UMD Summer School on Fire Safety Science Wildland/WUI Fire Behavior

Firebrands

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University of California, Berkeley

Spring 2022

Definition

- ***Firebrands*** and ***embers*** are similar items but with a slight distinction.
- "**Ember**" refers to any small, hot, carbonaceous particle
- "**Firebrand**" specifically denotes an object which is airborne and carried for some distance in an airstream. Thus, aerodynamic properties of firebrands become an important characteristic that needs to be considered.
  - Firebrands are also sometimes referred to as "flying brands" or "brands," and all of these terms have the same meaning.
  - Since firebrands or embers can be burning (flaming or smoldering), they can serve as ignition sources for vegetation, structures, or other target fuels
- "Blizzard", "storm", etc. all common to describe many firebrands

Babrauskas, V. (2020). Firebrands and Embers. In: Manzello, S.L. (eds) Encyclopedia of Wildfires and Wildland-Urban Interface (WUI) Fires. Springer, Cham. https://doi.org/10.1007/978-3-319-52090-2_3

Stuart Palley / https://www.stuartpalley.com/

Spot Fires


18 Watch Out Situations
16. Getting frequent spot fires across line.

WUI Fires

Camp Fire, Paradise, CA

AFP/Getty Images

https://www.bbc.com/news/world-us-canada-46198498

The Wildland Urban Interface (WUI)

The line, area, or zone where structures and other human development meet or intermingle with undeveloped ***wildland*** *or vegetation fuels*

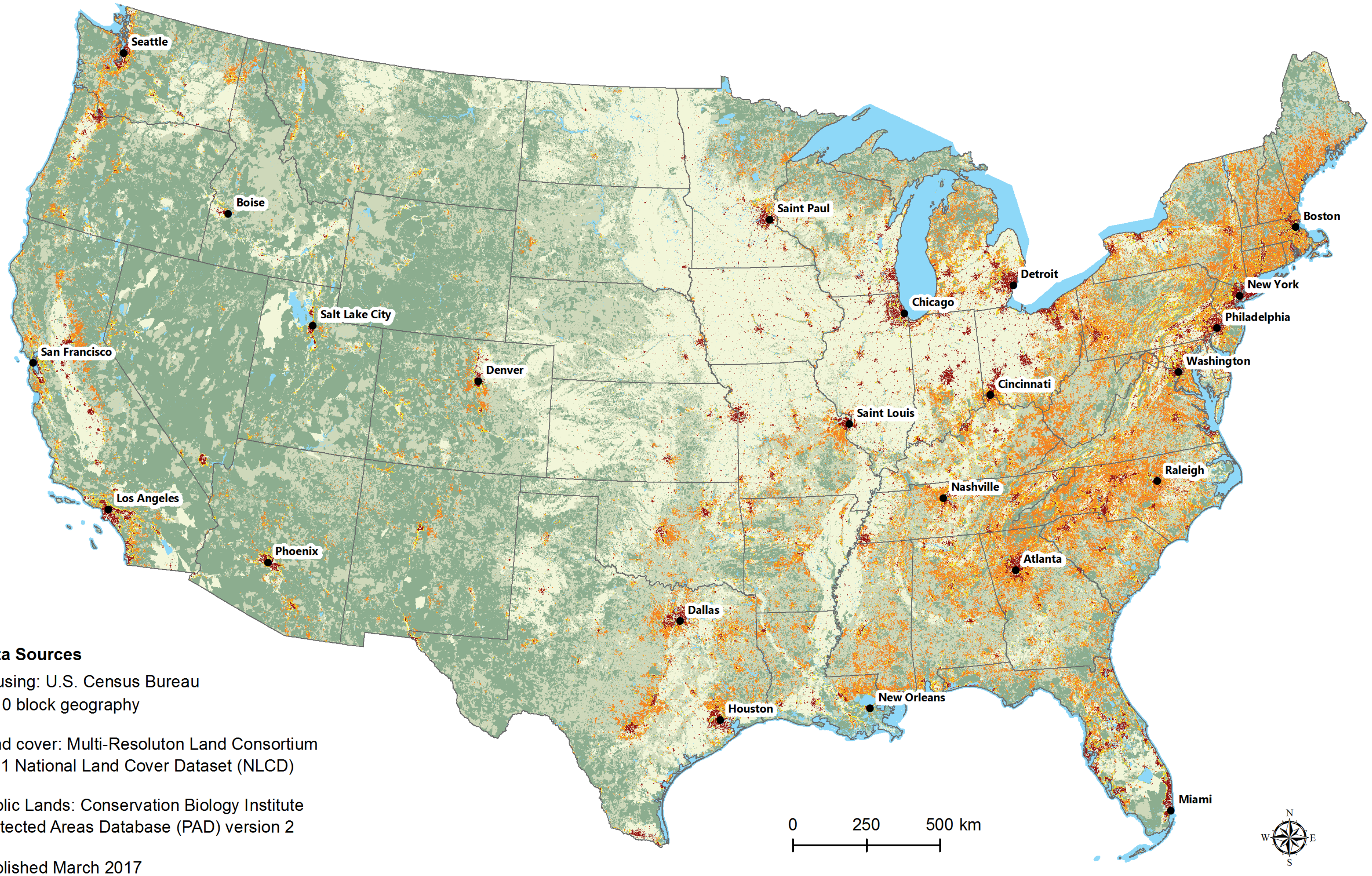
SPARK AND SPRAWL

A WORLD TOUR

"Wildland-urban interface" is a dumb term for a dumb problem, and both have dominated the American fire scene for nearly twenty years. It's a dumb term because "interface" is a pretty klutzy metaphor and because the phenomenon of competing borders it describes is more

BY STEPHEN J. PYNE

The 2010 Wildland-Urban Interface of the Conterminous United States



Data Sources

Housing: U.S. Census Bureau
2010 block geography

Land cover: Multi-Resoluton Land Consortium
2011 National Land Cover Dataset (NLCD)

Public Lands: Conservation Biology Institute
Protected Areas Database (PAD) version 2

Published March 2017

Contacts

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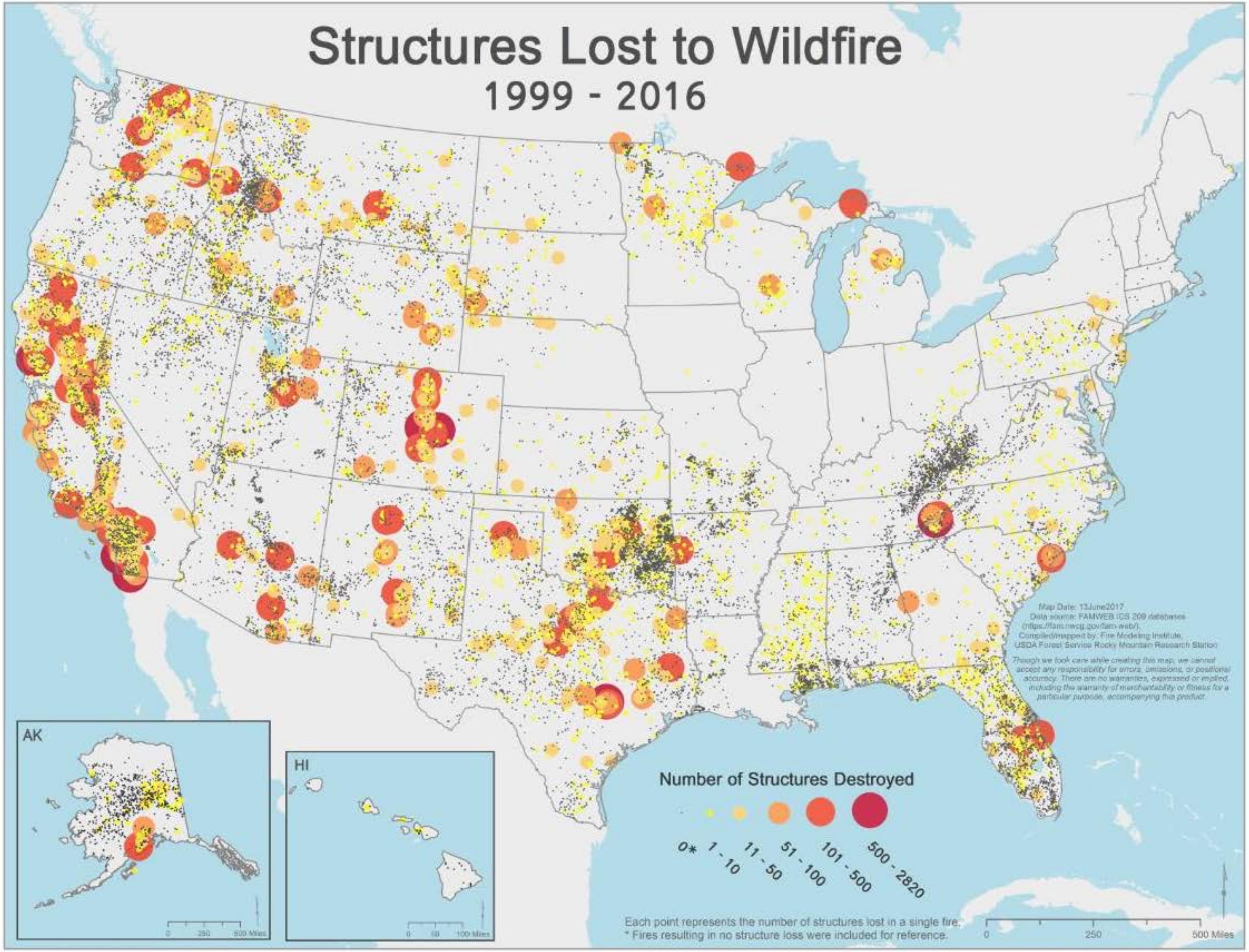
Wildland-Urban Interface (WUI)
- Interface
- Intermix

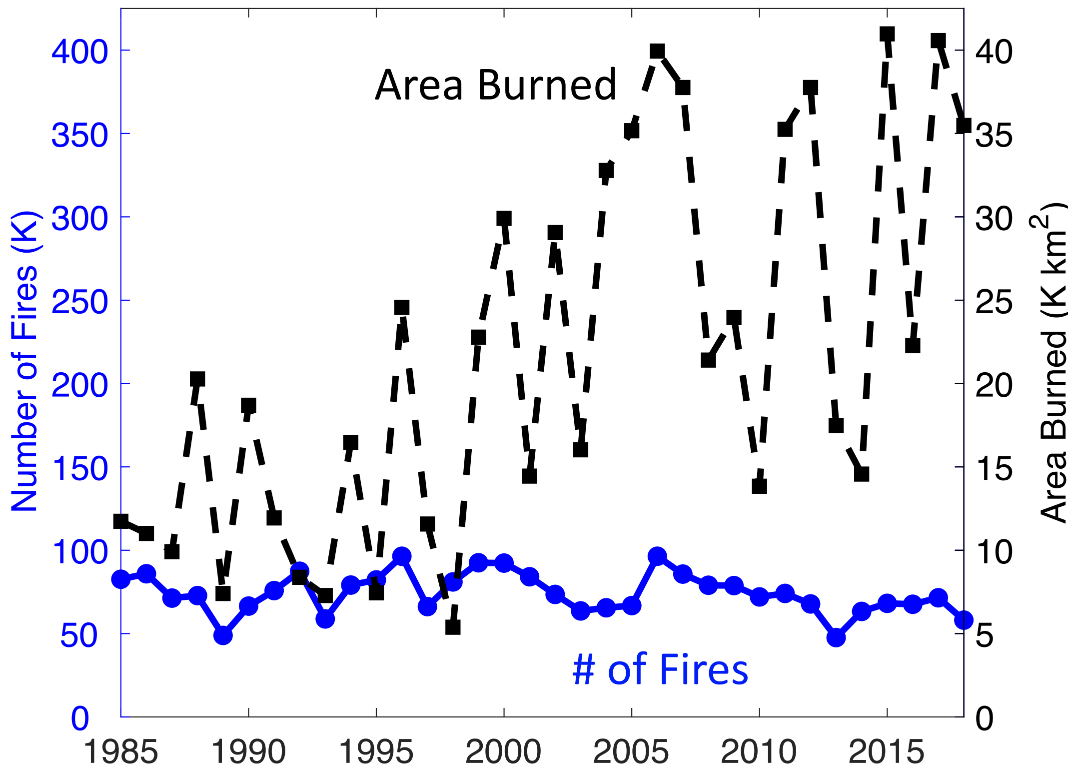
Non-WUI Vegetated
- No housing
- Very low housing density

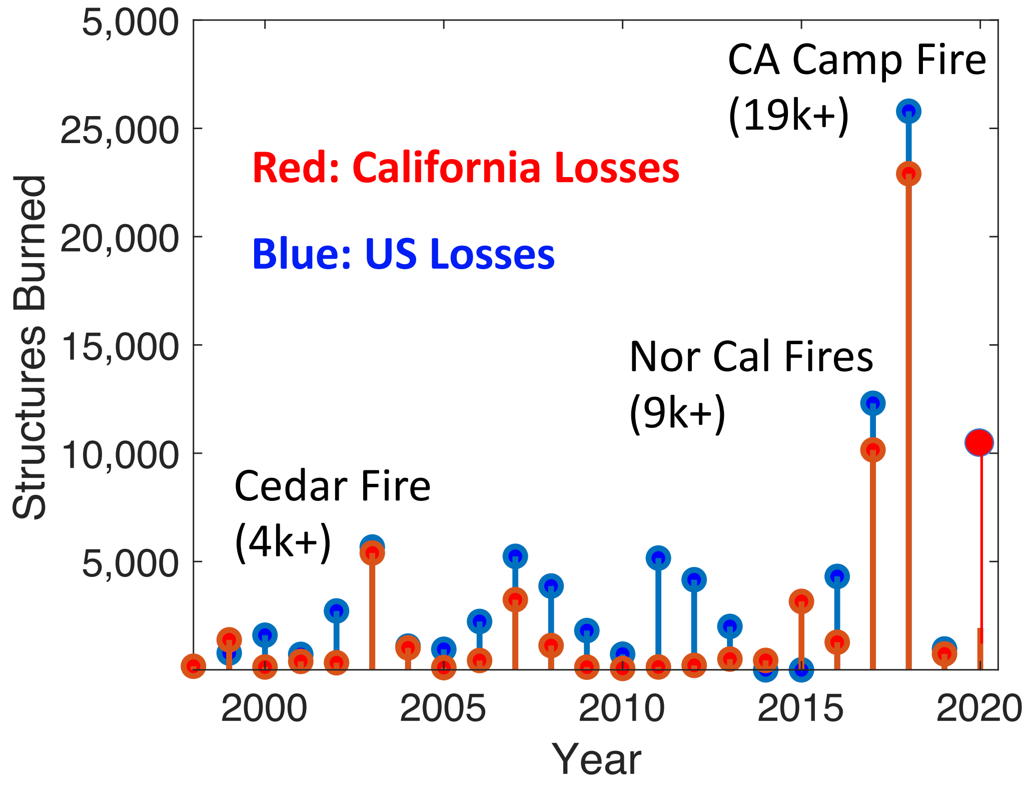
Non-vegetated or Agriculture
- Low and very low housing density
- Medium and high housing density
- Water



:ompiled and mapped by the Fire Mode
:nstitute; Fire, Fuel and Smoke Prograr
Aountain Research Station; Missoula, N
I/5/2012

Increasing Size and Cost of Fires





(Left) While the number of wildfires is somewhat steady (solid blue), the size and intensity of these fires (dashed black) is drastically increasing.

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

2018 Camp Fire Loss ~$16.5B, 85 deaths

Caton et al., Review of pathways to Fire Spread. Data: www.nifc.gov/nicc, fire.ca.gov


Barnes ST
Middletown California: BEFORE


Rocky Fire


Middletown California: AFTER
Barnes ST
Harbin Springs Retreat Center


Camp Fire
Paradise, CA (2018)
18,804 Structures Destroyed
losses ~$7.5-10 billion
85 Fatalities
Josh Edelson, AFP/Getty Images


Coffey Park
Santa Rosa, CA
Tubbs Fire – previously most destructive in CA history

Chimney Tops 2 Fire

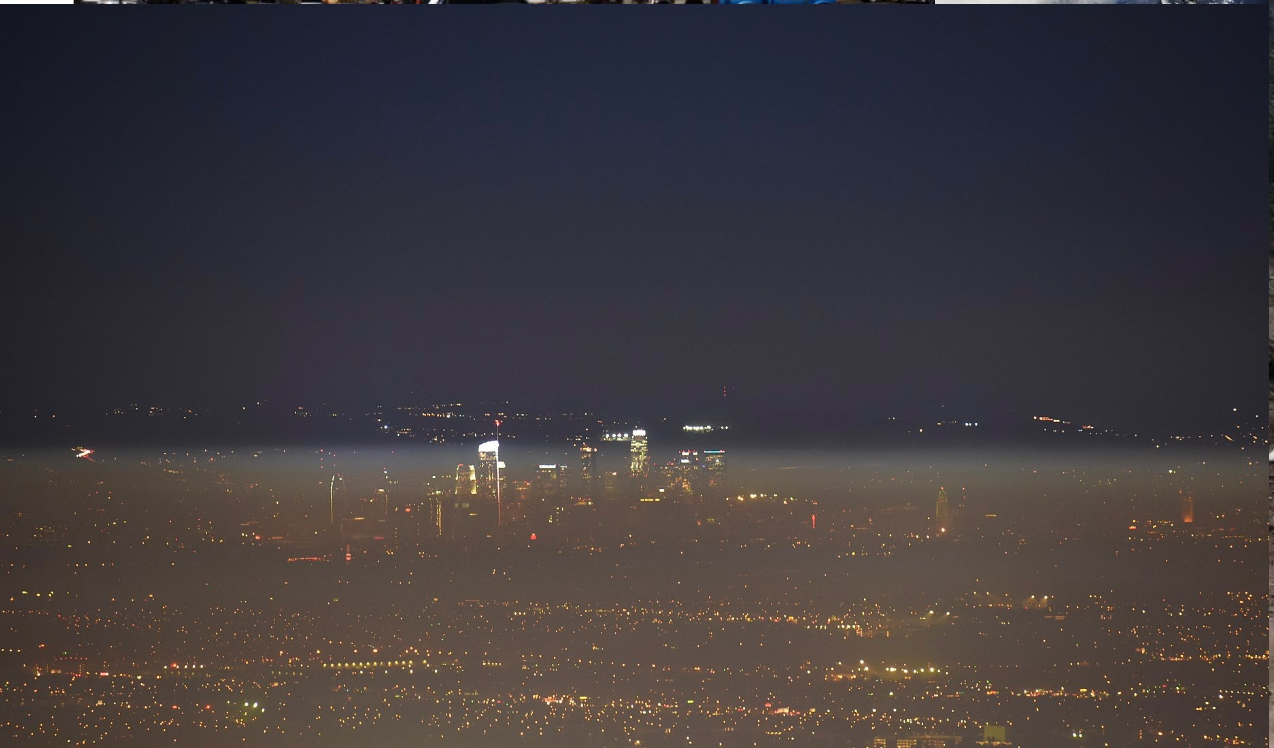
Gatlinburg, TN (2016)

