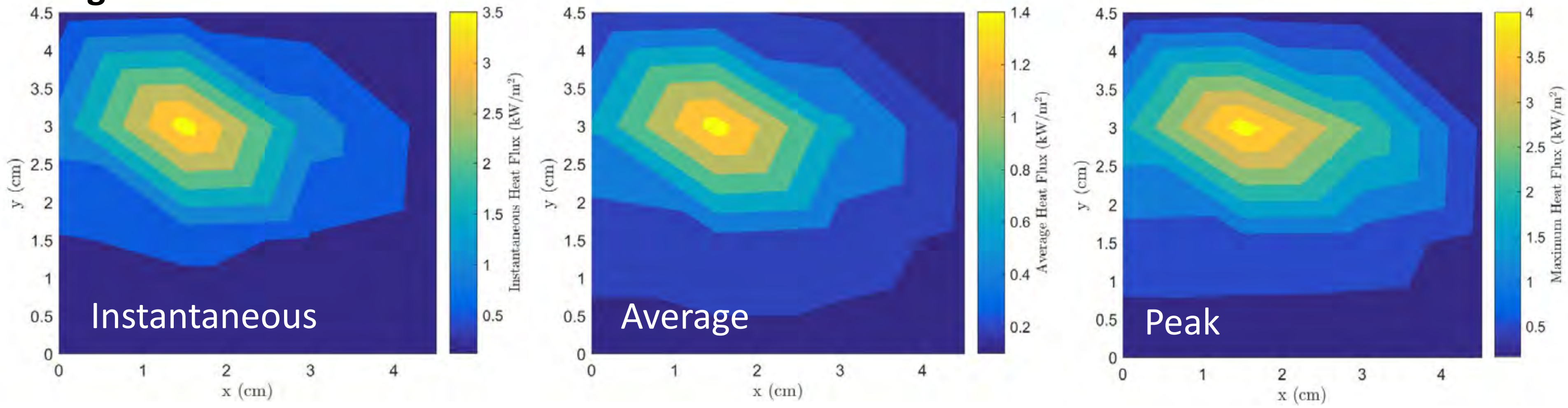


"Critical ignition conditions of wood by cylindrical firebrands." *Frontiers in Mechanical Engineering* 7 (2021): 17.

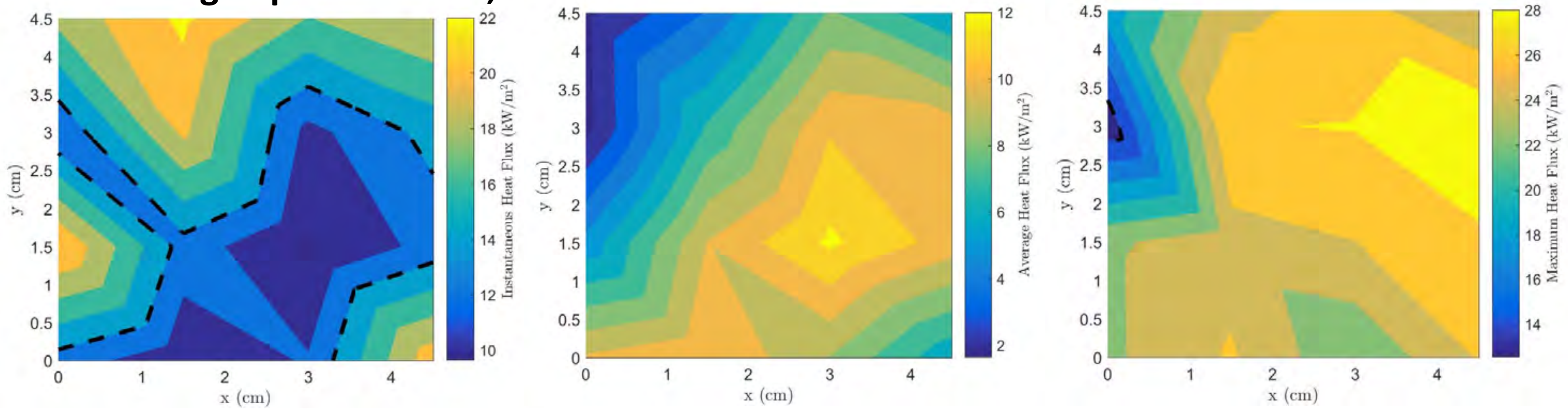
Firebrand Ignition – Single vs. Pile

Raquel Hakes Weston-Dawkes

Single 12.7 mm Firebrand:

