Quantification of Firebrand Production from WUI fuels for Model Development

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Berkeley Fire Lab Research

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

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Outline

- WUI Fire Problem
- Firebrand Ignition Studies
- Firebrand Generation – Completed Work
- Future work on Firebrand Generation
California – A History of Fire

Burned Area 1878-2010

Burned Area 2011-2021
California – A History of Fire

Burned Area 1878-2010

Burned Area 2011-2021

Structures Burned

Year

CA Camp Fire (19k+)

Nor Cal Fires (9k+)

Cedar Fire (4k+)

Red: California Losses

Blue: US Losses

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
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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Nathan Trauernicht, UC Davis Fire @ Tamarack Fire
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)
WUI Disaster Sequence

Severe Wildfire Conditions
High winds, dry fuels

Extreme Fire Behavior
Many home ignitions

Overwhelmed resources diminish in effectiveness

WUI Fire Disaster
High winds, dry fuels

Potentially 100's + homes destroyed

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

Extreme Fire Behavior
- High fire intensity & growth rates

Severe Wildfire Conditions
- High winds, dry fuels

Residential Fires
- Many home ignitions

Fire Protection Resources
- Overwhelmed resources diminish in effectiveness

Reducing Exposure
- Community Design
- Fuel Reduction
- Prescribed Fire

WUI Fire Disaster
- Potentially 100's + homes destroyed

Improve Response
- Notification
- Evacuation
- Response Coordination
- Planning & Communication

Adapted from Calkin, et al., 2014. PNAS. 111, 746–51.
Firebrand Generation and Transport

- Firebrand formation and break-off
- Various types of firebrands
- Spot fire ignition after landing
- Lofting due to fire plume
- Transport due to wind

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 Measurements

Generation Under Wind
(IBHS - Farahani, Tohidi)

Figure by Tohidi et al., 2015
Manzello, Maranghides, Mell, UIWE, 2007, 16, 458-462; El Houssami et al., Fire Technology 2016
Firebrand Generation and Transport

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Firebrand Ignition Studies – Past Work

Firebrand Ignition – Single vs. Pile

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)

Ignition & Heat Flux in a Crevice

Pressure-treated wood

Redwood

Wind speed
Heat Flux in a Crevice

Wind parallel to crevice

Wind 30 deg to crevice

Flat – no crevice
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
Experimental Setup
Wind Speed Characterization
Previous Work

- FMC: 3%
- Length: 10-15 cm
- $D_{avg}$ of lodgepole pine: $6.2 \pm 1.9$ mm
- $D_{avg}$ of Douglas fir: $2.9 \pm 0.8$ mm
Previous Work
Firebrand Yield, Lodgepole Pine

Dry lodgepole pine @ 4 m/s wind speed: 3% FB yield

\[ y = 0.0534x - 0.5031 \]
\[ R^2 = 0.7193 \]
Firebrand Yield, Douglas fir

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

Gaseous Species and HRR

Gaseous species concentrations

Mass of generated gases & Heat Release Rate

Carbon Balance, MCE, EF

\[ \text{Carbon in Fuel} = \text{Carbon in Product Gases} + \text{Carbon in Firebrands} + \text{Carbon in Fuel Residue} \]

\[ \begin{align*}
\text{EF} &= \frac{\text{Mass of product species} [g]}{\text{Mass of consumed dry fuel} [kg]} \\
\eta &= \frac{\text{Mass of Carbon in CO}_2 [g]}{\text{Mass of Carbon in CO}_2 [g] + \text{Mass of Carbon in CO} [g]}
\end{align*} \]

Average values for dry Douglas fir:

\[ \eta = 90.28 \pm 1.91 \% \]
\[ \text{EF}_{CO} = 76.51 \pm 10.91 \]
\[ \text{EF}_{CO_2} = 726.90 \pm 90.75 \]

Good agreement with other studies

\( y = 0.9139x - 0.9465 \)
\( R^2 = 0.9289 \)
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!