2,400+ Structures Destroyed
Damage ~$500 million
Firefighting ~$7 million
14 Fatalities

The Knoxville Mercury


Wildfire Shuts Down Los Alamos Lab

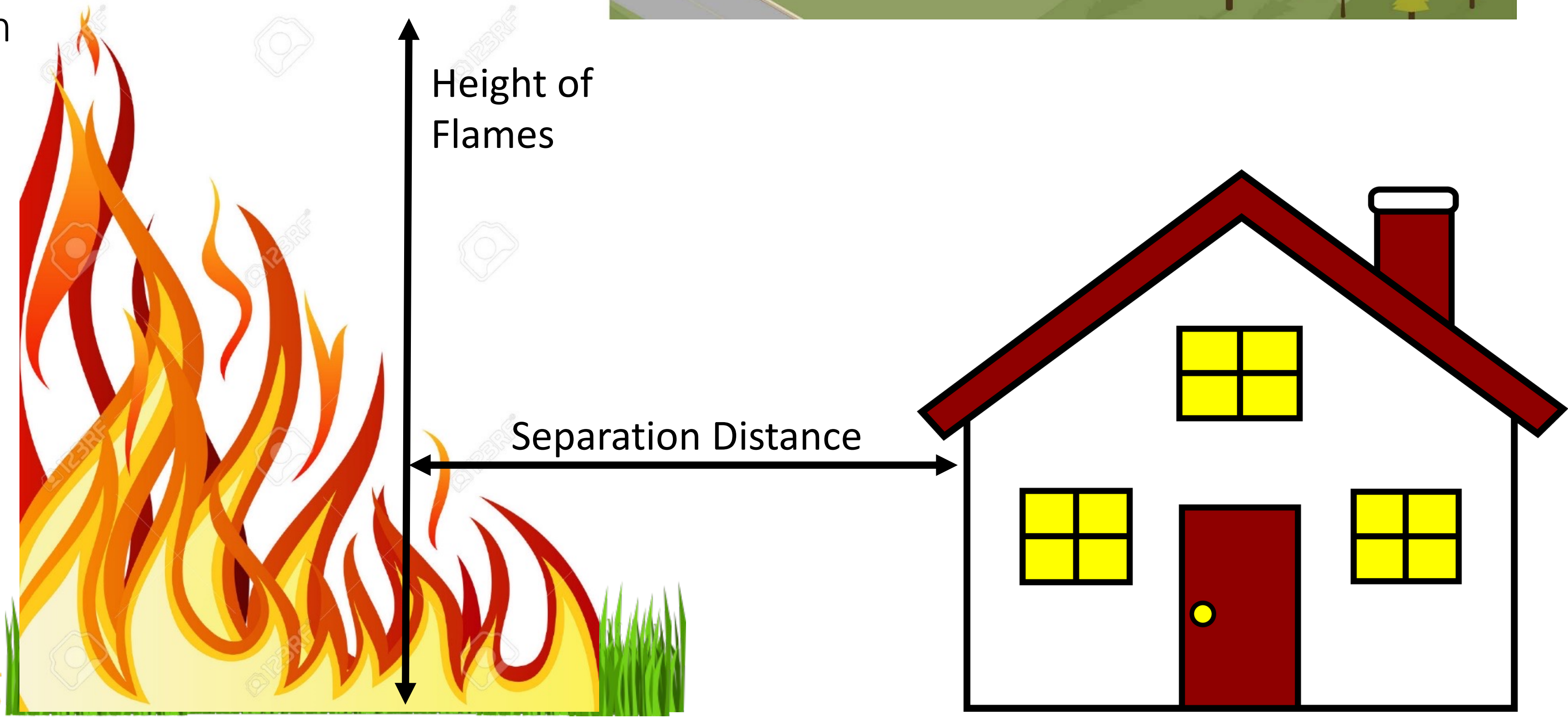
By Manikandan Raman
06/27/11 AT 7:18 AM



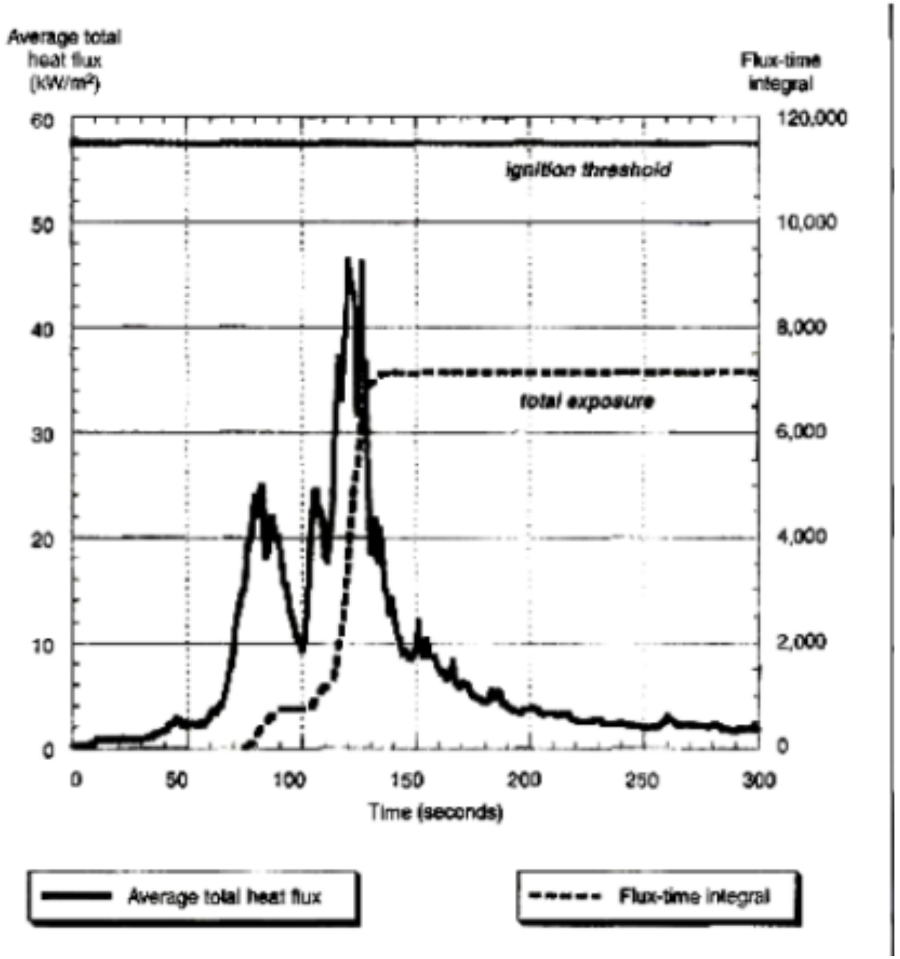

Why are our communities burning?
Coffey Park
Santa Rosa, CA
Tubbs Fire – previously most destructive in CA history

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



Aftermath – No Ignition



- Panels 40 m (130 ft) away could not ignite, even from the most intense fires.
- International Crown Fire Modeling Experiments

If fuels are cleared away from a structure, it is very difficult to ignite by radiation!

Cohen, J., 2004a. Can. J. For. Res. 1626, 1616–1626

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 cause spot ignitions

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 cause spot ignitions

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 cause spot ignitions


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

JFSP No. 12-1-03-11: Fuel Treatment Effectiveness


© Ryan Babroff/ LACoF


© Ryan Babroff/ LAC


2016/05/04
02:44:20
Always
/9750/H


2016/05/04
02:47:20
Always
/9750/H

WUI Investigations/History

- USFS (Jack Cohen)
    - International Crown Fire Modeling Experiments
    - Grass Valley Fire (Cohen & Stratton 2008)
    - Fourmile Canyon Fire (Graham et al. 2012)
- NIST (Alex Maranghides, Ruddy Mell, etc.)
    - Witch & Guejito
    - Waldo Canyon
    - Camp
- IBHS (Quarles, etc.)

Grass Valley Fire, Cohen

a)

b)

Figures 1a, b.

a) Home destruction across a residential area during the 2007 Grass Valley Fire, Lake Arrowhead, CA. b) Rows of destroyed homes with adjacent unconsumed tree canopies during the 2007 Grass Valley Fire in Lake Arrowhead, CA.

A – Potential structure ignition due to continuous fire spread through vegetation to the structure

B - Structures where there was burned vegetation sufficiently close to the structure to be a potential source of structure ignition

C – Structure ignitions that were a direct result of embers

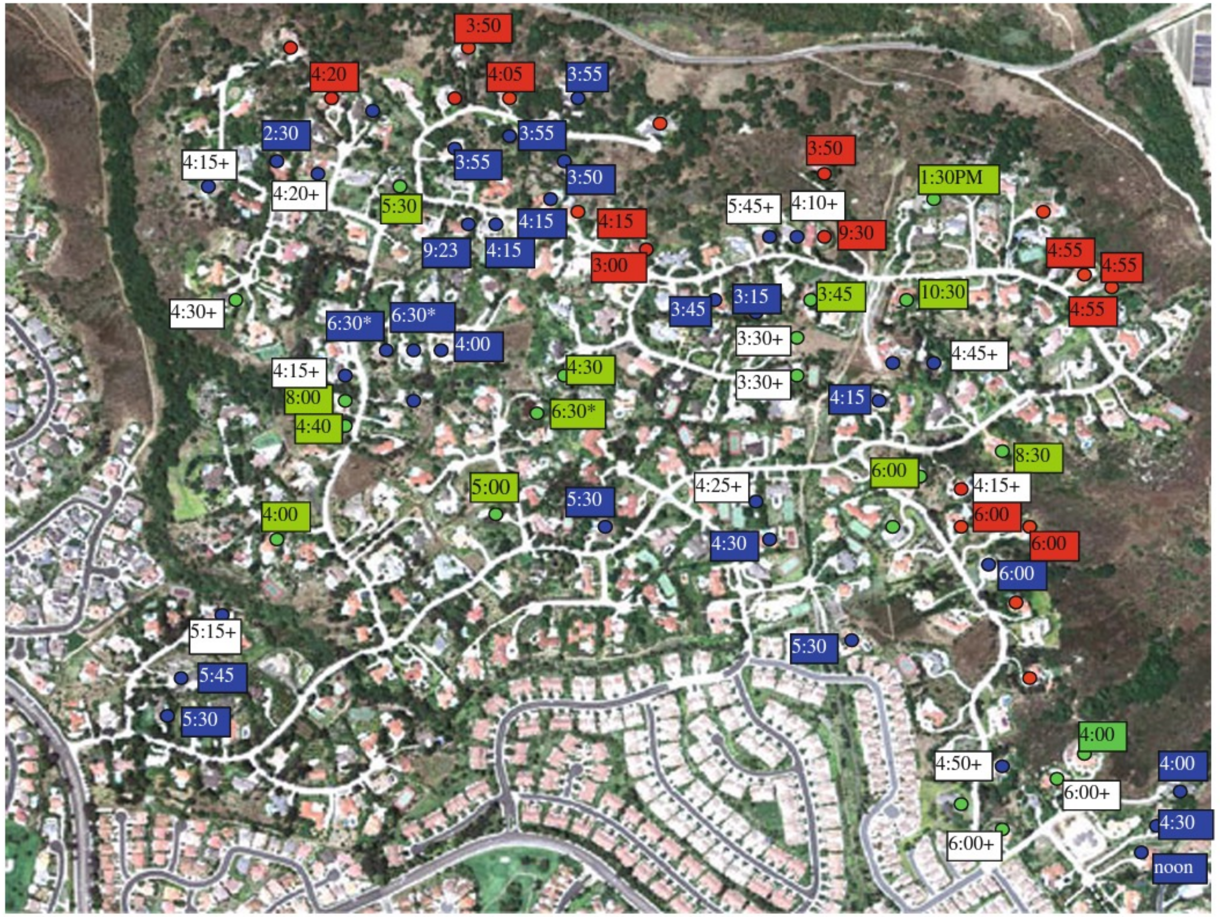


Figure 30. Potential structure ignition categories A, B and C.

Table 17 Roofing material example.

	Sample Population	Destroyed Structures Wood Shake Roofs	Destroyed Structures Spanish Tile Roofs	Typical Comparisons	
Typical (only destroyed homes)	74	12	37	**16% of destroyed** homes had wood shake roofs	**50% of destroyed** homes has Spanish tile roofs
Complete (all structures within fire line)	242	12	154		
Technically Valid Comparisons		**100% of exposed** wood shake roofs destroyed	**24% of exposed** Spanish tile roofs destroyed		

Structure Ignitions

http://dx.doi.org/10.6028/NIST.TN.1796

Alexander Maranghides
Derek McNamara
William Mell
Jason Trook
Blaza Toman

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

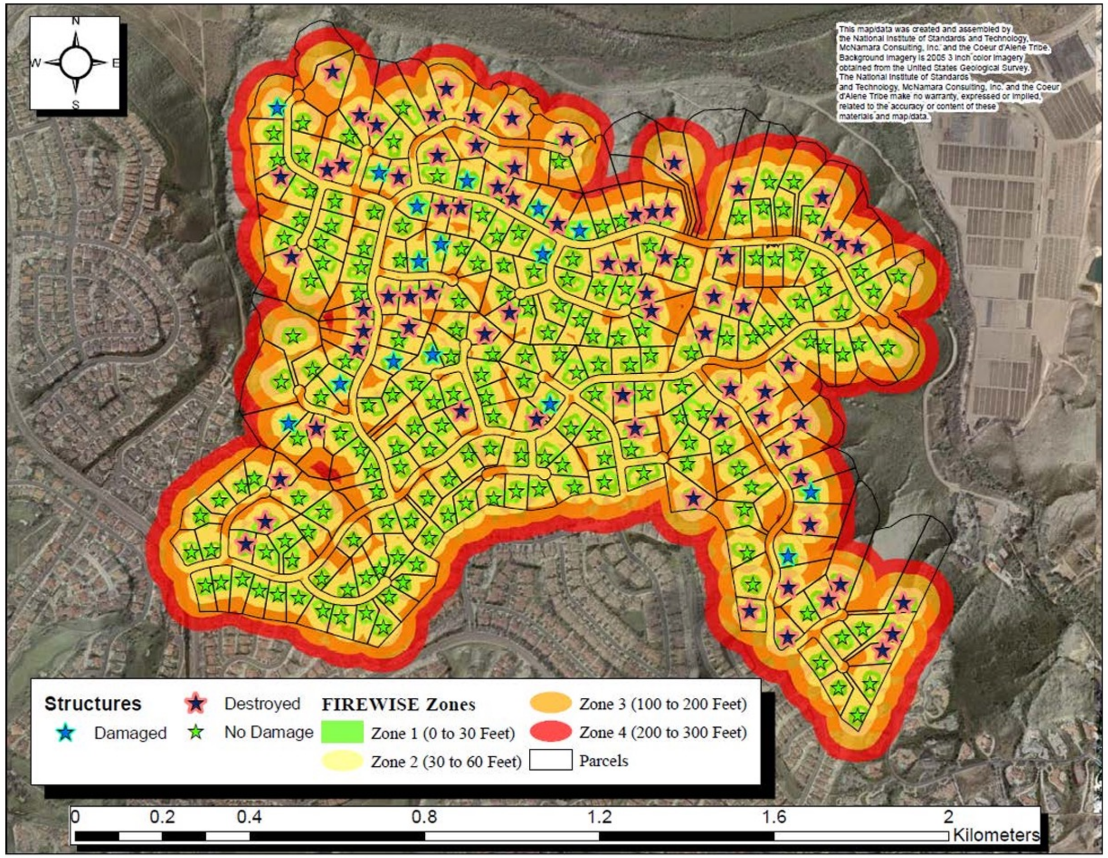
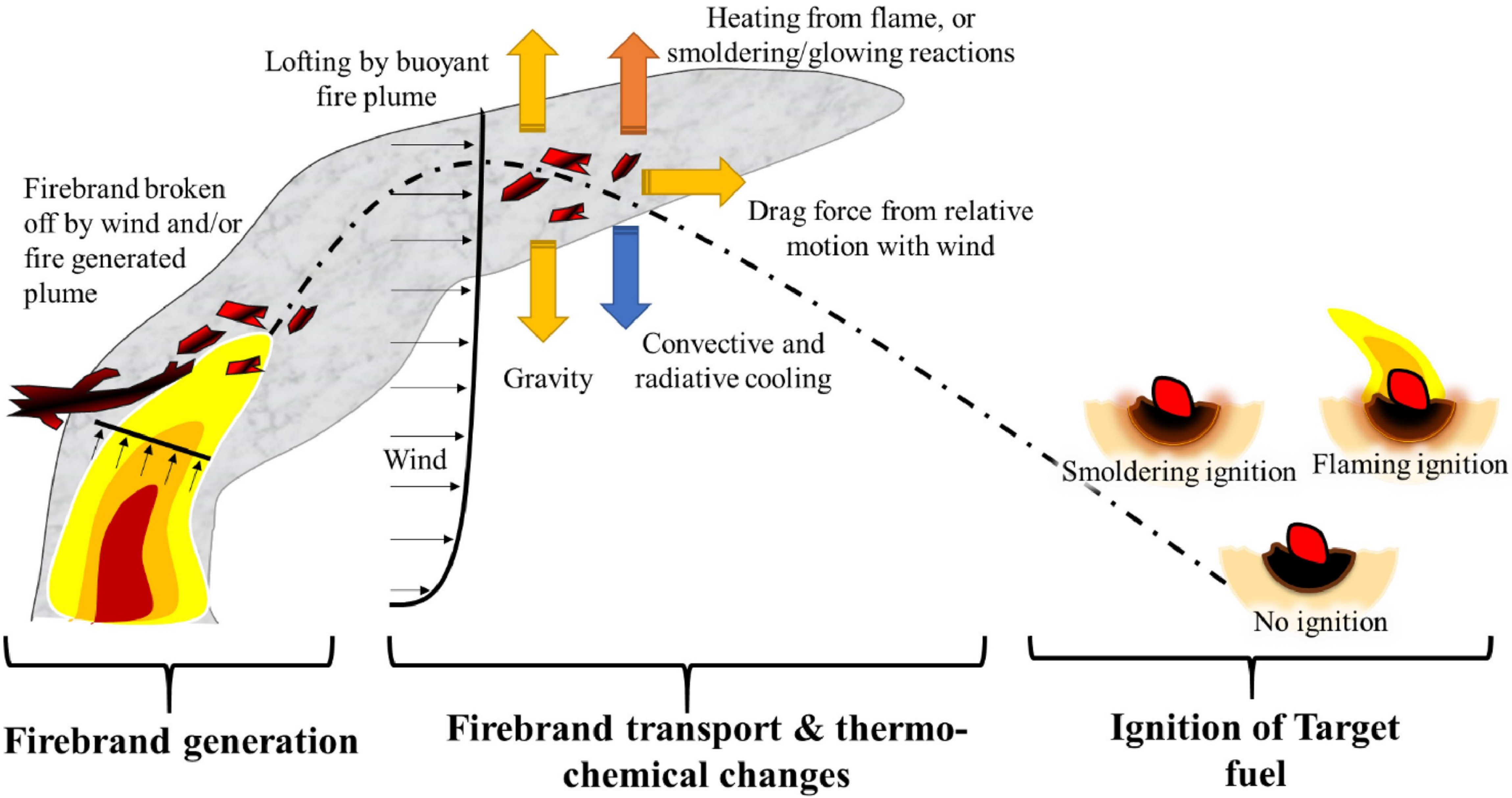


Figure 17 Geographic distribution of Firewise Zones assuming homeowner cooperation.