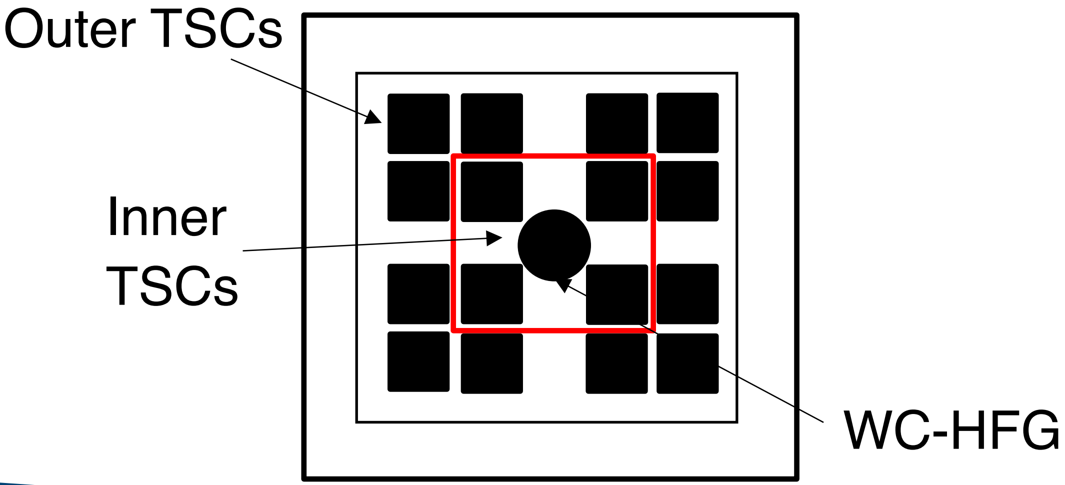


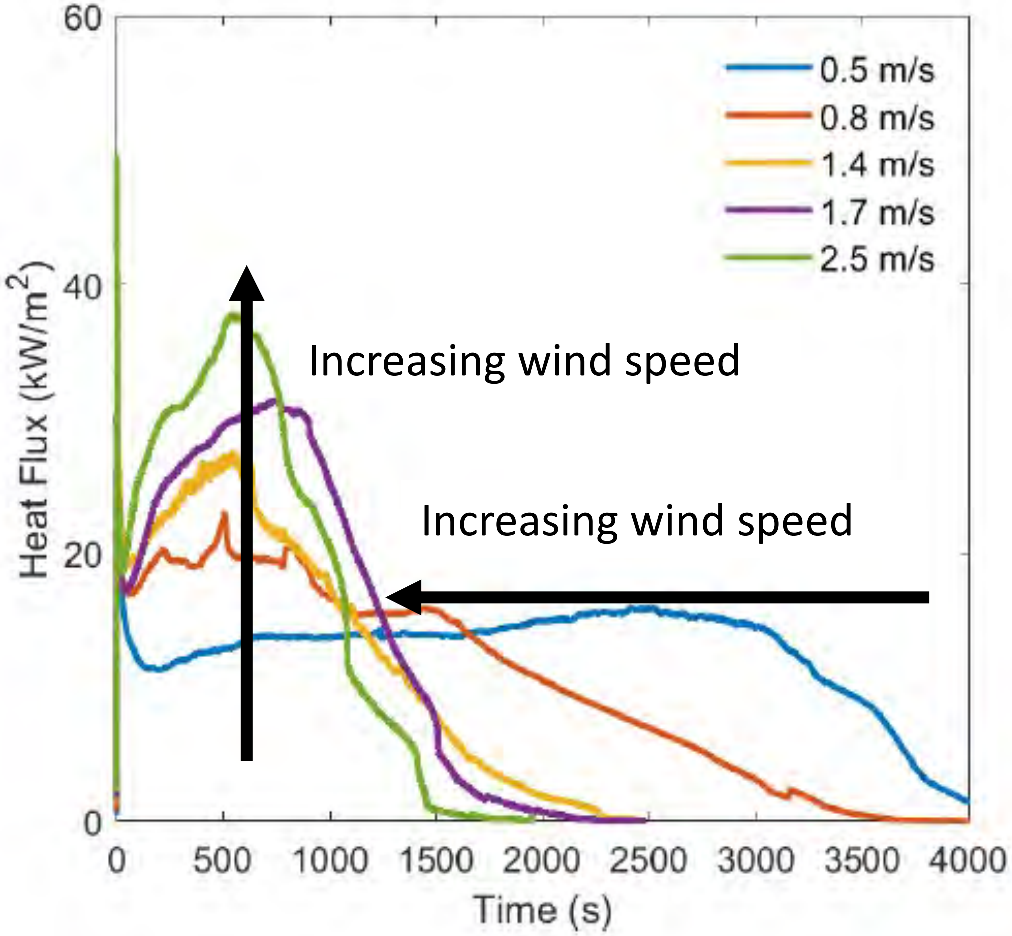
Pile of 10 g deposited mass, 12.7 mm firebrands:



Ember Studies – Wind Effects on Heating

- Heat flux averaged between tests from WC-HFG (16 g)



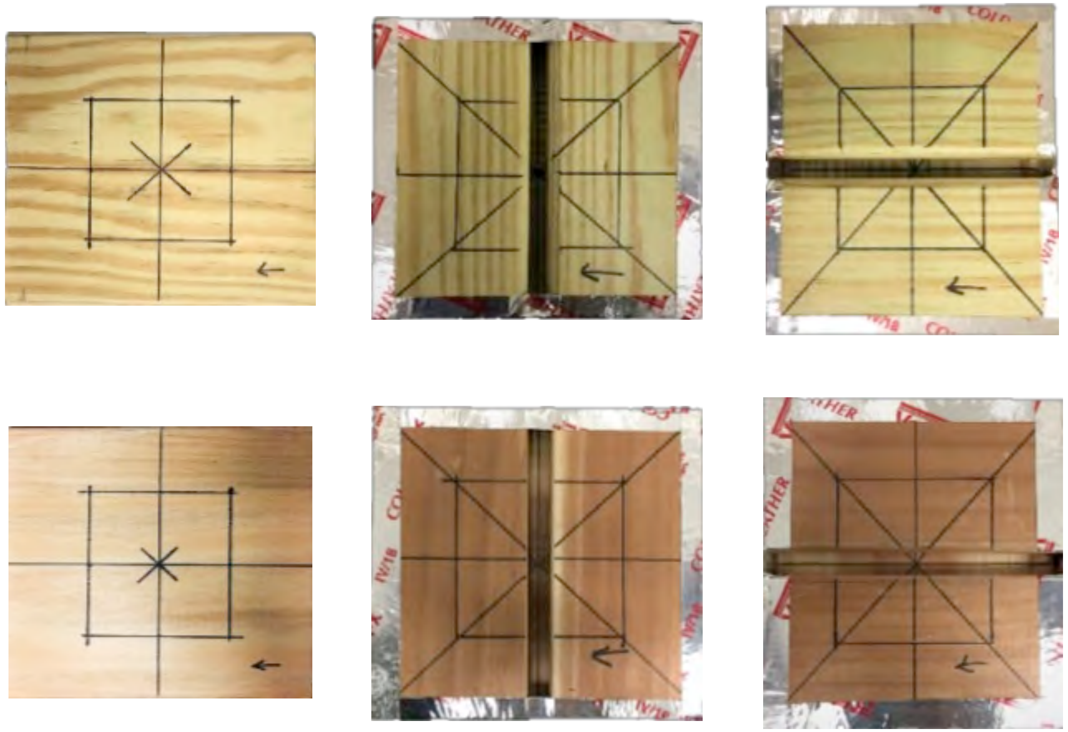


"Critical ignition conditions of wood by cylindrical firebrands." *Frontiers in Mechanical Engineering* 7 (2021): 17.

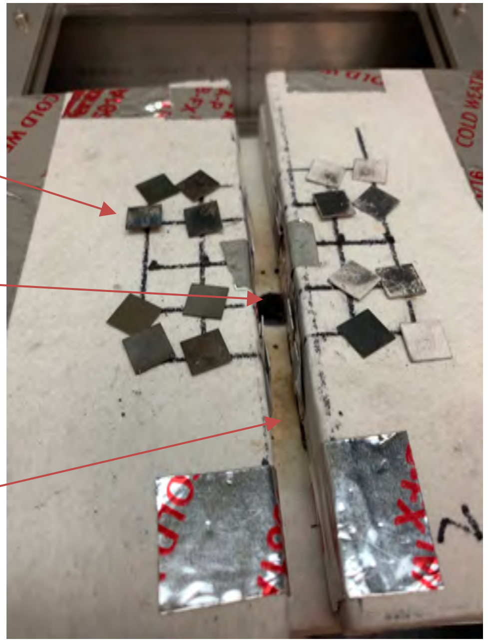
Ignition & Heat Flux in a Crevice

Bryce Bathras
Julia Barbetta Duarte

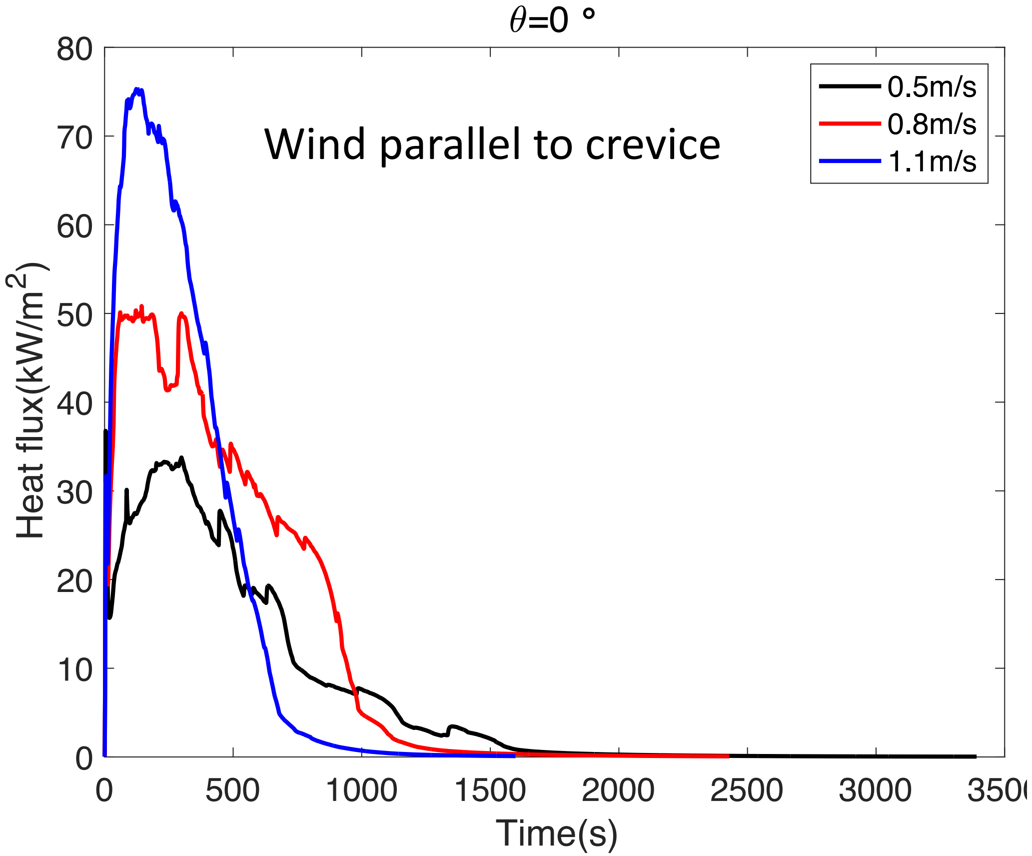
	Flat	90° Crevice	0° Crevice
Pressure-treated wood			
Redwood			