Firebrand Processes



Manzello, S. L., Suzuki, S., Gollner, M. J., & Fernandez-Pello, A. C. (2020). Role of firebrand combustion in large outdoor fire spread. *Progress in energy and combustion science*, *76*, 100801.

Firebrand Production

Douglas-fir with tree height 5.2 m, moisture content 20%.

4 m Korean Pine with moisture content 13%

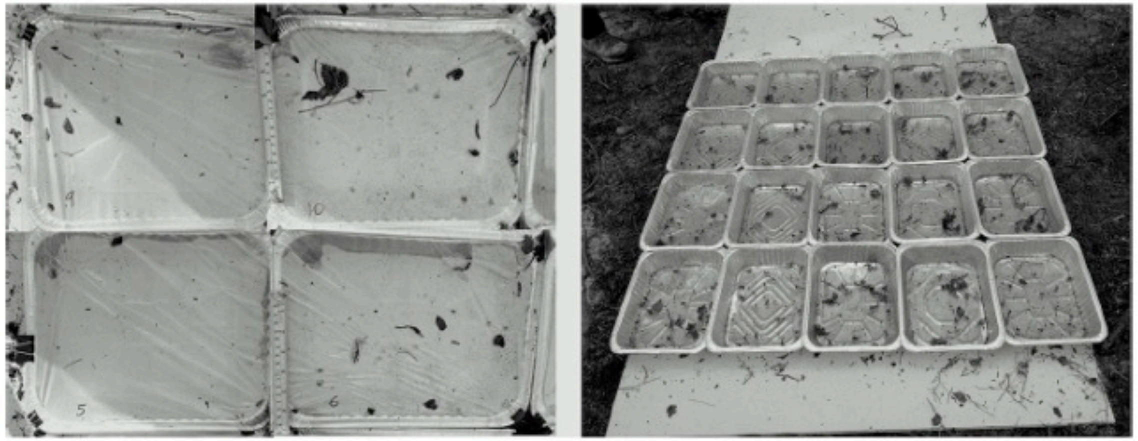


Figure 10. Plots 2 and 3 after the fire.

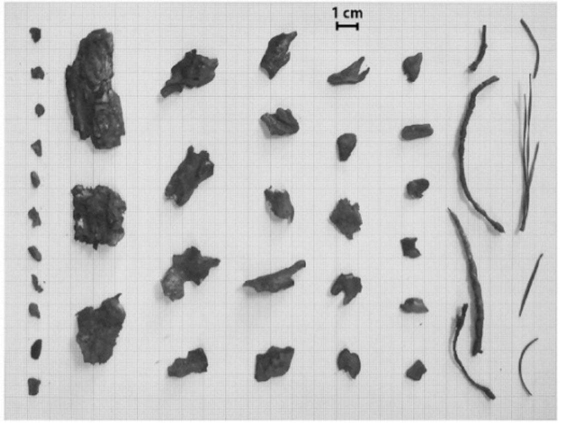


Figure 9. Firebrand samples.

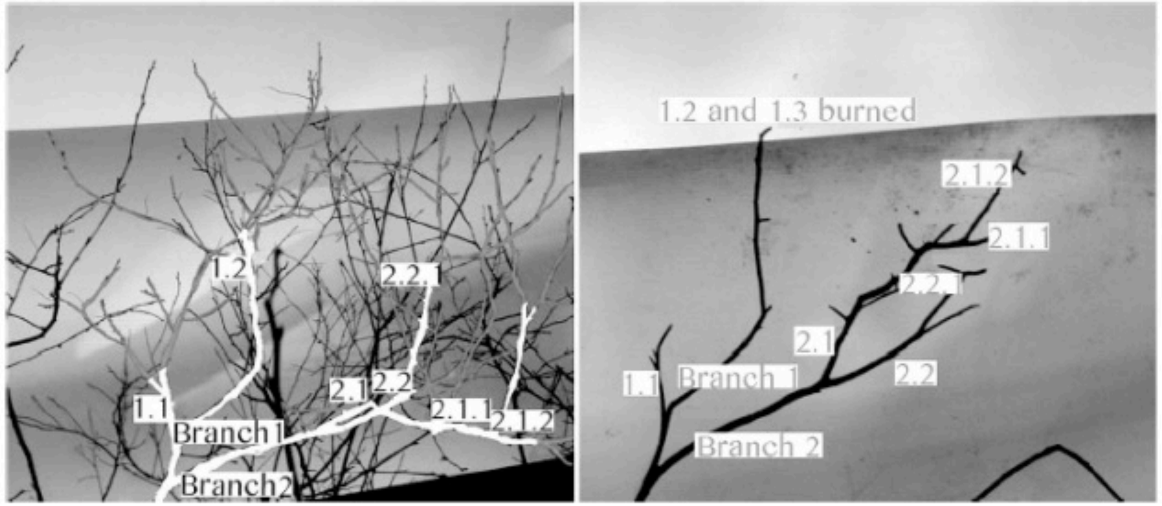
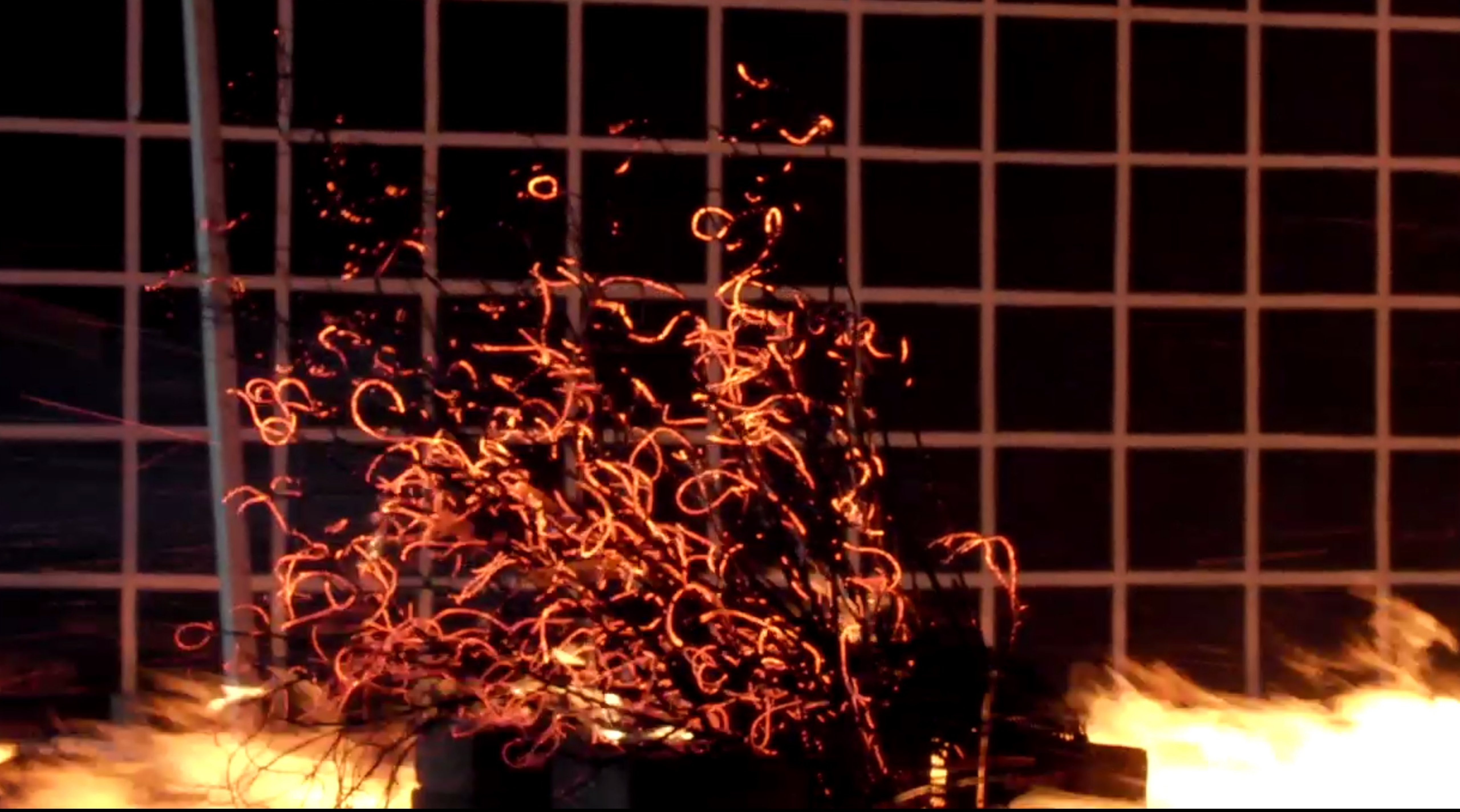


Figure 6. Sampled shrub, pre and post fire.

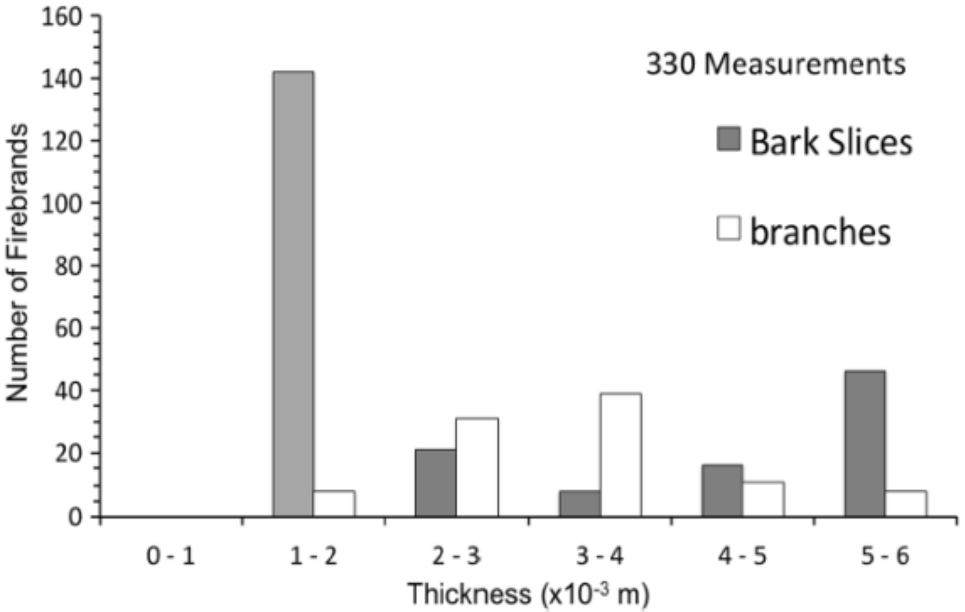
Manzello, S.L., Maranghides, A., Mell, W.E., 2007 Int. J. Wildl. Fire 16, 458
Manzello, S.L., Maranghides, A., Shields, J.R., Mell, W.E., Hayashi, Y., Nii, D., 2009. Fire Mater. 33, 21–31