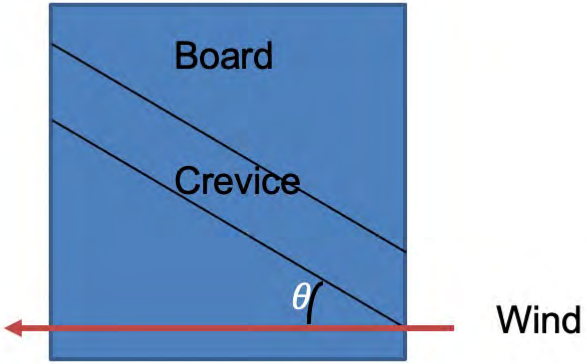


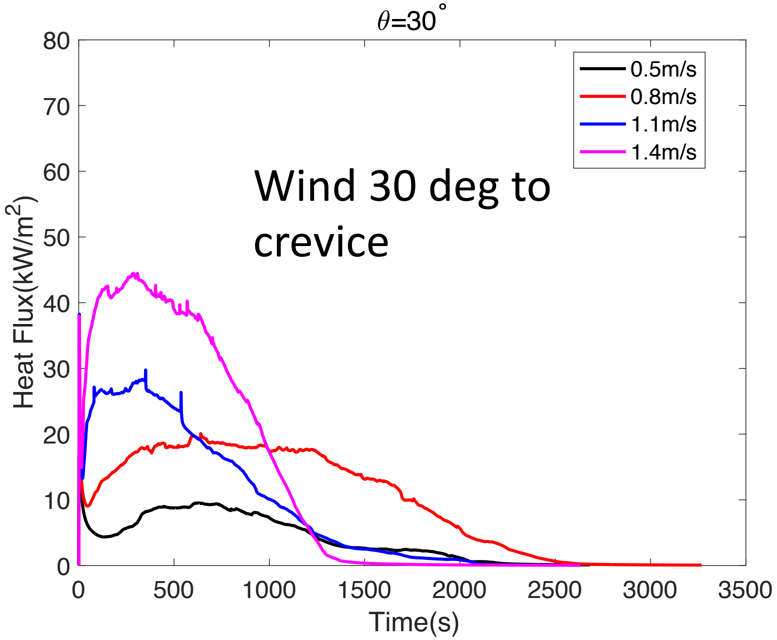
Wind speed

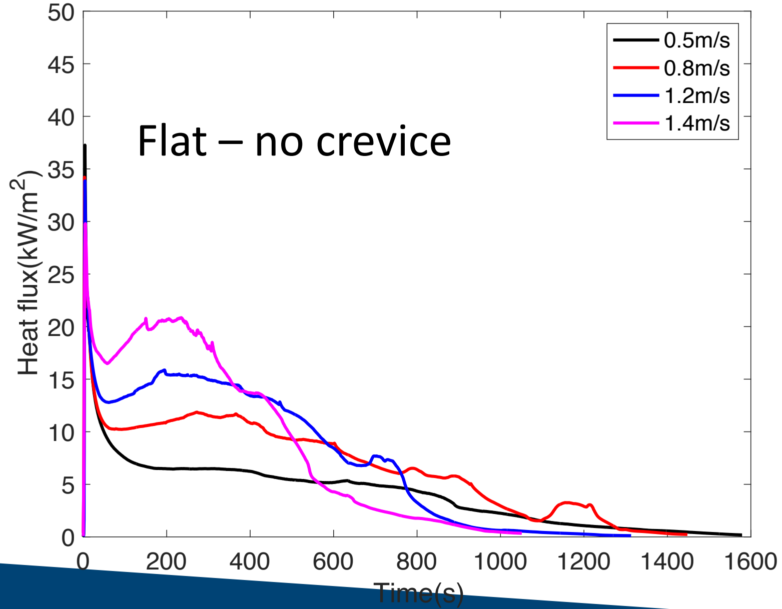


Heat Flux in a Crevice









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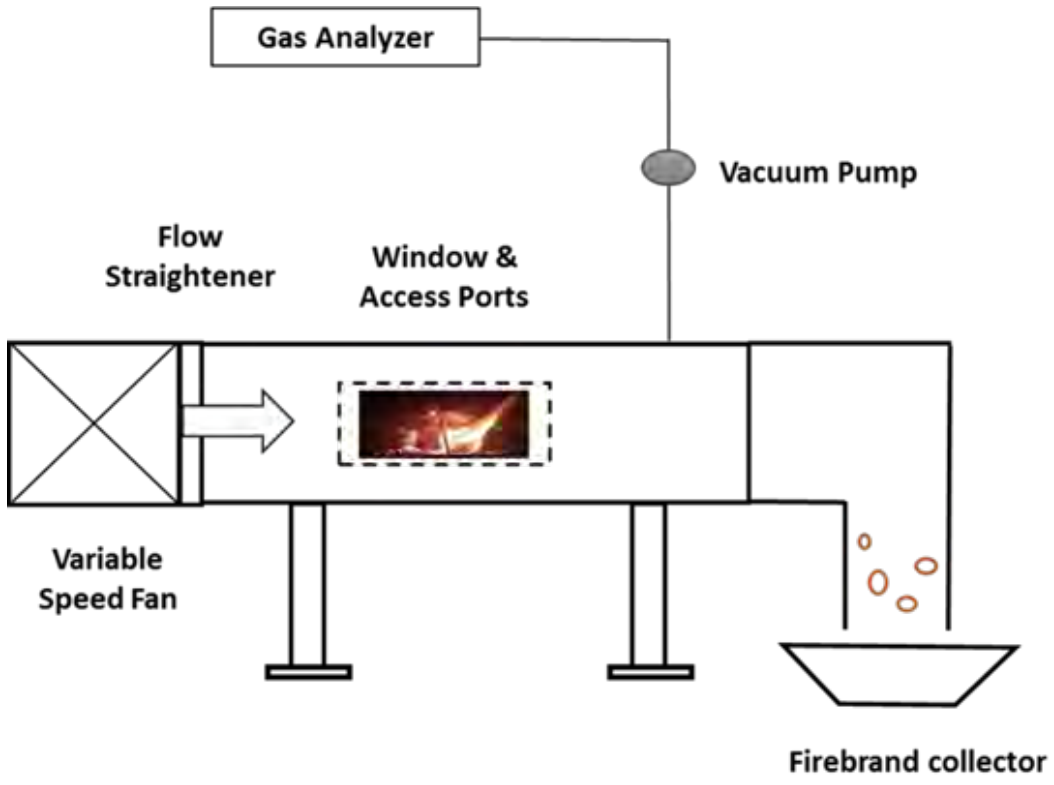
Firebrand Generation

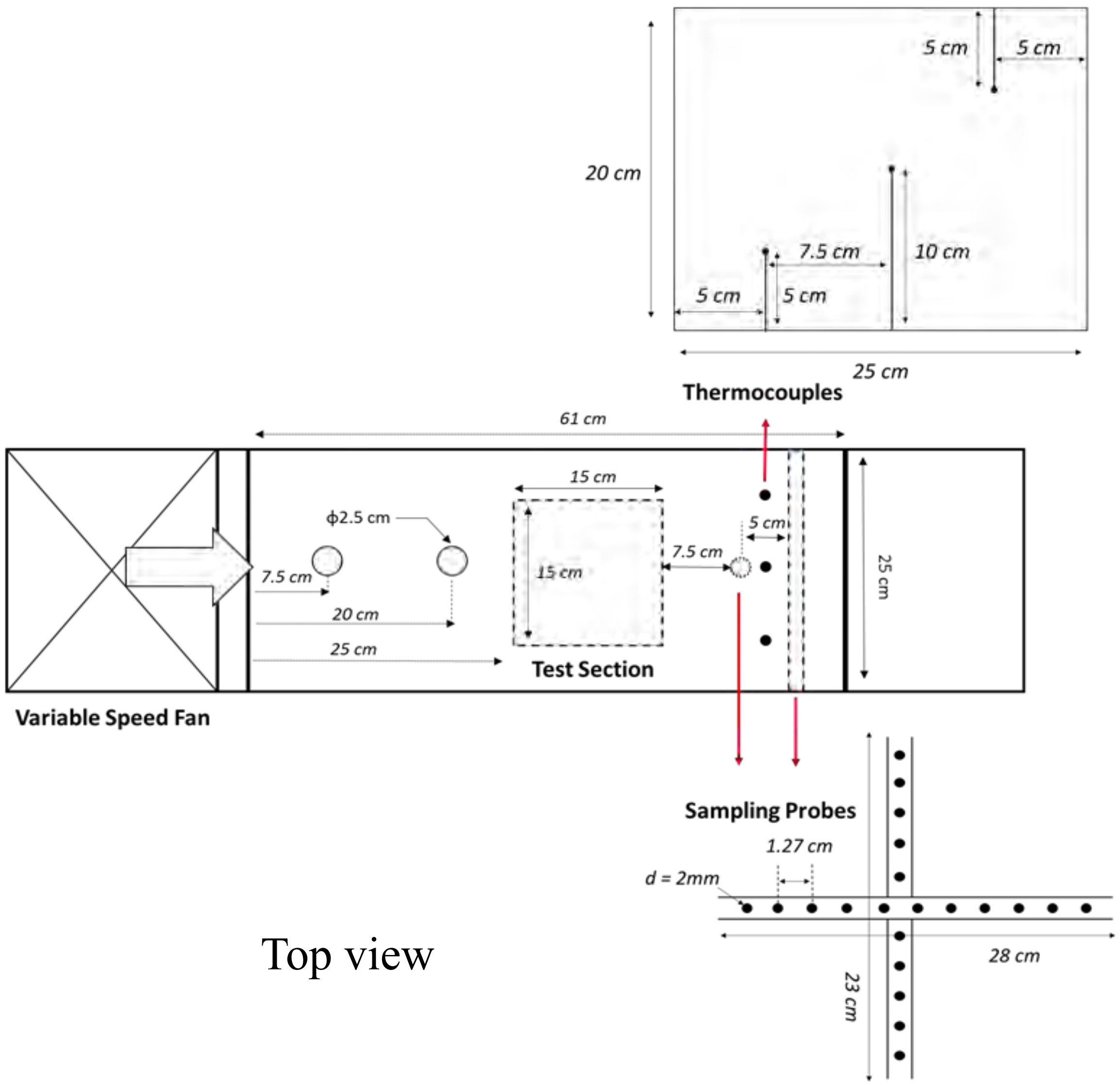
Firebrand Generation Objectives

- How much of a burning fuel burns & transitions to firebrands vs. product gases?
  - Provide quantitative data on firebrand generation through the burning of WUI fuels in a laboratory-scale wind tunnel
  - Function of *ignition condition*, *fuel size & type*, *moisture content*, *wind speed*
  - Enable a simple multi-variable regression model which can be used to estimate the mass and number of firebrands from a full-sized fuel sample
- Important input for fire simulations
  - Fire Dynamics Simulator (FDS)
  - Link to input variables (heat-release rate)

Experimental Setup



Side view



Top view

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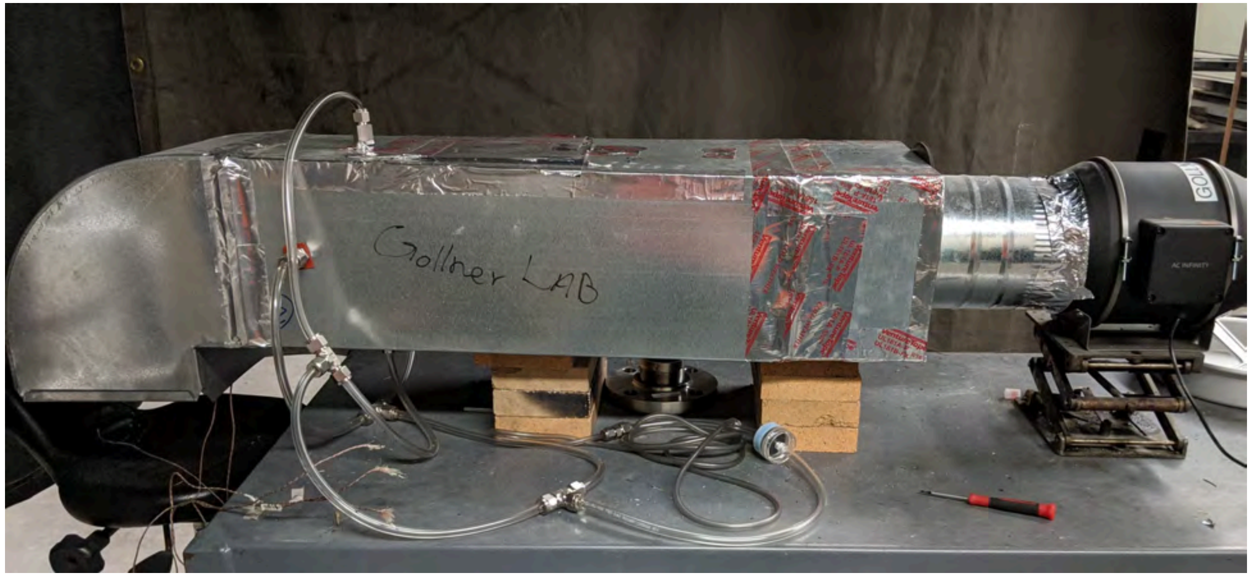
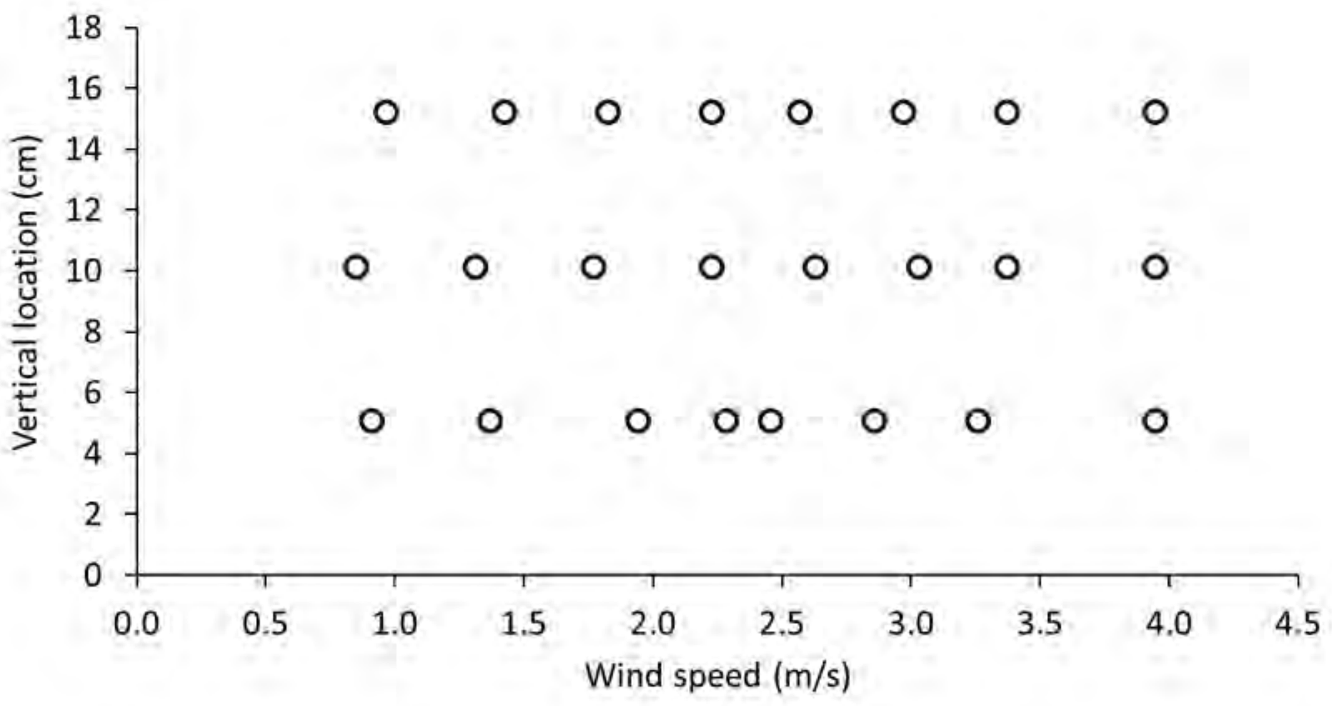
Experimental Setup



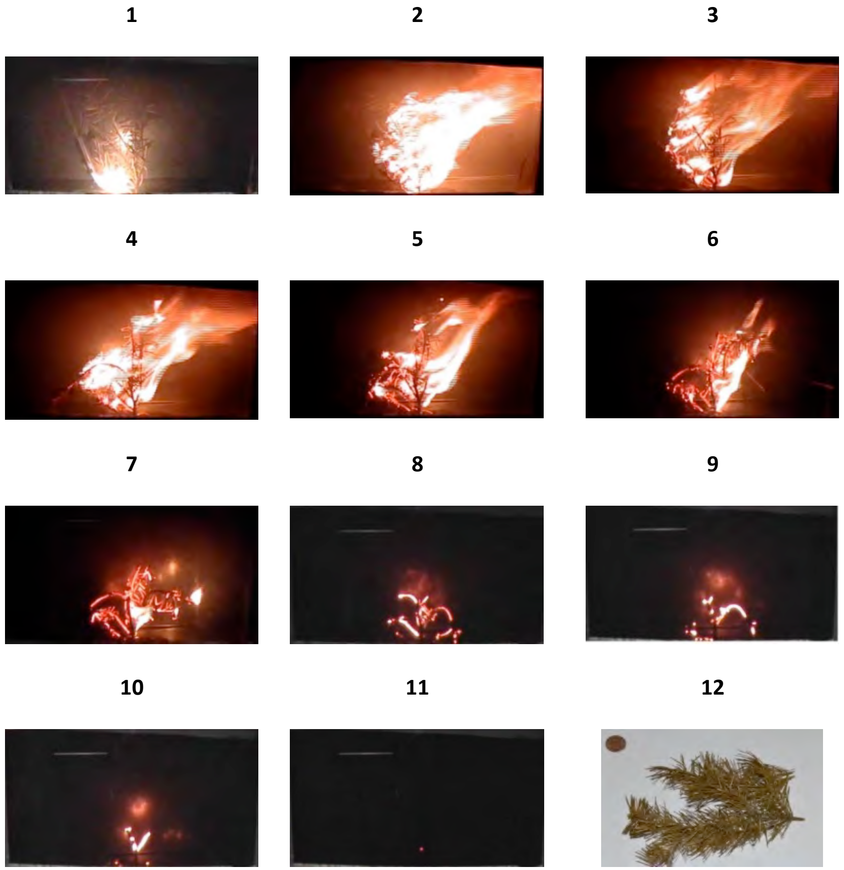
Wind Speed Characterization



Previous Work

Lodgepole pine   Douglas Fir

- FMC: 3%
- Length: 10-15 cm
- D_{avg} of lodgepole pine: 6.2 ± 1.9 mm
- D_{avg} of Douglas fir: 2.9 ± 0.8 mm