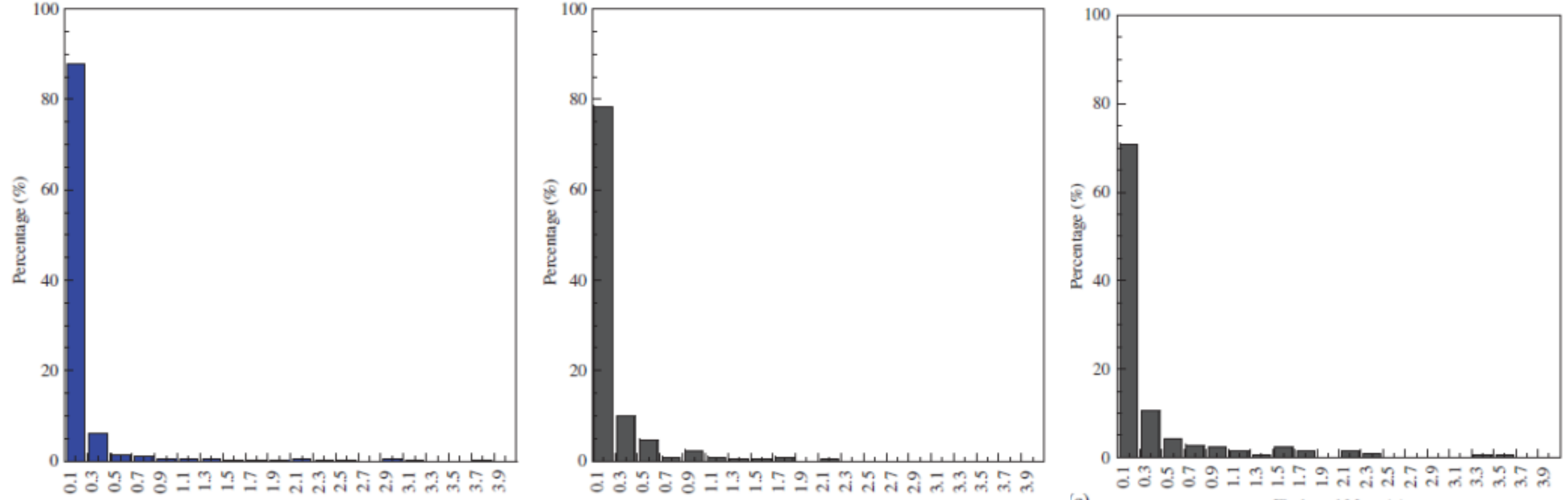

IBHS/UMD study on generation


Insurance Institute for Business & Home Safety®
JOINT FIRE SCIENCE PROGRAM

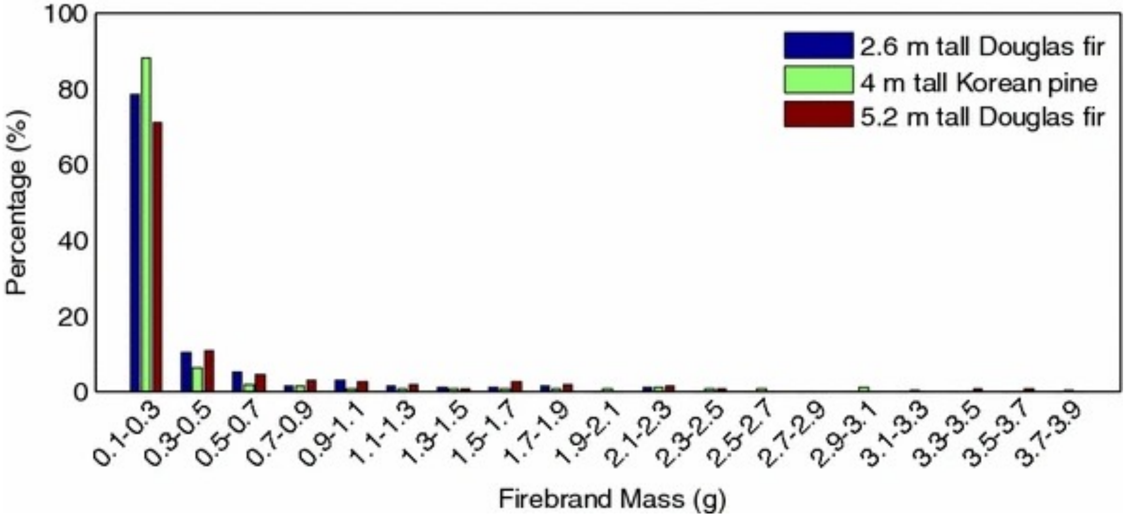


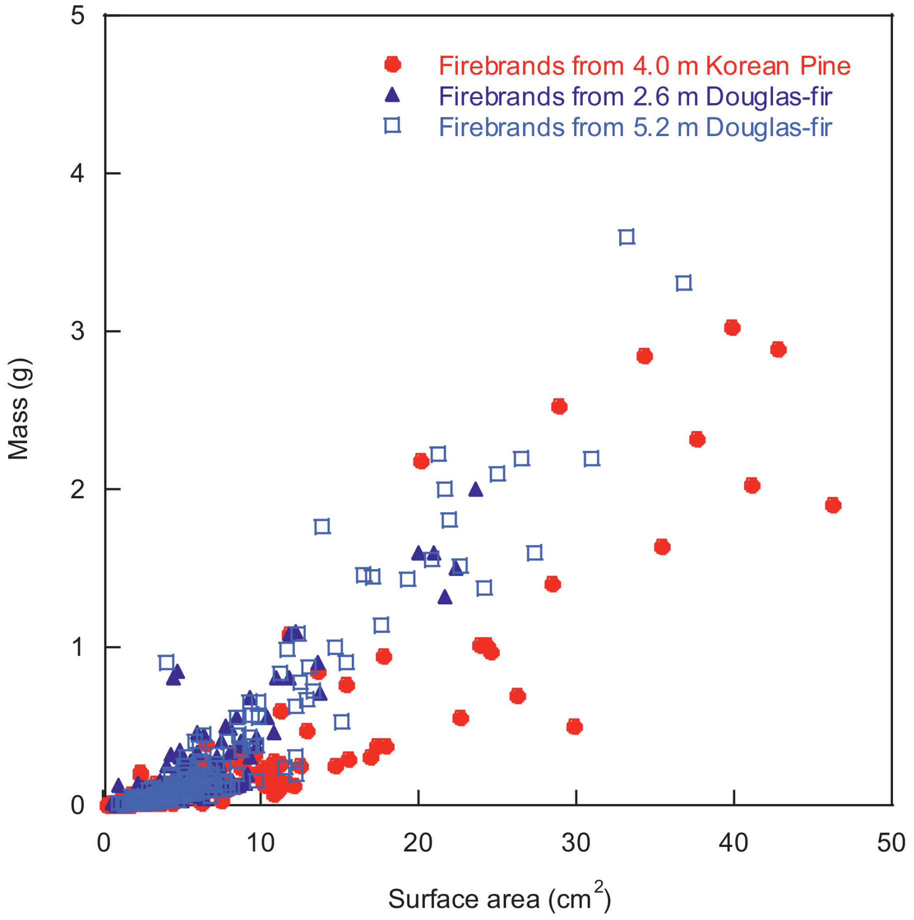
Most firebrands are SMALL





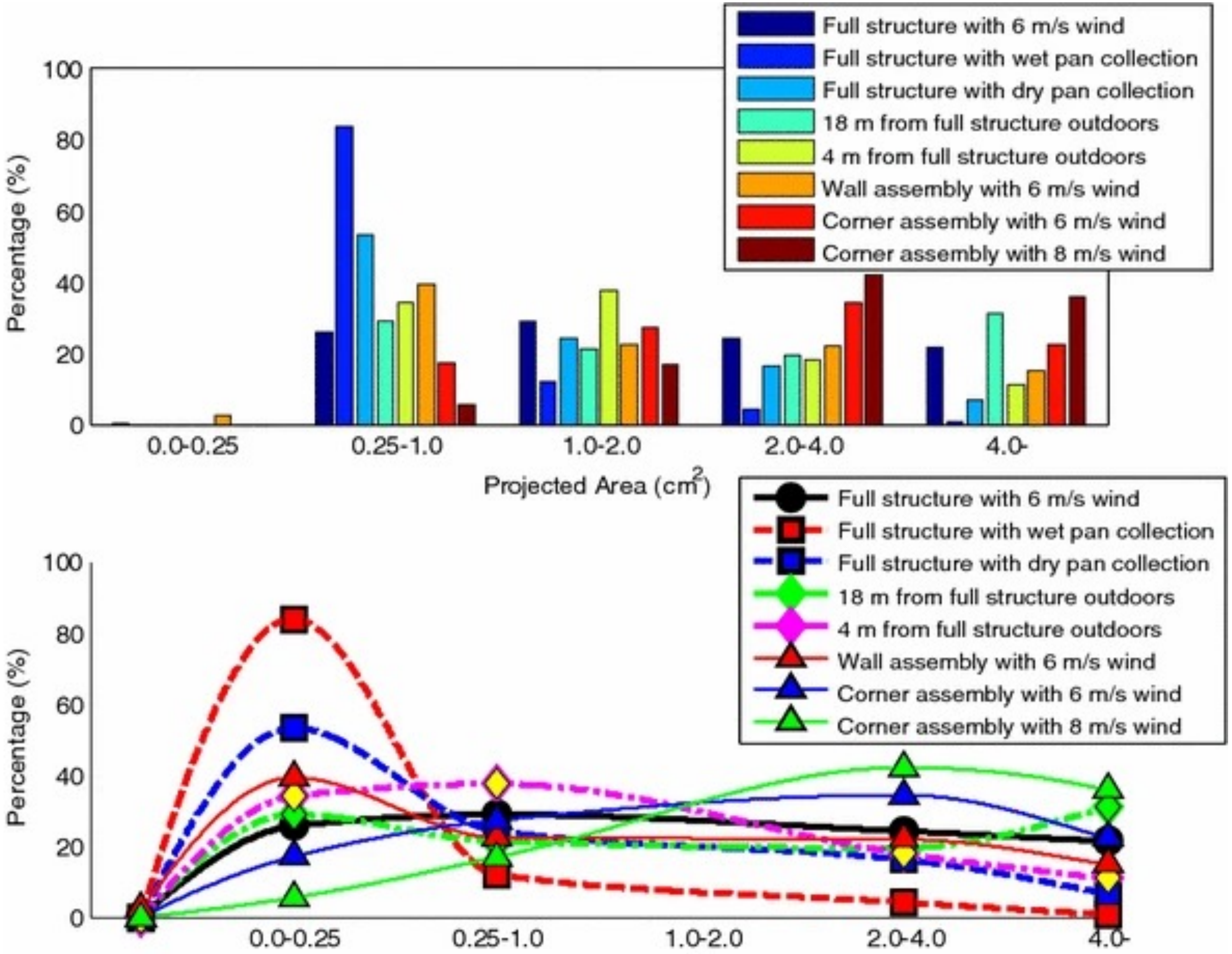
The mass distribution of collected firebrands from (a) 4 m tall Korean pine trees *(Manzello et al., 2009)* and (b) 2.6 m tall Douglas-fir and (c) 5.2 m Douglas-fir trees from *(Manzello et al., 2007)*.c





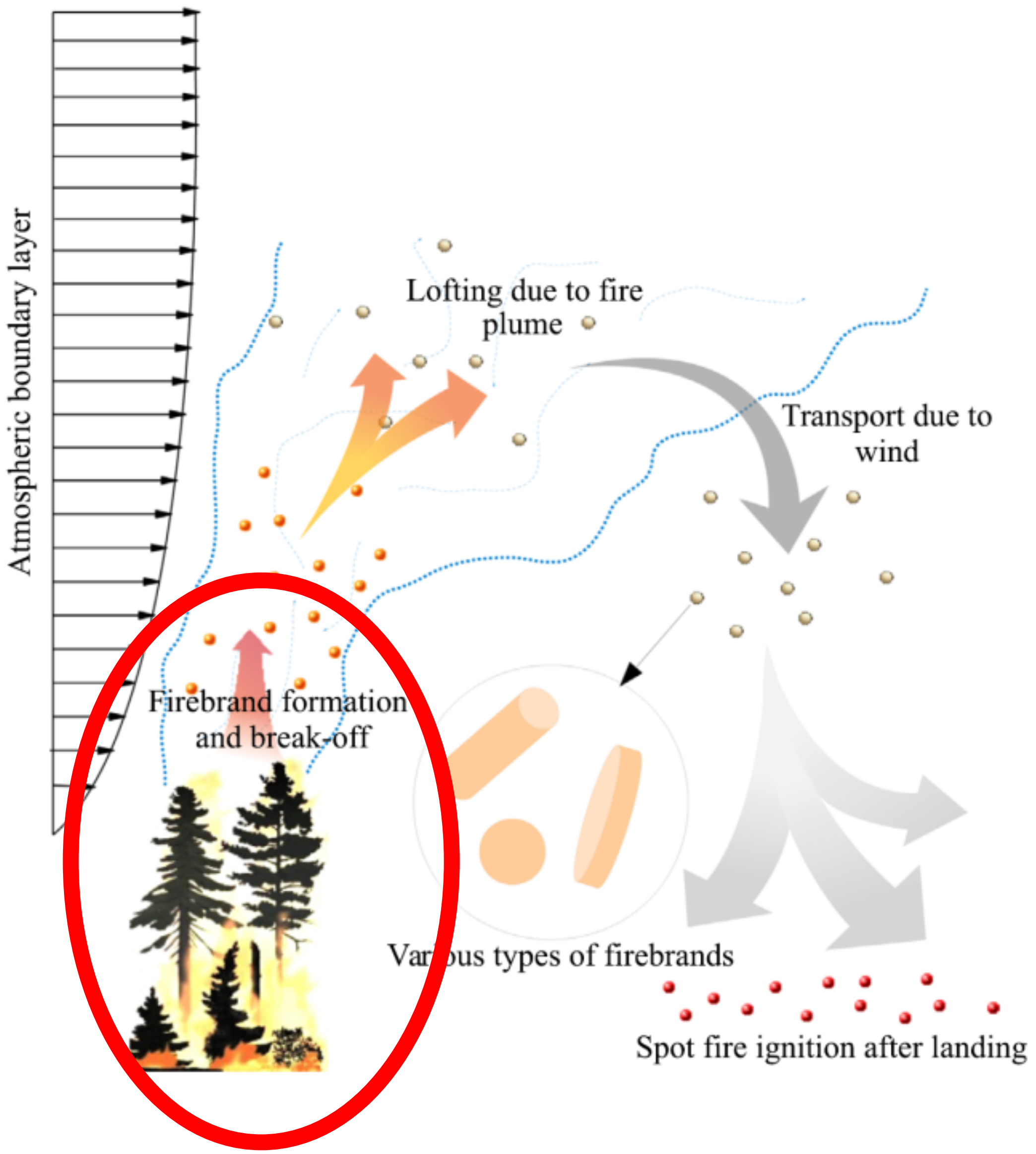
The mass distribution of collected firebrands from 2.6 m tall Douglas fir, 4 m tall Korean pine trees, and 5.2 m Douglas fir trees from Manzello et al. [120, 121]

Summary



Firebrand size distributions from a full structure in a 6 m/s wind by Suzuki et al. [123], a full structure by Yoshioka et al. with wet and dry pans capturing brands [119], 18 m and 4 m from a full-scale structure by Suzuki et al. [124]

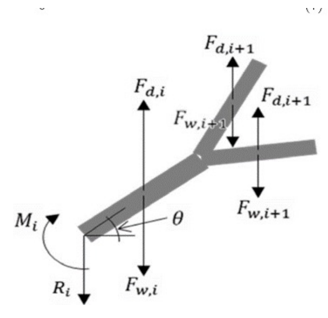
Firebrand Generation



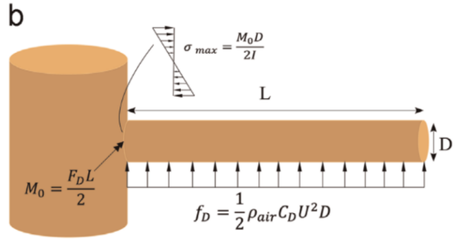
Firebrand Formation and Break-off

Only 2 models:

Barr & Ezekoye



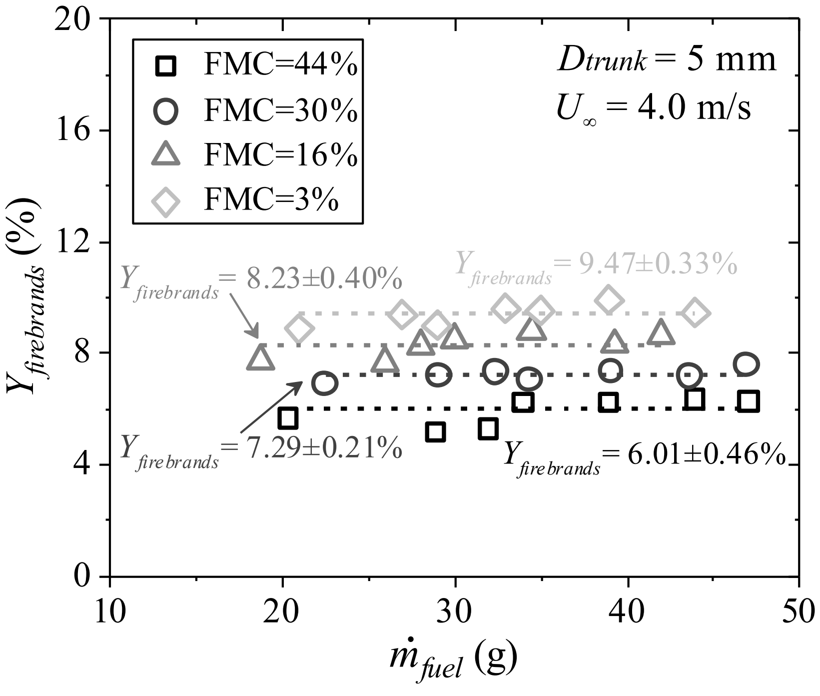
Tohidi et al.



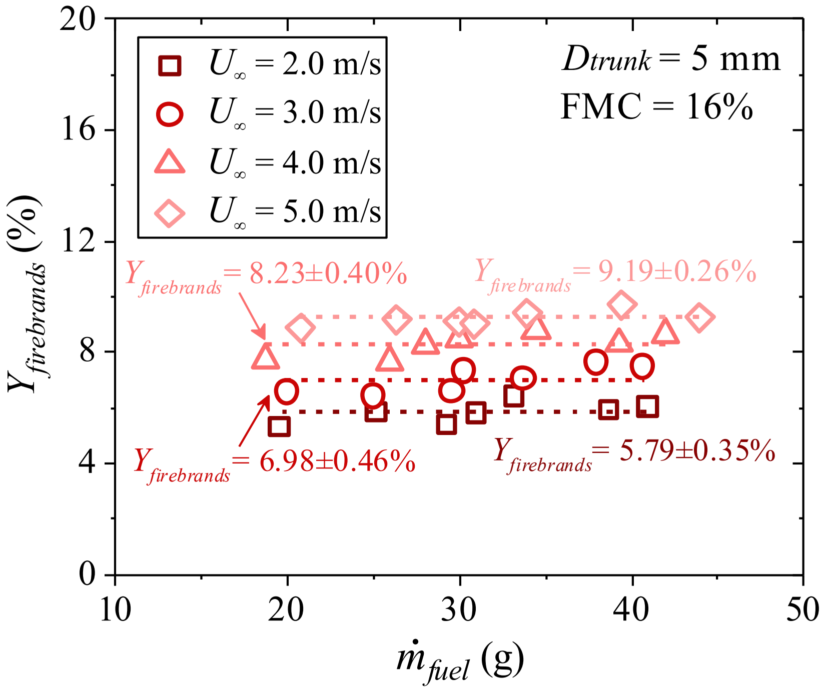
Still not complete

Firebrand yields – Laboratory Wind Tunnel

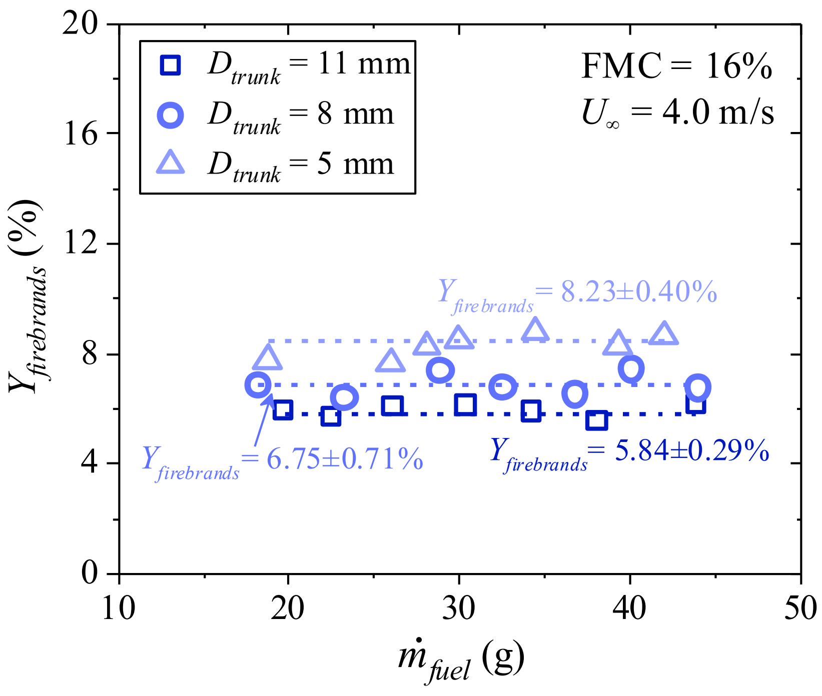
Errors of firebrand yields relative to the average value at each test condition (unit: %)



Effect of FMC

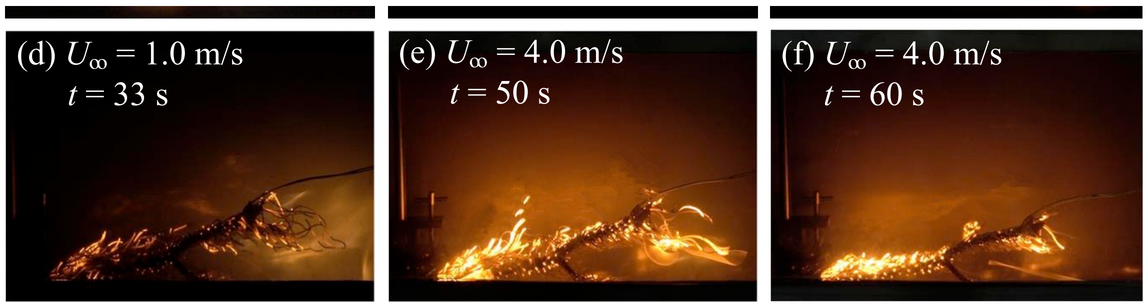


Effect of U_∞



Effect of D_{trunk}

Firebrand yields of **Douglas fir**



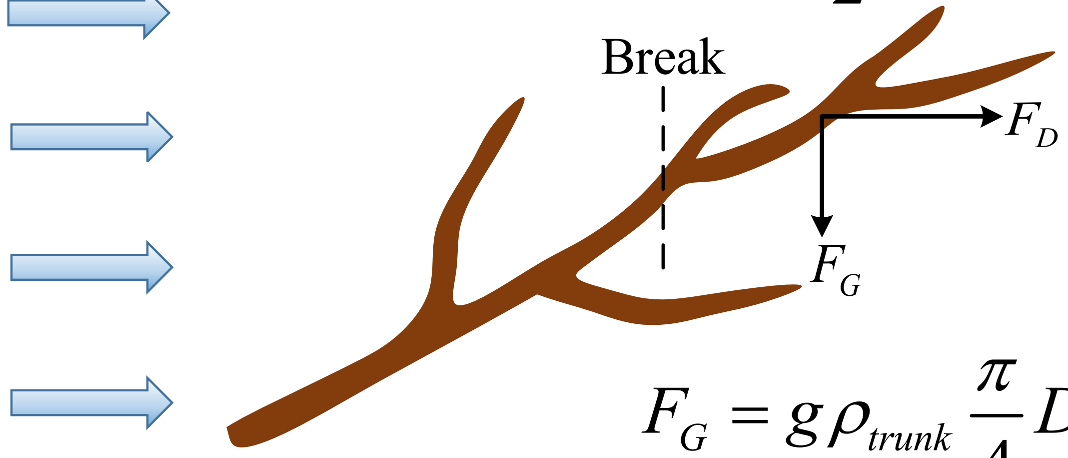
Ju et al, IAFSS under review

Recent Results-Firebrand yields

Scaling analysis of firebrand yields ($Y_{firebrands}$)

U_∞

$$F_D = \frac{1}{2}\rho_\infty U_\infty^2 D_{trunk} L_{total}$$



$$F_G = g\rho_{trunk}\frac{\pi}{4}D_{trunk}^2 L_{total}$$

L_{total} –The total length of the trunk facing the wind

$$Y_{firebrands} \sim (\mathrm{FMC}, \rho_\infty, U_\infty, \rho_{trunk}, D_{trunk}, L_{total})$$

Balance between drag force and gravity

$$Y_{firebrands} \sim (\mathrm{FMC}, \frac{U_\infty}{\sqrt{gD_{trunk}}} \sim \frac{F_D}{F_G})$$