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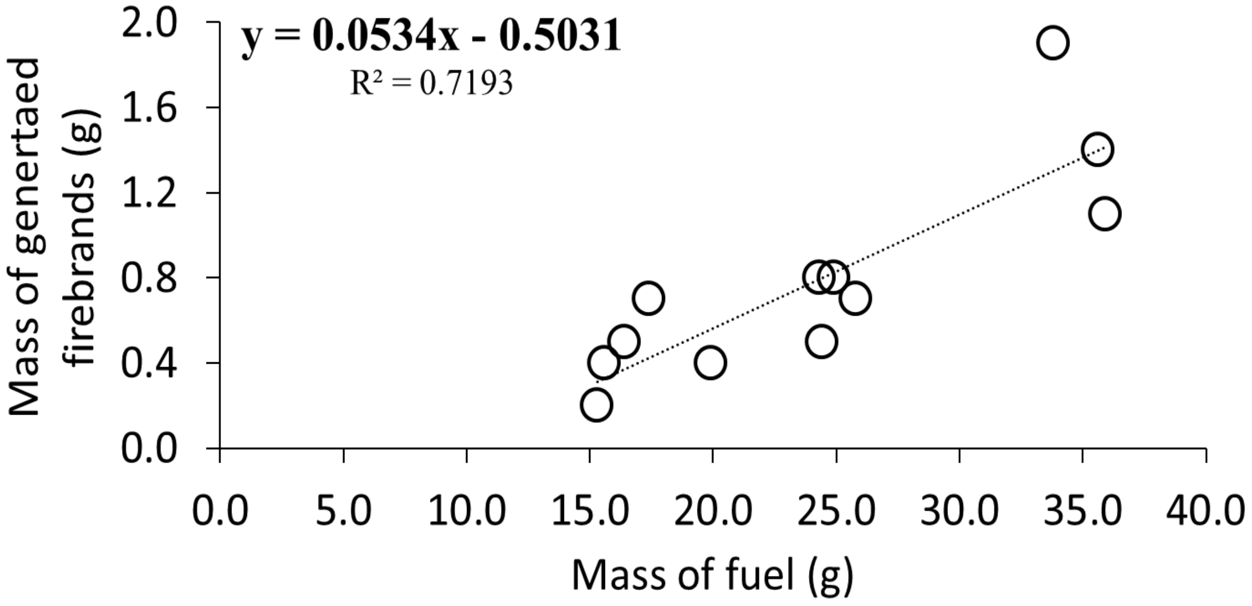
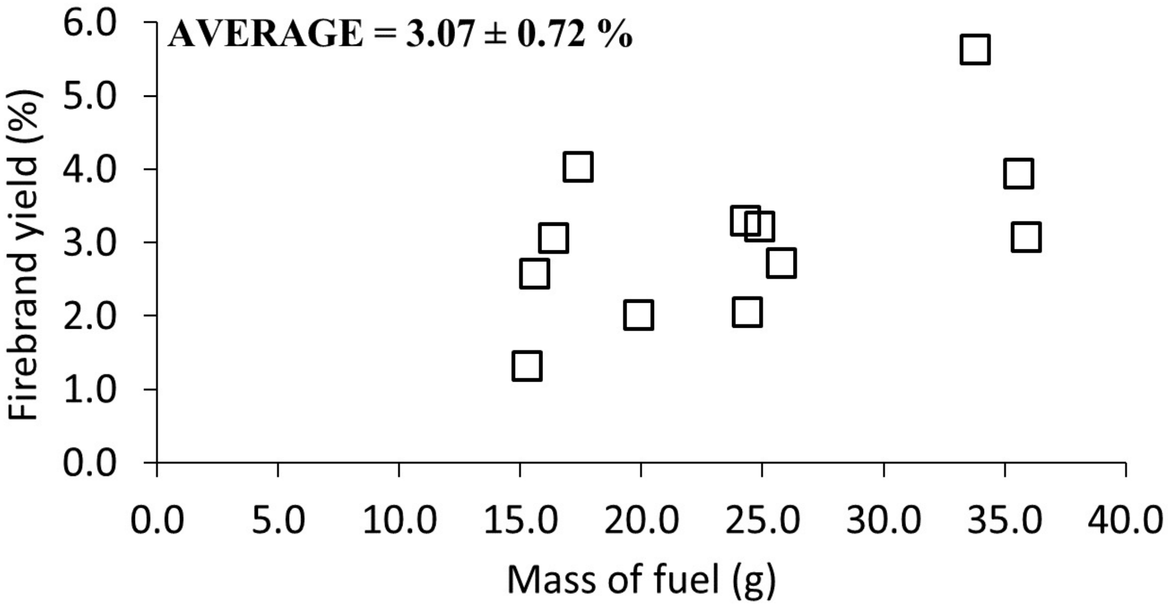
Previous Work

Firebrand Yield, Lodgepole Pine





Dry lodgepole pine @ 4 m/s wind speed: <u>**3% FB yield**</u>

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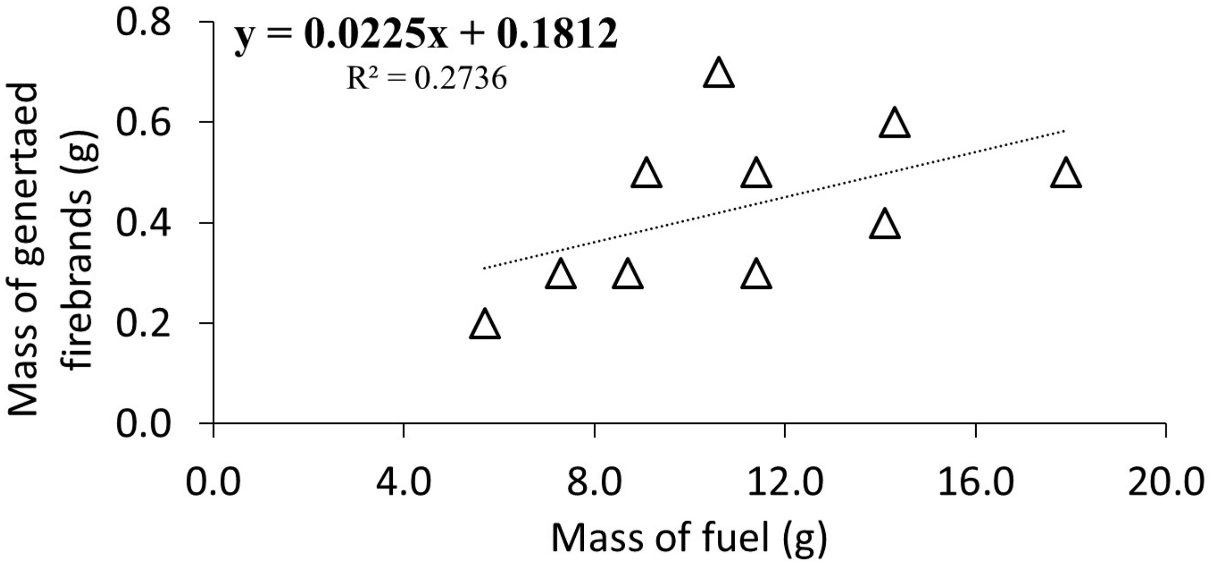
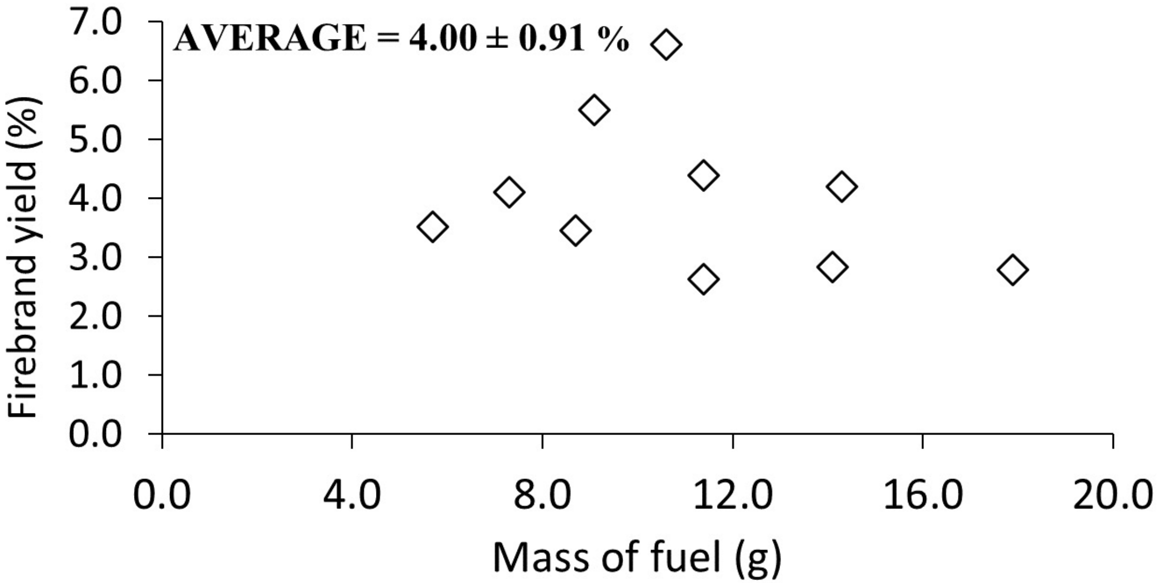
Firebrand Yield, Douglas fir