Separately fitting

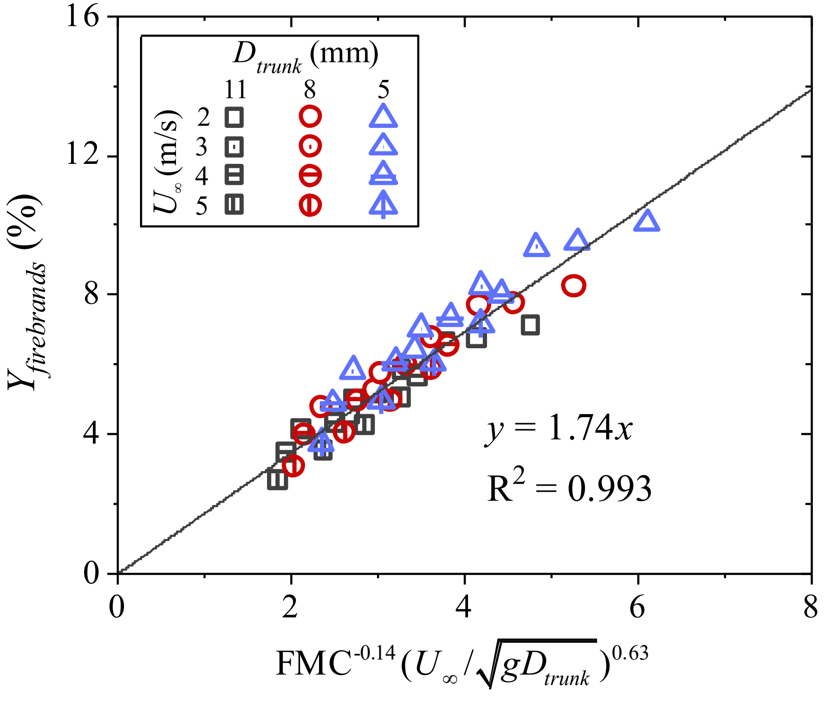
$$Y_{firebrands} \sim \mathrm{FMC}^a$$

$$Y_{firebrands} \sim \left(U_\infty/\sqrt{gD_{trunk}}\right)^b$$

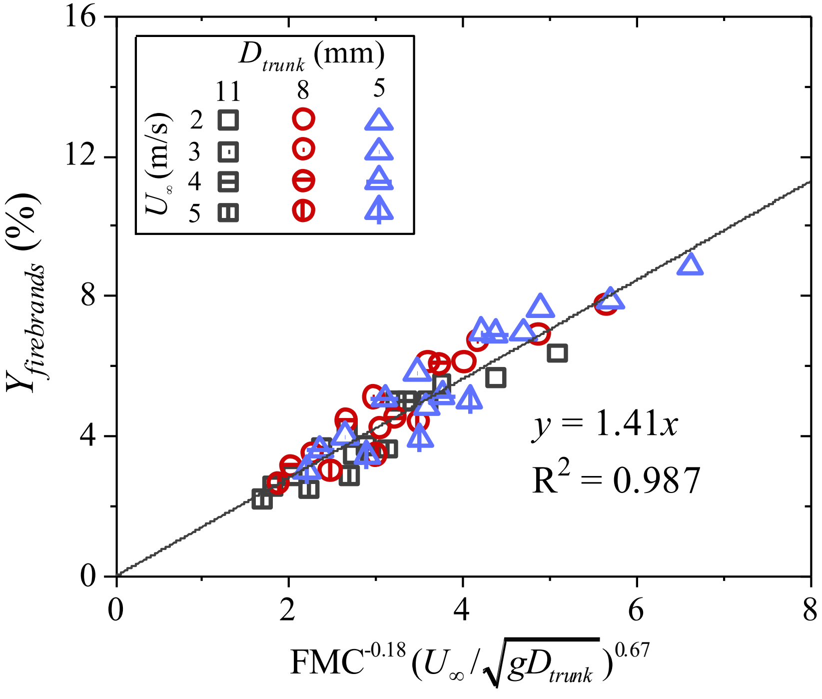
Ju et al, IAFSS under review

Results-Firebrand yields

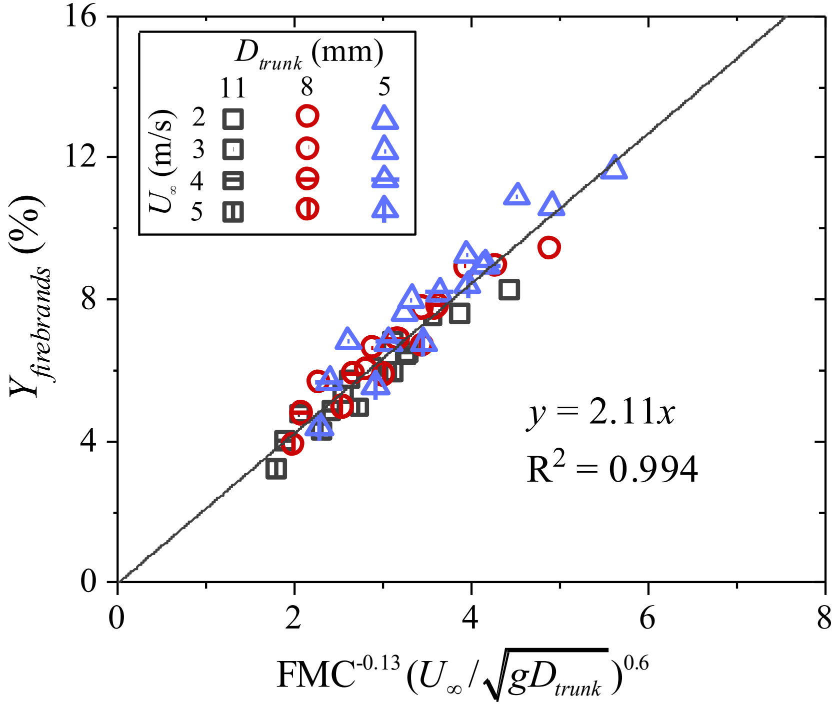
Scaling analysis of firebrand yields ($Y_{firebrand}$)



Douglas fir



Eucalyptus globulus

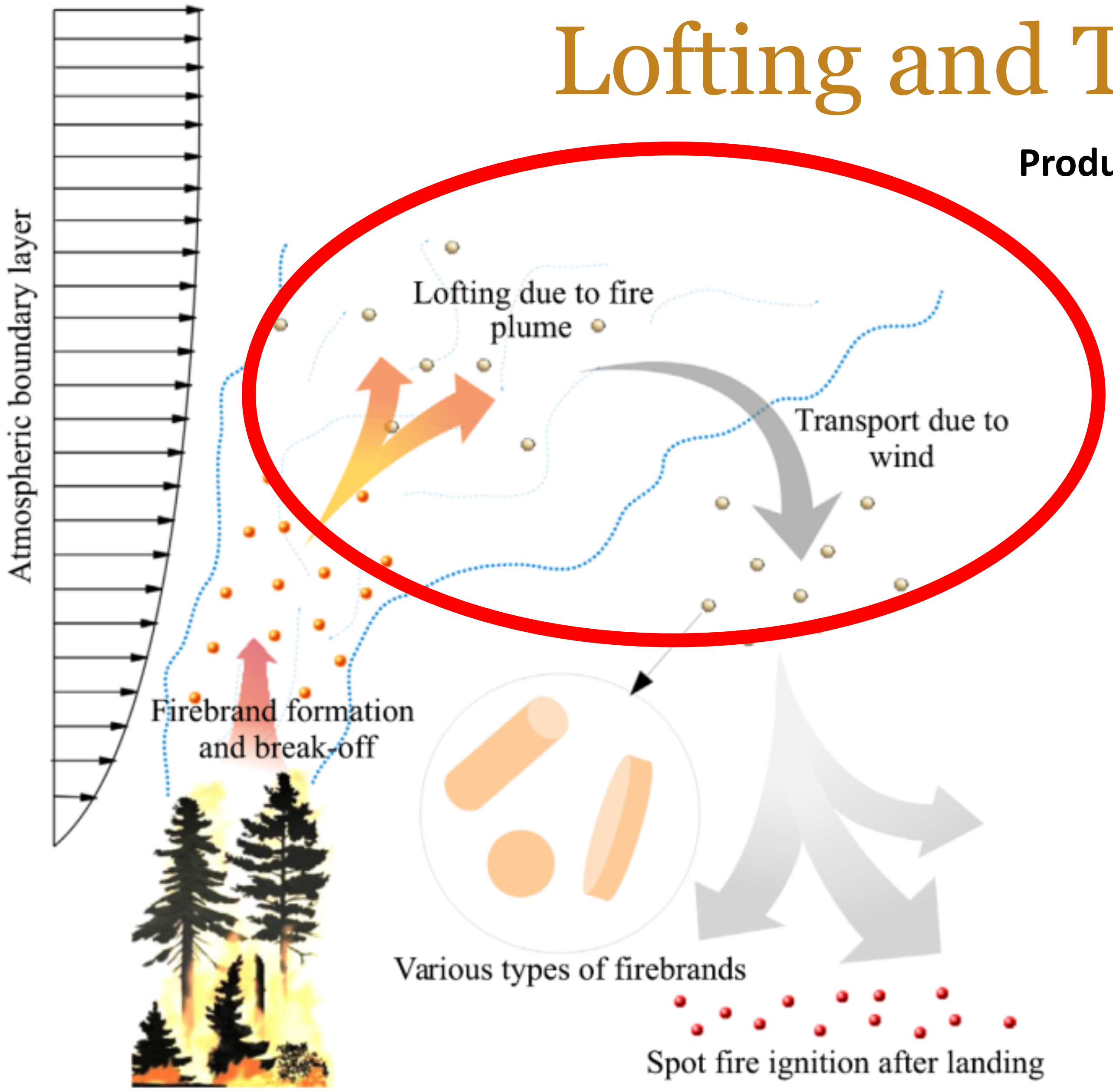


Coast live oak

All variables are in SI units

Ju et al, IAFSS under review

Lofting and Transport



Tohidi et al

Production and Ignition are least understood

Many Models & Measurements!!!

1. Koo E, Linn RR, Pagni PJ, Edminster CB (2012) Modelling f
2. Clements HB (1977) Lift-off of Forest Firebrands (Res. Pap
3. Manzello SL, Maranghides A, Shields JR, et al. (2009) Mas
4. Ellis PF (2000) The Aerodynamic and Combustion Charact
5. Woycheese J., Pagni PJ Brand Lofting in Large Fire Plumes
6. Albini F (1979) Spot fire distance from burning trees: a pr
7. Albini FA (1981) Spot fire distance from isolated sources–
8. Albini F a, Alexander ME, Cruz MG, Miguel G Cruz (2012)

The List goes on!!!!

Lofting/Propagation

- In 2007 in San Diego, firebrands arrived 1 hour before arrival of the flame front
  - Travelled up to 9 km
  - Ignited properties over the following 9 hours.
- Many models available for transport
- Consider burning and aerodynamics
- First by Tarifa et al. in 1960's
- Modeled in many CFD applications and Farsite (Albini)

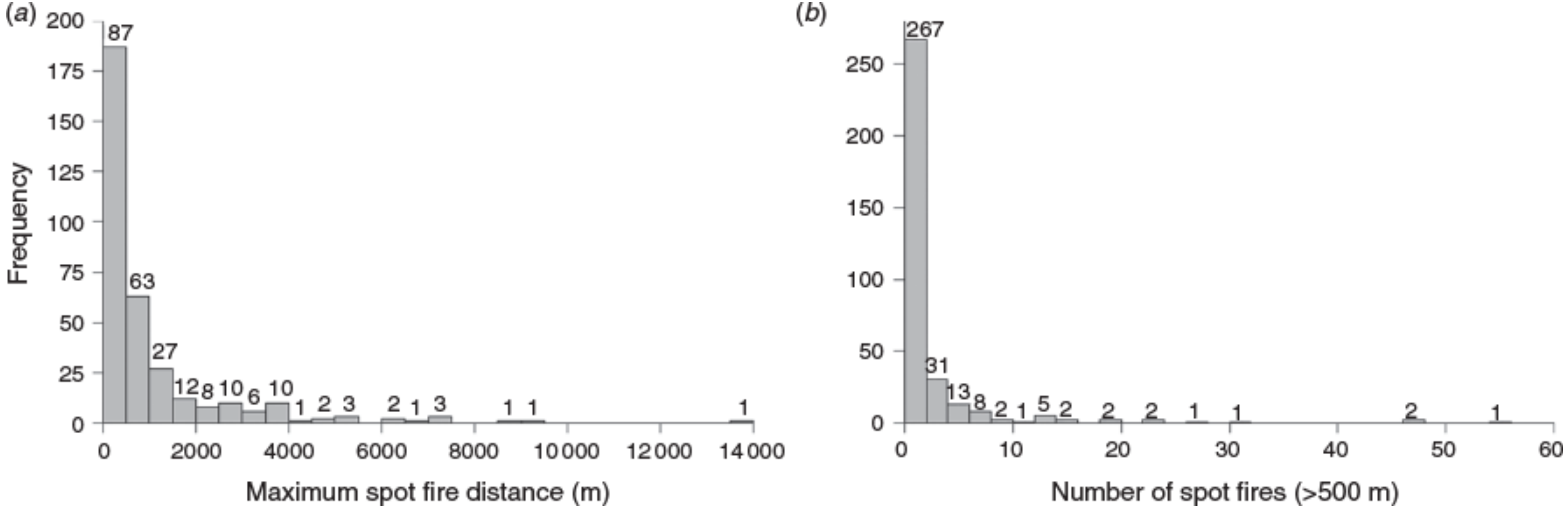
Maranghides, A., McNamara, D., Mell, W., Trook, J., Toman, B., 2013. A case study of a community affected by the Witch and Guejito fires : report #2
Tarifa, C.S., Notario, P.P. Del, Moreno, F.G., 1965. Symp. Combust. 10, 1021–1037
Woycheese, J.P., Pagni, P.J., Liepmann, D., 1999. J. Fire Prot. Eng. 10, 32–44
Koo, E., Linn, R.R., Pagni, P.J., Edminster, C.B., 2012. Int. J. Wildl. Fire 21, 396
Albini, F.A., 1983. Res. Pap. INT-309.

How far can they go?

During the 2009 Black Saturday bushfires in eucalpyt-dominated forests in Australia the maximum spot fire distances were 30 to 35 km (18 to 22 miles) and during the 1965 wildfires in eastern Victoria were 29 km (18 miles). Spot fires in North America have been documented at distances of up to 19 km (12 miles).

Important parameters to maximum distance

- Wind speed
- Steep slope somewhere in source fire
- Fire area/size



Storey, M. A., Price, O. F., Sharples, J. J., & Bradstock, R. A. (2020). Drivers of long-distance spotting during wildfires in south-eastern Australia. *International journal of wildland fire*, *29*(6), 459-472.

Table 3
Summary of Firebrand Lofting and Transport Experiments and Models Adapted from Koo et al. [40]

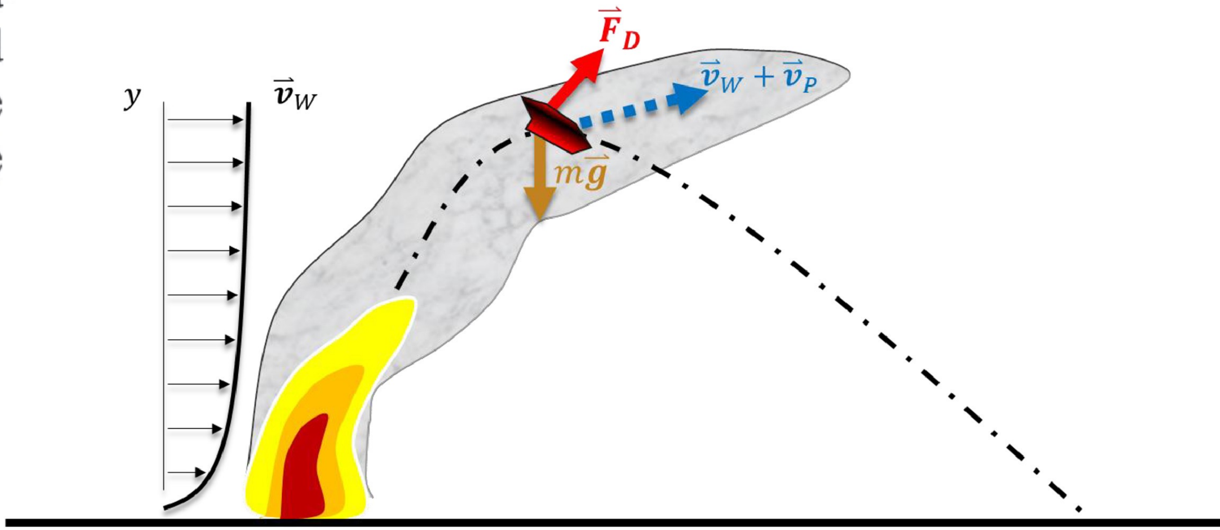
Authors	Experiment	Firebrand model	Plume and wind model
Tarifa et al. [8]	Burning firebrands in wind tunnel	Sphere and cylinder with combustion	Inclined convective plume [154], given launching height in constant horizontal wind
Lee and Hellman [155, 156]	Particles in vertical plume generator [156]	Spheres with combustion [155]	Turbulent swirling natural convective plume [156]
Muraszew and Fedele [135, 138, 139, 141]	Burning firebrands in wind tunnel and fire whirl in vertical channel [138]	Statistical model [140]	Fire whirl [141]
Fernandez-Pello et al. [157–159]	–	Sphere with combustion [157] disc, cylinder, and sphere [159]	Given launching height [158], McCaffrey plume [148, 159] in constant boundary layer wind
Albini [143–145, 160]	–	Cylinder with combustion [135]	Launching height from flame structure analysis in constant horizontal wind
Woycheese and Pagni [9, 40, 117, 118]	Burning firebrands in wind tunnel	Non-dimensional model with combustion [161]	Baum and McCaffrey plume model [148]
Himoto and Tanaka [162]	–	Disc without combustion	Given launching height in turbulent boundary layer
Porterie et al. [152]	–	Small world network model, disc with combustion	Steady state crown fire [77].
Koo et al. [40, 111]	–	Disc and cylinder with combustion	HIGRAD/FIRETEC wildfire model [163, 164]
Sardoy et al. [153]	–	Disc with combustion	Buoyant line plumes in stratified crossflows
Wang [149]	–	Sphere with combustion	Baum and McCaffrey plume model [148] with Rayleigh form pattern [165]
Baum and Atreya [150]	–	Prolate and oblate ellipsoids with combustion	Potential flow model
Zhou et al. [127]	Cubic firebrands released from NIST Dragon. Gaussian distributions fitted	–	-

From Albini, 2012

Conceptualisation and simplifying assumptions in the mathematical model

Chandler *et al*. (1983, p. 104) very succinctly outline the spotting phenomenon involved in wildland fires:

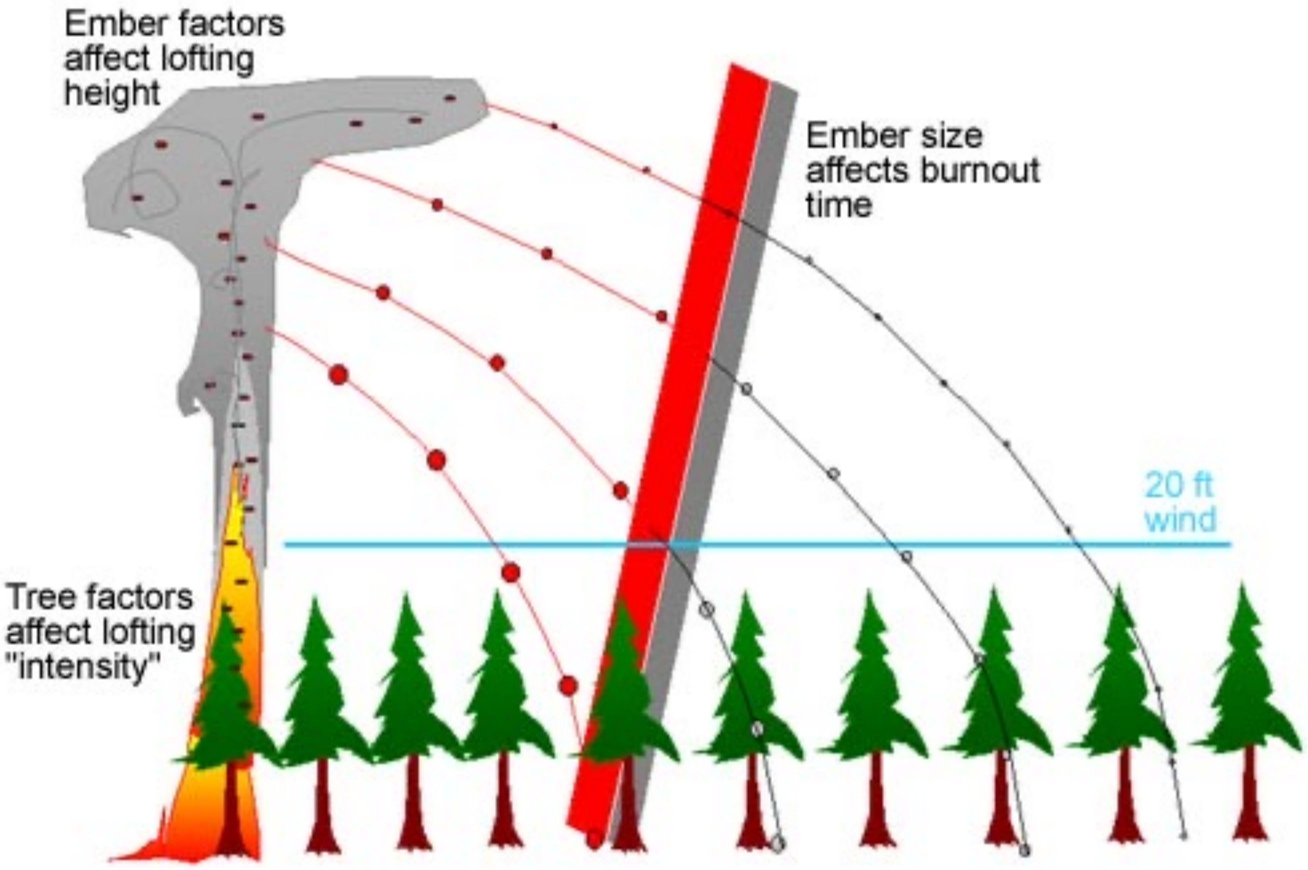
> A firebrand or burning ember is lofted into the rising stream of flame and combustion gases, rises in the convection column until it is ejected into the ambient wind field, and falls under the influence of gravity while being moved laterally by the wind until it lands on the surface. If the firebrand has sufficient energy left when it lands, a spot fire will result.



Spotting in USFS models: https://www.nwcg.gov/publications/pms437/crown-fire/spotting-fire-behavior

Spotting Parameters

- Intensity/fire information
  - Max lofting height
  - Size/distribution
- Transport
  - Terminal velocity
  - Size
  - Wind/boundary layer
- Burning duration
  - Size/burning rate
- Spotting ignition
  - probability



Factors Affecting Spotting

United States
Department of
Agriculture

Forest Service

**Intermountain
Forest and Range
Experiment Station
Ogden, Utah 84401**

Research
Paper INT-309

April 1983

Potential Spotting Distance from Wind-Driven Surface Fires

Frank A. Albini

United States
Department of
Agriculture

Forest Service

**Intermountain
Forest and Range
Experiment Station**

Research Note
INT-309

March 1981

Spot Fire Distance from Isolated Sources--Extensions of a Predictive Model

Frank A. Albini

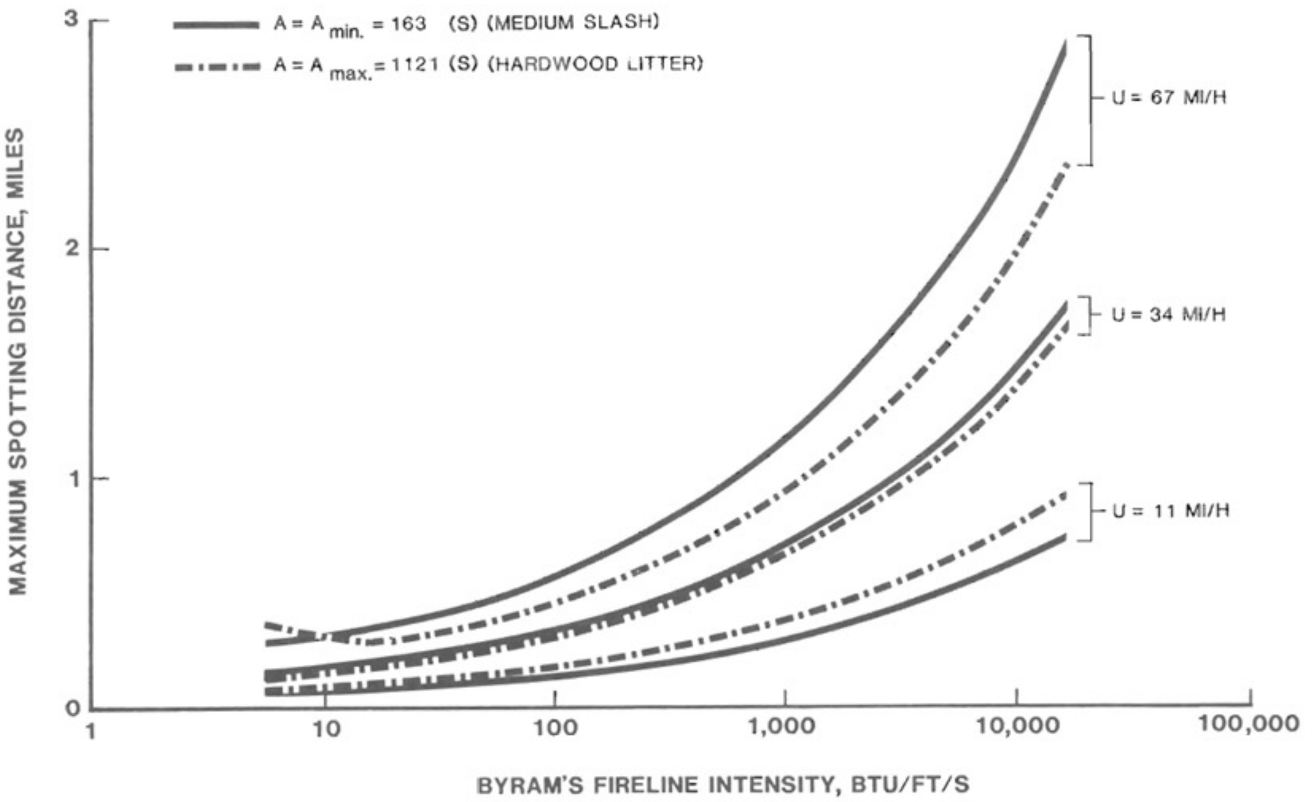


Figure 1—Sensitivities of maximum spotting distance to mean fireline intensity, mean 20-ft windspeed (*U*), and fuel model.

Simplified graph from Morris, 1987

Tarifa – burning of brand in a wind tunnel

- Role of Force balance
  - Move at terminal velocity
- Koo (below)
  - Fabulous review
  - Earlier papers by Koo, Pagni & Woycheese propose physical models of transport

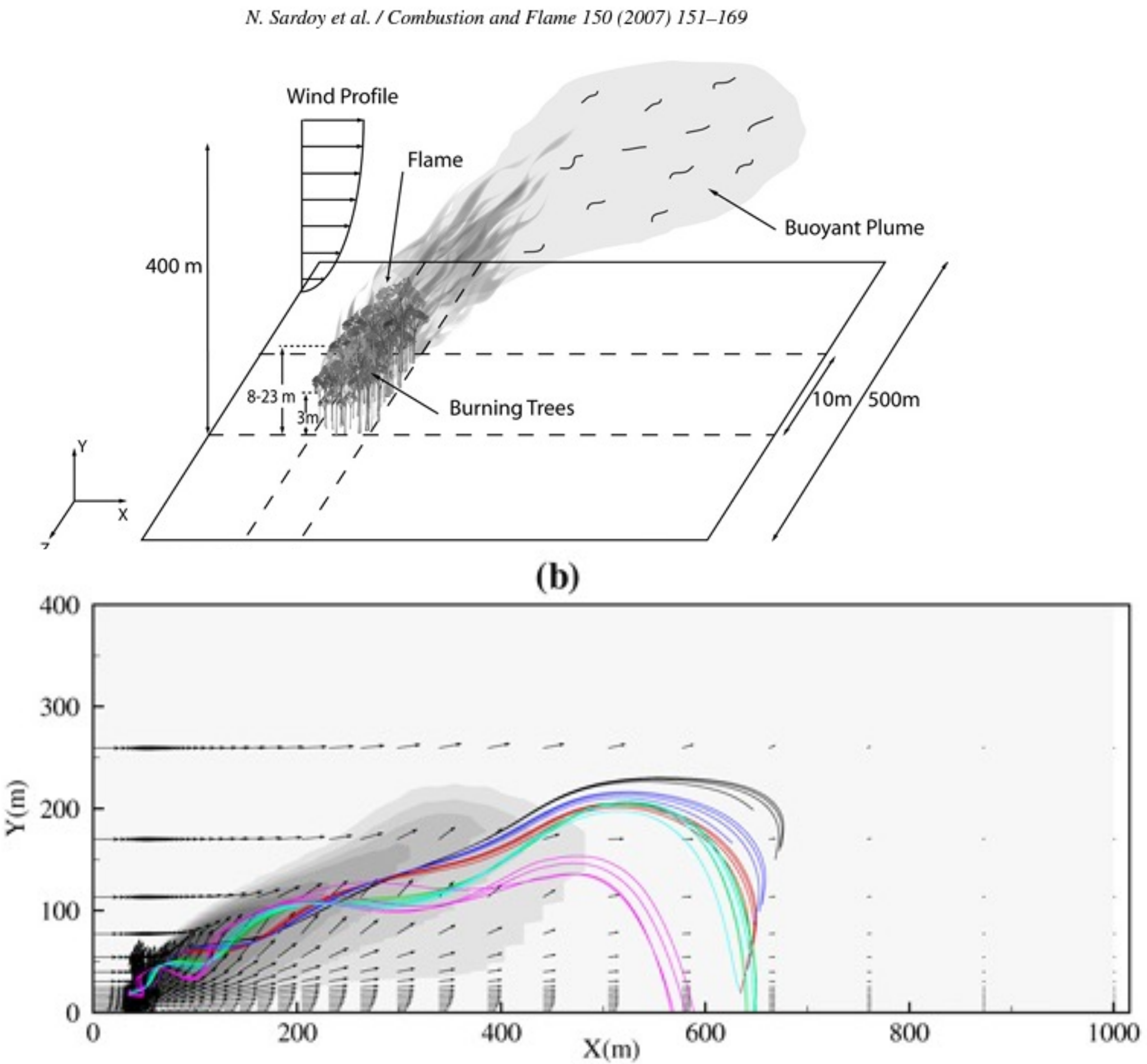
Finally, from his wind-tunnel firebrand combustion experiments, Tarifa observed that the density and radius histories of a small sphere or cylinder of wood at constant wind speed undergoing convective combustion speeds could be approximated by the expressions:

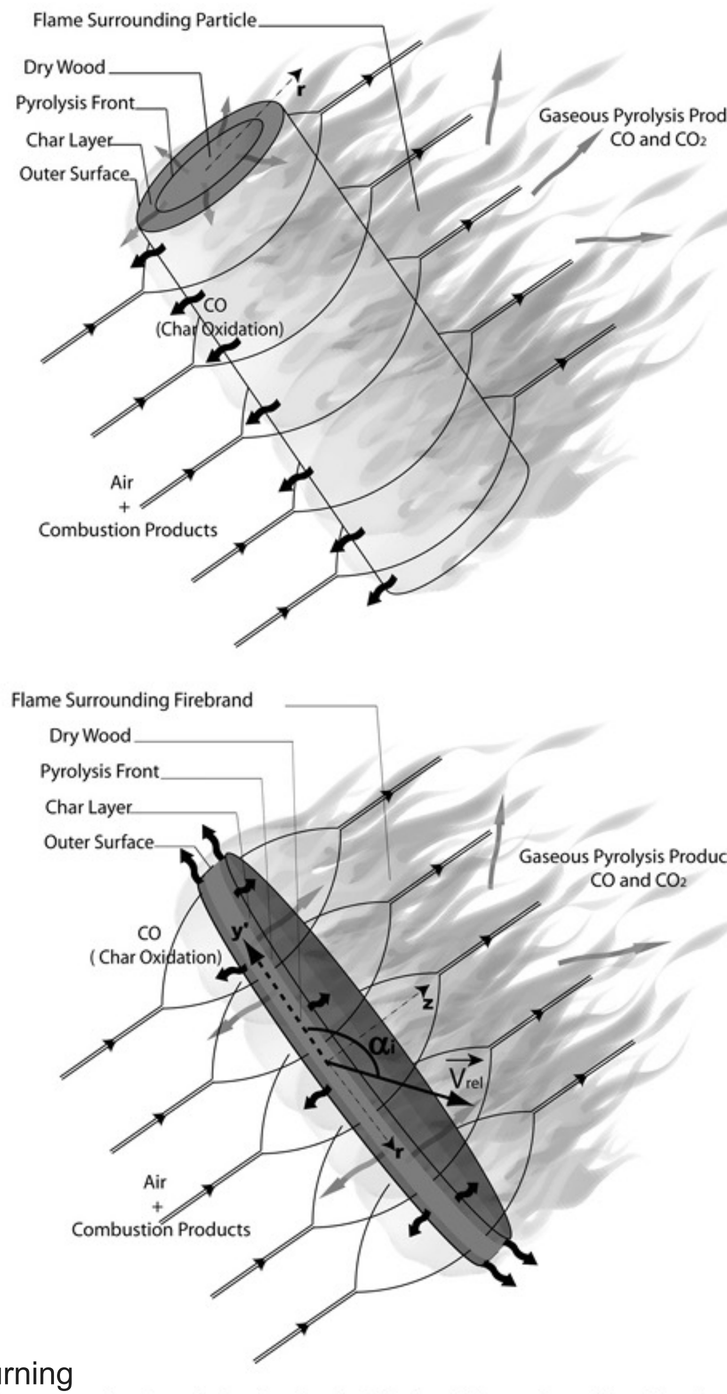
$$\frac{\rho_s}{\rho_{s,o}} = (1 + \eta t^2)^{-1}$$
$$\frac{r_s}{r_{s,o}} = 1 - \left(\frac{\beta + \delta W}{r_{s,o}^2}\right) t \qquad (2)$$

where ρ is density, r is radius, t is time, and W is the relative wind speed. The subscripts s and o mean solid (firebrand) and initial value respectively, and the parameters η, β, and δ depend on the species of wood and moisture content of the firebrand. It was further observed from these relations that the density of the firebrand does not depend on the wind speed, and the law of radius change is similar to that of a combusting liquid droplet.

Koo, E., Pagni, P. J., Weise, D. R., & Woycheese, J. P. (2010). Firebrands and spotting ignition in large-scale fires. *International Journal of Wildland Fire*, *19*(7), 818-843.

Sardoy et al. CFD distribution



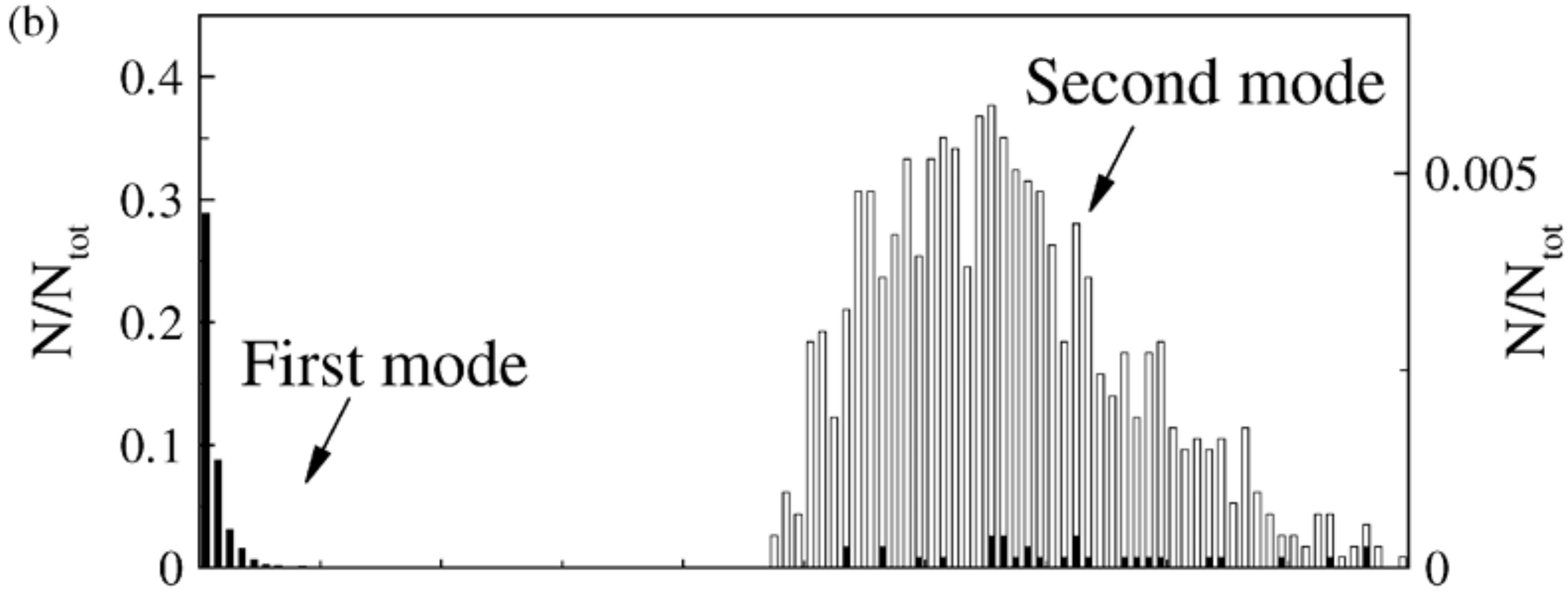


Schematic representation of a cylinder-shaped and a disk-shaped dry wood particle undergoing

Sardoy, N., Consalvi, J. L., Porterie, B., & Fernandez-Pello, A. C. (2007). Modeling transport and combustion of firebrands from burning trees. *Combustion and Flame*, *150*(3), 151-169

Firebrand Distribution

- Spotting distance is modeled as a lognormal distribution with the mean and standard deviation determined semi-empirically as a function of ambient wind speed and fireline intensity



Sardoy, N., Consalvi, J. L., Kaiss, A., Fernandez-Pello, A. C., & Porterie, B. (2008). Numerical study of ground-level distribution of firebrands generated by line fires. *Combustion and Flame*, *154*(3), 478-488.

fire

MDPI

Article

Evaluating the Ability of FARSITE to Simulate Wildfires Influenced by Extreme, Downslope Winds in Santa Barbara, California