Dry Douglas fir @ 4 m/s wind speed: **4% FB yield**

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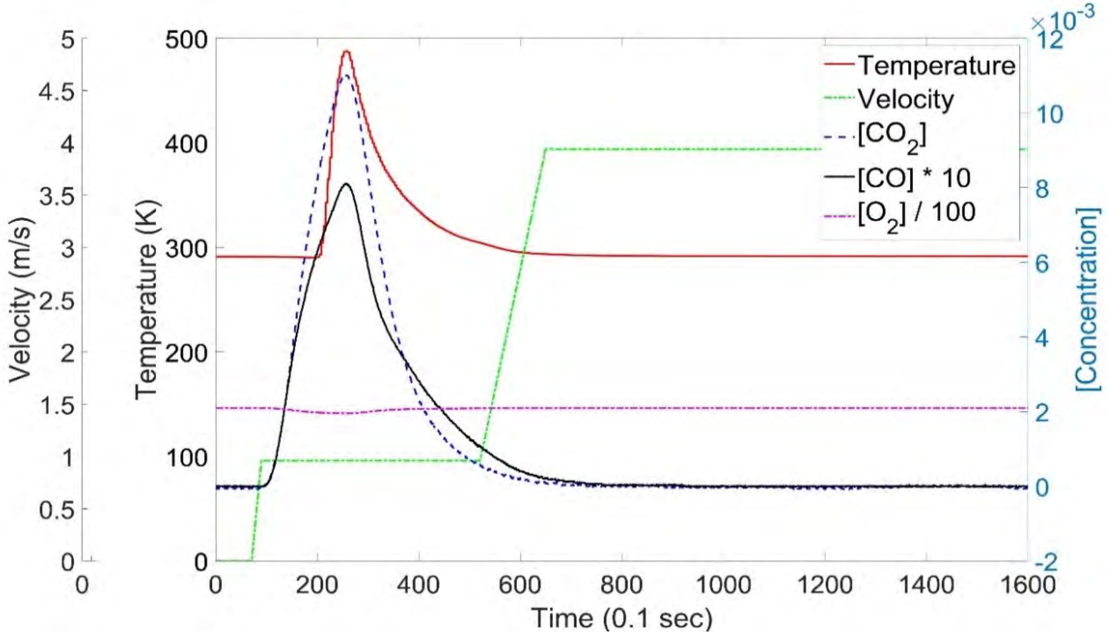
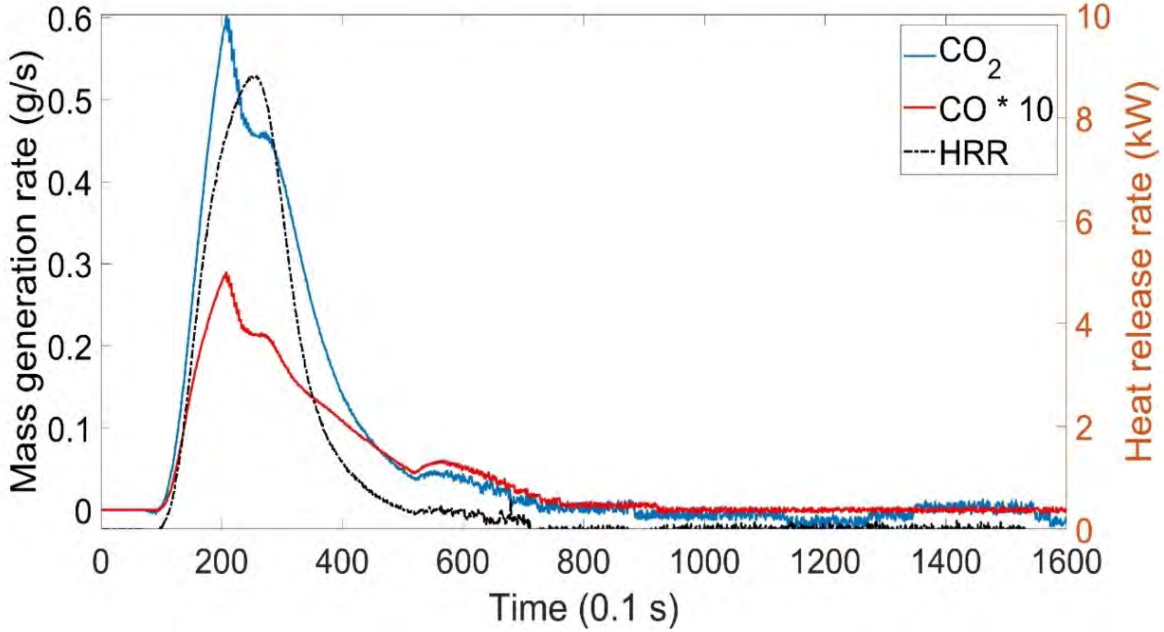
Gaseous Species and HRR