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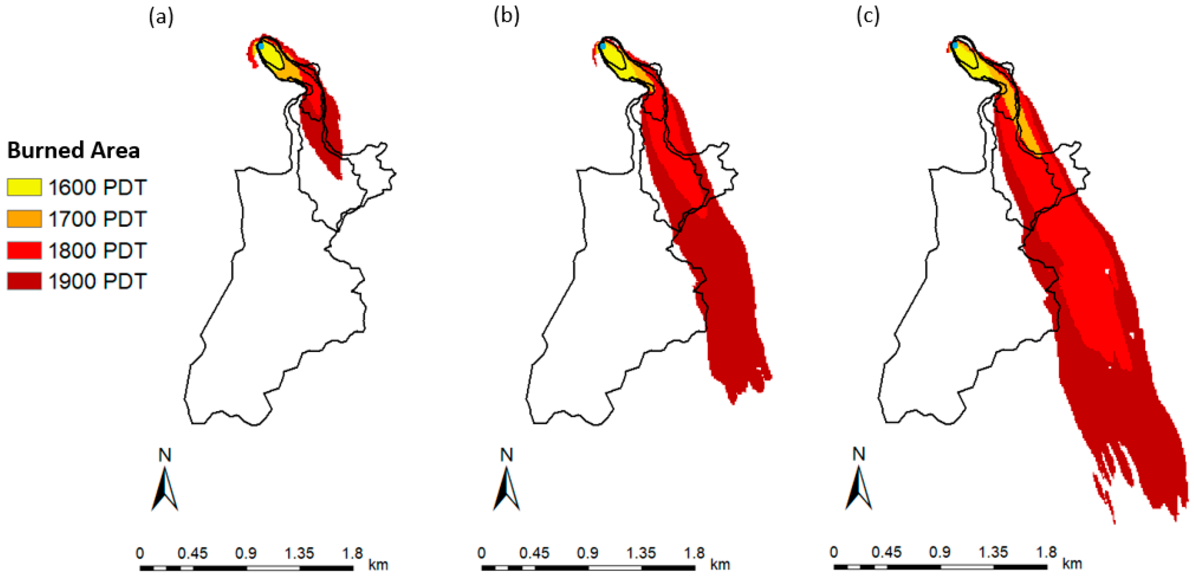
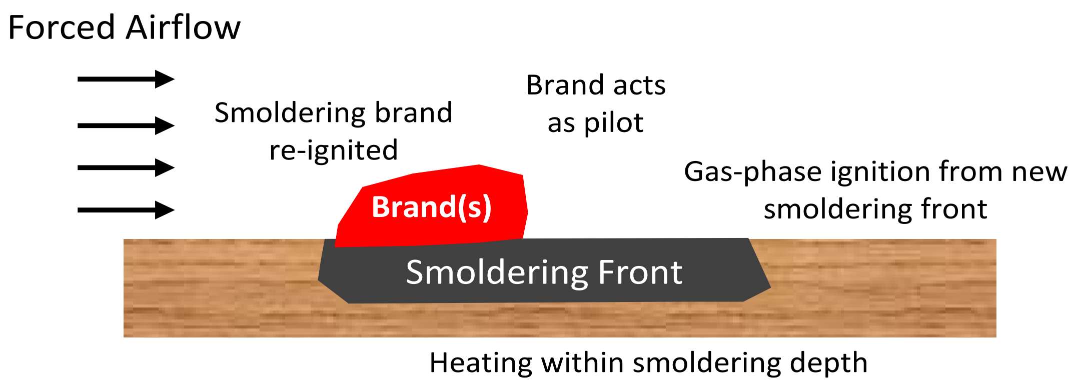
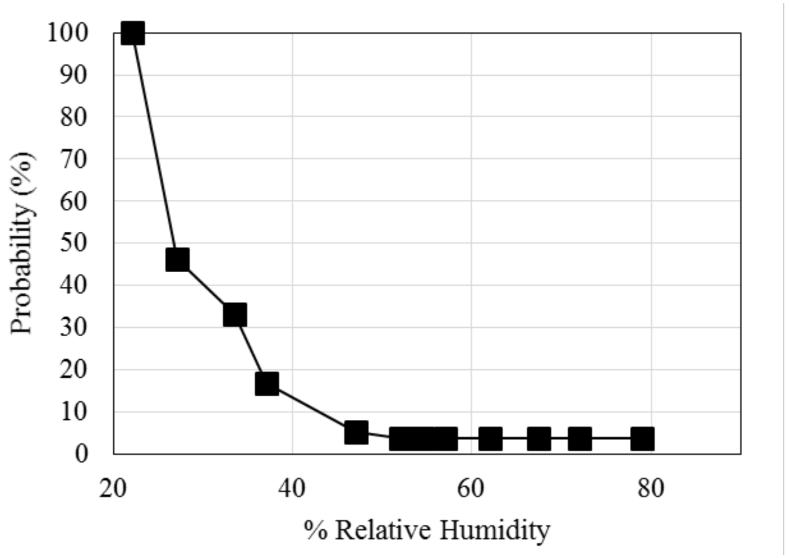
check for updates



Firebrand Ignition of Fuel

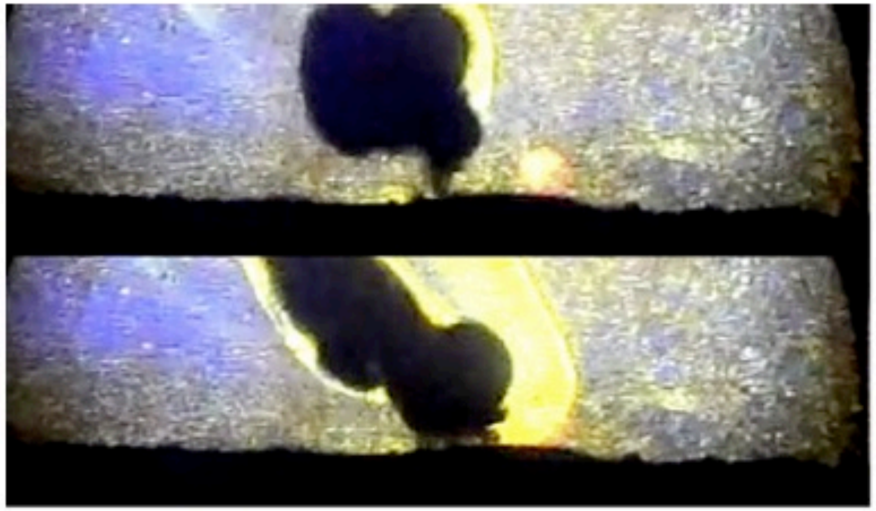


- ***<u>Not well understood or characterized</u>***
  - Physical dimensions of the firebrand, properties of the material and ambient weather conditions
- Ignition can proceed by
  - Direct flaming ignition (flaming firebrand)
  - Transition from smoldering to flaming (NOT understood)
    - From glowing firebrands
- Most data is available for tests on wildland fuels
- Will always be probabilistic

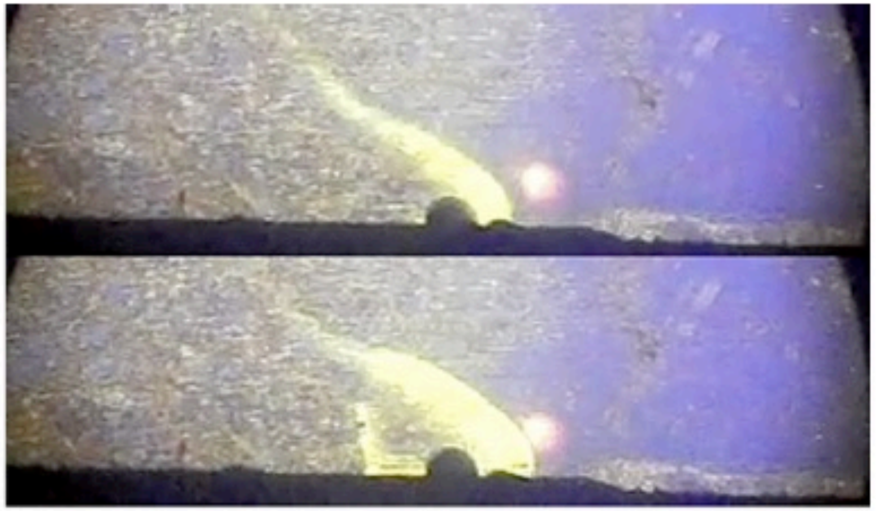


The probability of spot fires as a function of relative humidity, based on 99 prescribed fires conducted across Oklahoma from 1996 to 2002

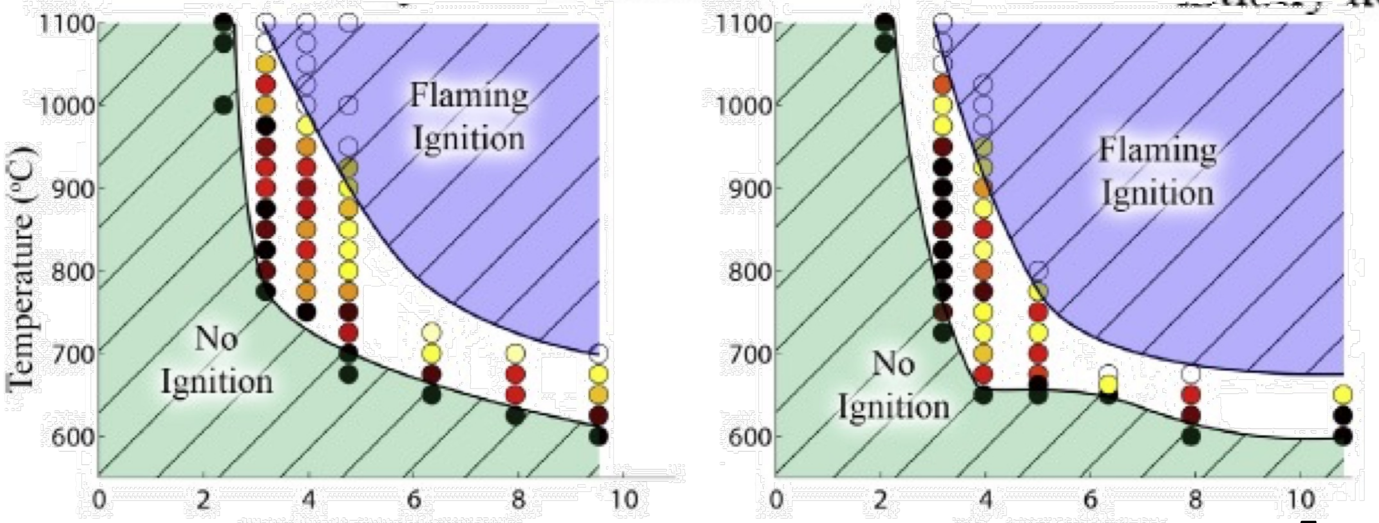
Steel Particle Ignition of Cellulose



(a) 9.5 mm Steel particle intially heated to 675ºC



(b) 4.8 mm Steel particle intially heated to 900ºC



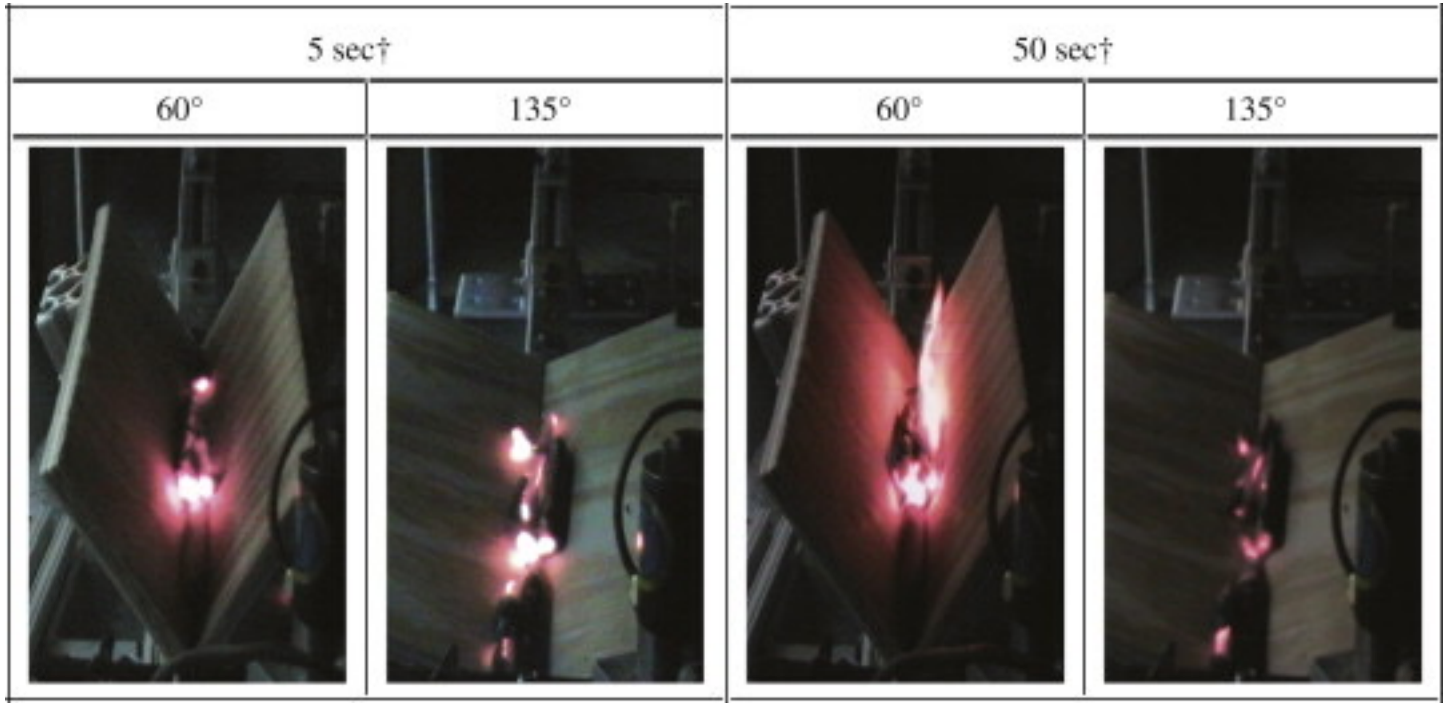
(a) Stainless Steel ***(b) Aluminum***

Hot spot theory
Minimum radius for ignition

$$r_{cr} = \delta_{cr}\sqrt{\frac{k}{\rho A \Delta H}\frac{RT_{p0}^2}{E}\exp\left(\frac{E}{RT_{p0}}\right)}$$

Fernandez Pello et al

Ignition of Fuels



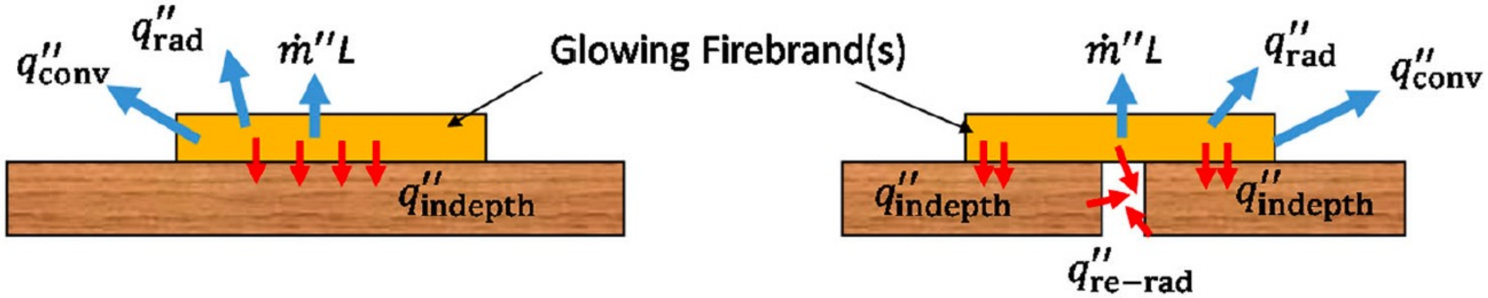


Figure 8. Heat and mass transfer processes that cool both the fire-brand and target fuel as well as heating processes that provide re-radiation and/or in depth conduction leading toward ignition.

Manzello, S. L., Park, S. H., & Cleary, T. G. (2009). Investigation on the ability of glowing firebrands deposited within crevices to ignite common building materials. *Fire Safety Journal*, *44*(6), 894-900

Firebrand Reproduction for Testing

A typical experiment with the NIST Dragon in BRI's FRWTF

"Ember storm" produced in the IBHS research facility

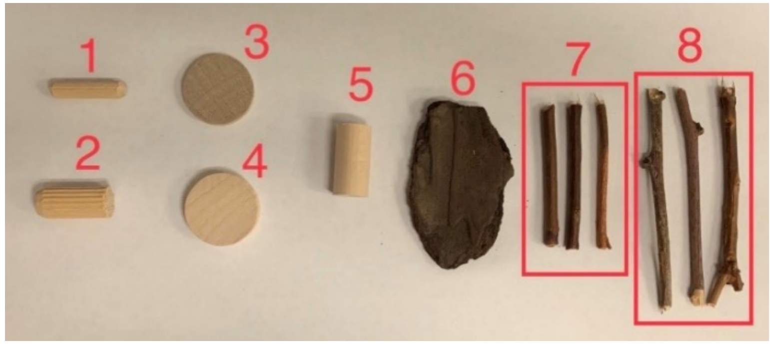
https://www.youtube.com/watch?v=IvbNOPSYyss

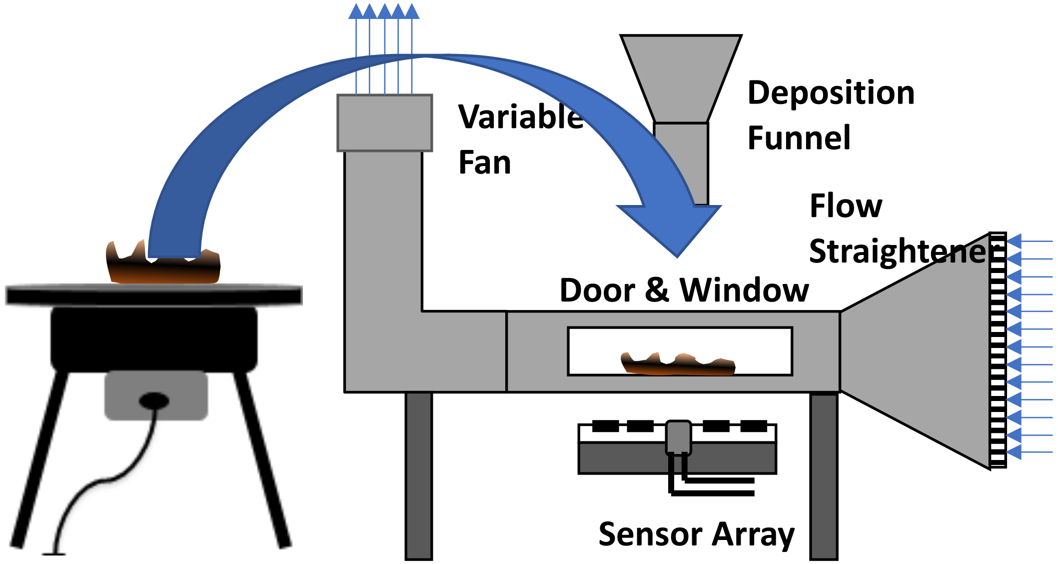
Manzello, S.L., 2014. Enabling the Investigation of Structure Vulnerabilities to Wind- Driven Firebrand Showers in Wildland-Urban Interface (WUI) Fires. Fire Saf. Sci. 11
IBHS, 2014. http://www.disastersafety.org.