Gaseous species concentrations



Mass of generated gases &
Heat Release Rate

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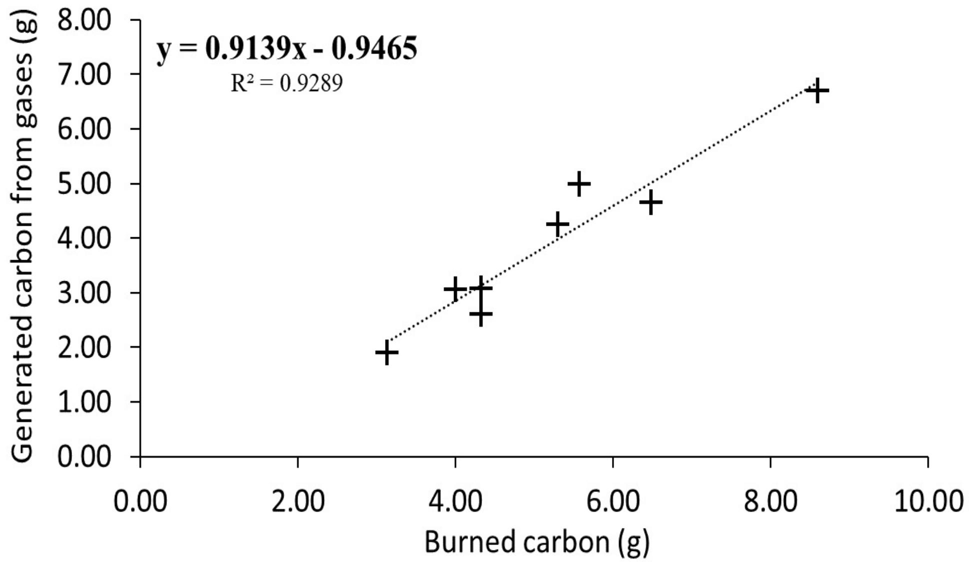
Carbon Balance, MCE, EF

Carbon in Fuel = Carbon in Product Gases + Carbon in Firebrands + Carbon in Fuel Residue

$$\mathrm{EF} = \frac{Mass\ of\ product\ species\ [g]}{Mass\ of\ consumed\ dry\ fuel\ \ [kg]} \qquad \eta = \frac{Mass\ of\ Carbon\ in\ CO_2\ [g]}{Mass\ of\ Carbon\ in\ CO_2\ [g]+Mass\ of\ Carbon\ in\ CO\ [g]}$$



Average values for dry Douglas fir:

η = 90.28 ± 1.91 %

EF_{CO} = 76.51 ± 10.91

EF_{CO2} = 726.90 ± 90.75

Good agreement with other studies

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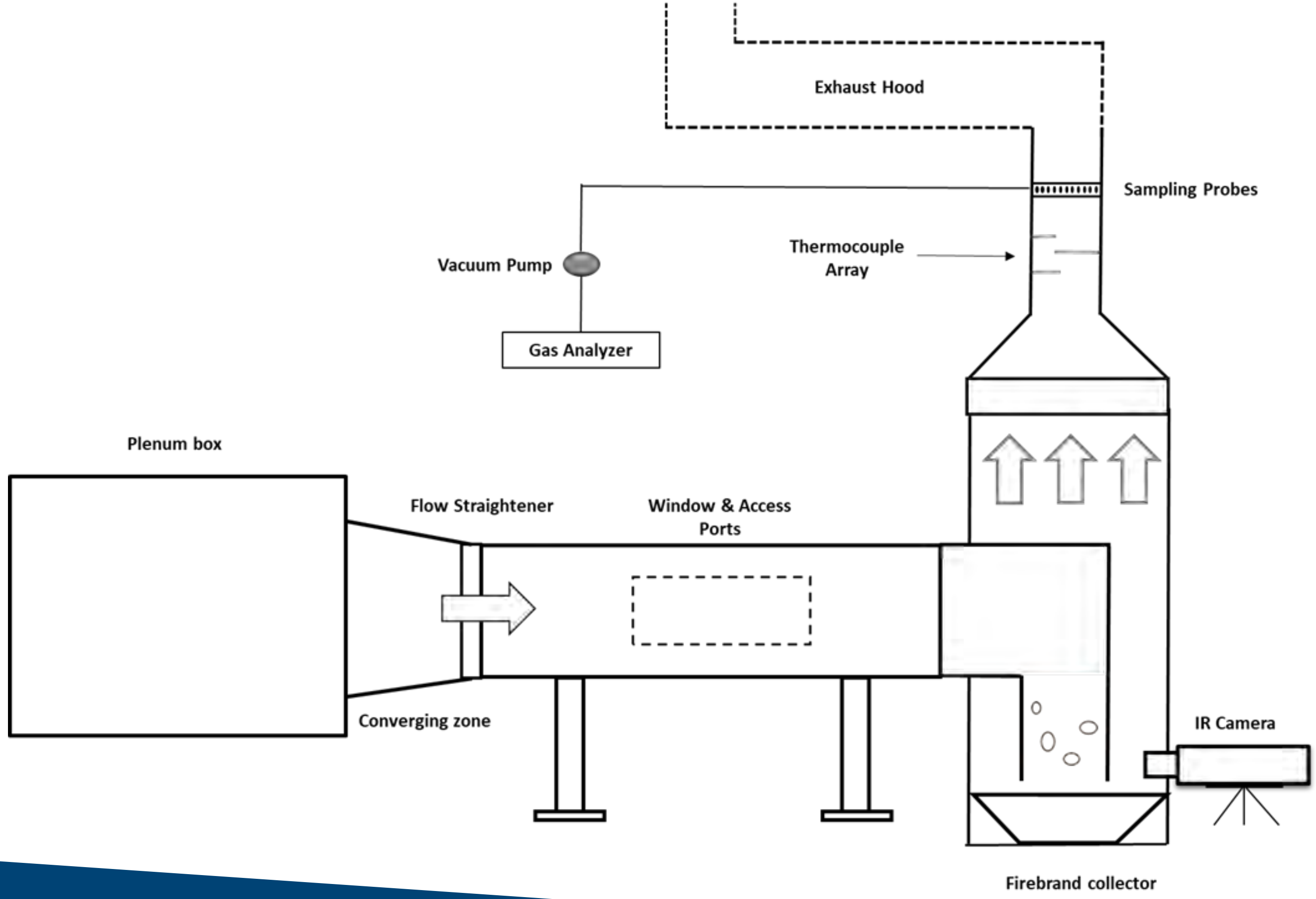
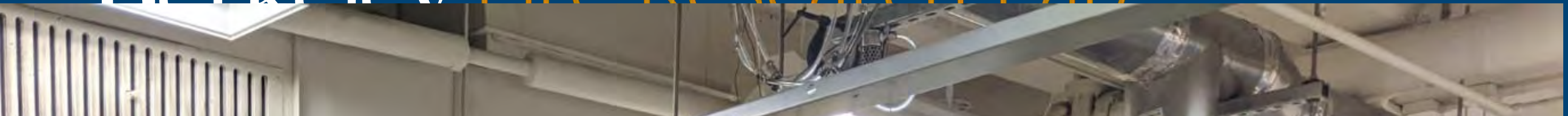
Improved Wind Tunnel Design



Ongoing Work

- Wind speed: 0 - 8 m/s
- Different fuel types
- Firebrand yield
- Carbon mass balance



Left: Pressurized plenum to generate flow
Bottom: Test section (combustion chamber) which deposits
into a water tray below a calorimetry hood

Thank you!