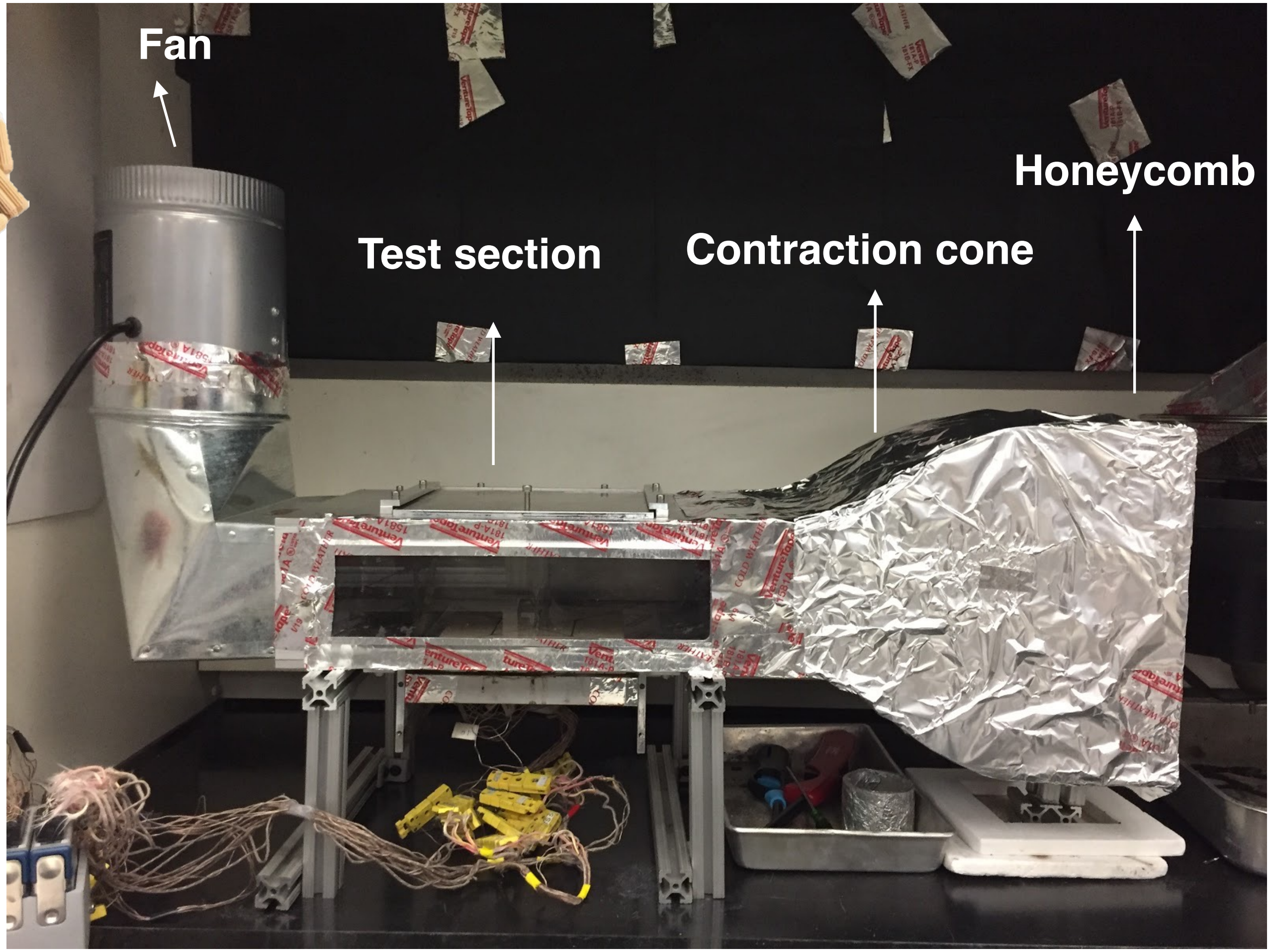
Table 4
Summary of Existing Studies on Ignition of Fuel Beds

Authors	Target fuel	Conditions	Results
Waterman and Tanaka [114]	Urban fuels	External winds, steady and oscillating	Ignition probability increased with winds >2.7 m/s. Oscillating winds decreased the probability of ignition
Dowling [167]	Timber bridges	Brands from burned wood cribs deposited onto 10 mm crevice	7 g of firebrands were able to produce smoldering ignition of the wood
Manzello et al. [16, 168]	Pine needles, shredded paper and cedar shingles	Glowing and flaming firebrands	Single flaming firebrands ignite fuel beds. Multiple glowing brands required to ignite most beds. MC and wind play a critical role
Manzello et al. [170]	OSB and plywood	V-shaped angle, wind speed and number of firebrands varied	Ignition sensitive to mass of firebrands, external wind and angle of crevice
Hadden et al. [177]	Cellulose powder fuel beds	Hot metal particles dropped onto fuel bed	Found a hyperbolic relationship between particle temperature and size
Manzello et al. [186]	Cedar crevices	6 m/s ambient wind	Transition from smoldering to flaming ignition was observed in all loading rates at or above 23.1 g/min, and ignition times decreased for larger loading rates
Viegas et al. [184]	Mediterranean vegetative fuel beds	11 pairs of burning embers	Ignition depended more on fuel bed than ember characteristics, especially MC
Yin et al. [17]	Pine needle beds with different MC	MC between 25% and 65% of fuel bed, 3 m/s wind, square glowing firebrands	Relationship between ignition time and MC of fuel bed established
Manzello and Suzuki [180]	Western red cedar, Douglas fir and redwood decks	Firebrand mass flux of 17.1 g/m^2s	20% of ejected brands accumulate on decks. Sensitive to density of wood baseboard
Zak et al. [187]	Cellulose powder fuel beds	Hot metal particles dropped onto fuel bed	Expanded results for several different metals
Wang et al. [185]	Expanded PS foam	Hot metal particles	Hot particles act as both heating and pilot sources, with ignition times occurring due to competition between gas mixing and particle residence times
Santamaria et al. [172]	Wood crevices	V-shaped wood crevice with stagnant conditions. Bark brands and charcoal used as brands	Brand heating could be simulated by electric heater. Ignition is still not formulated, but aided by exposure to airflow

Ember Studies – Wind Effects on Heating

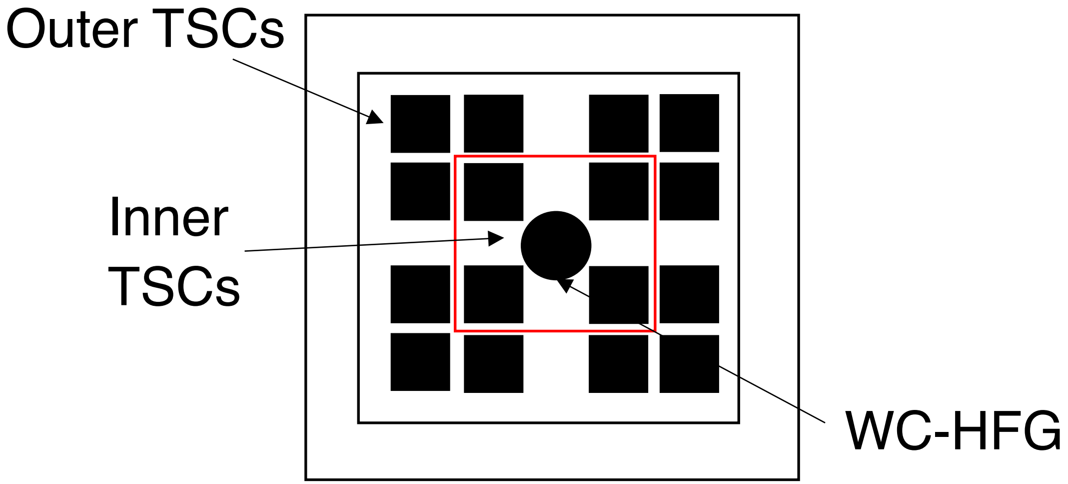


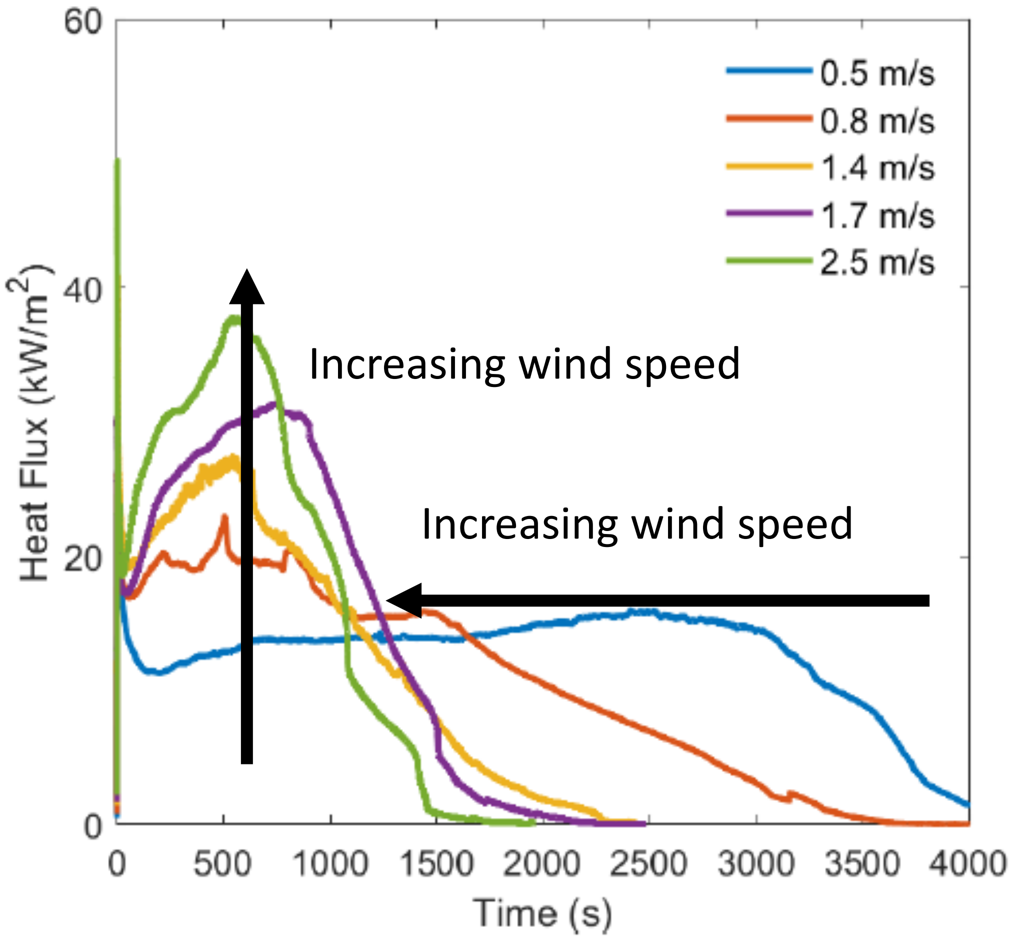




Ember Studies – Wind Effects on Heating

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



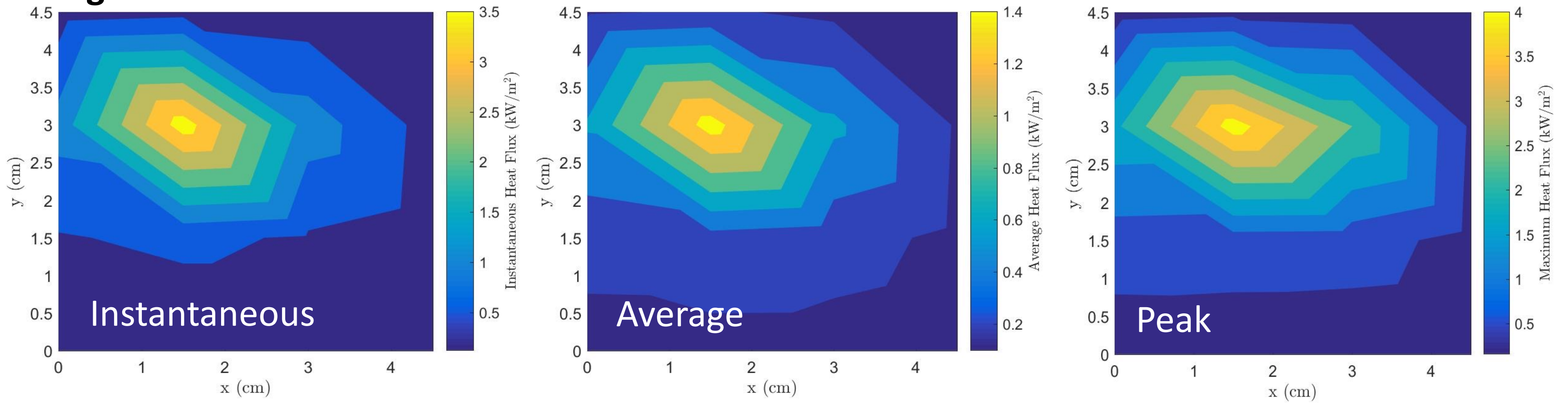


Context: Critical Radiant Heat Fluxes

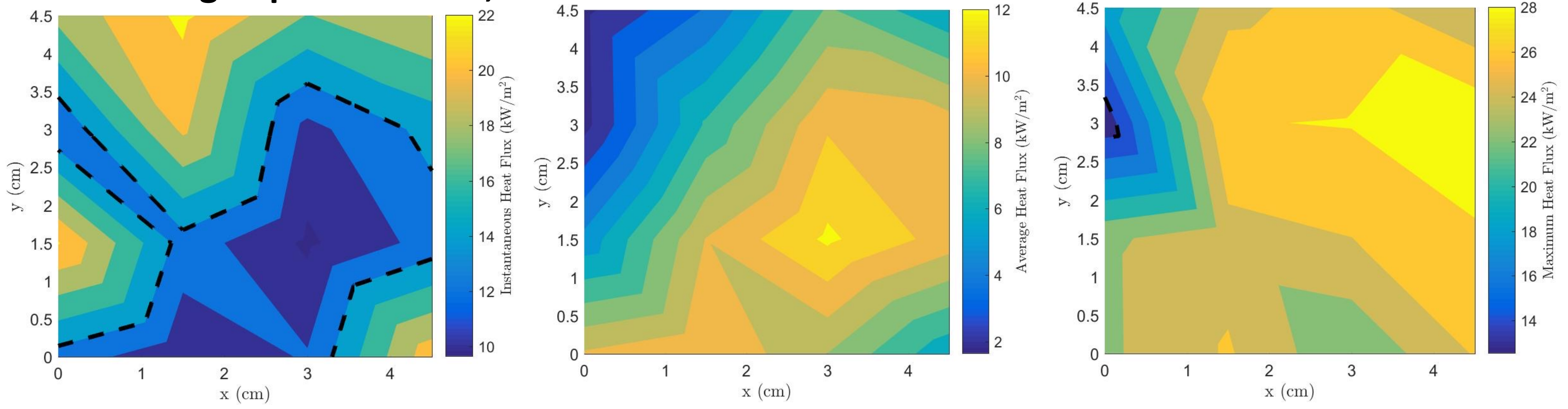
Material	Critical radiant heat flux (kW/m^2)	
	Pilot	Spontaneous
'Wood'	12[a]	28[a]
Western red cedar	13.3[d]	–
Redwood	14.0[d]	–
Radiata pine	12.9[d]	–
Douglas fir	13[d]	–
Victorian ash	10.4[d]	–
Blackbutt	9.7[d]	–
Polymethylmethacrylate	21[e]	–
Polymethylmethacrylate	11[f]	–
Polyoxymethylene	13[g]	–
Polyethylene	15[g]	–
Polypropylene	15[g]	–
Polystyrene	13[g]	–

No-Wind Single Brand vs. Large Pile

Single 12.7 mm Firebrand:



Pile of 10 g deposited mass, 12.7 mm firebrands:

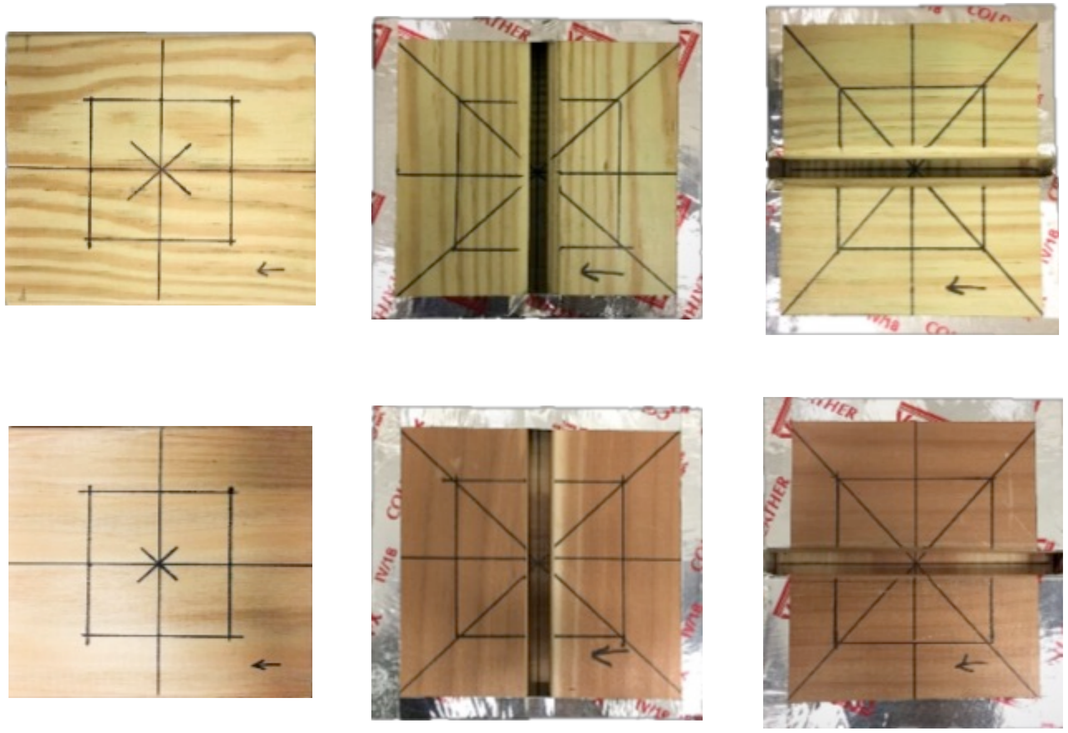


Ignition & Heat Flux in a Crevice

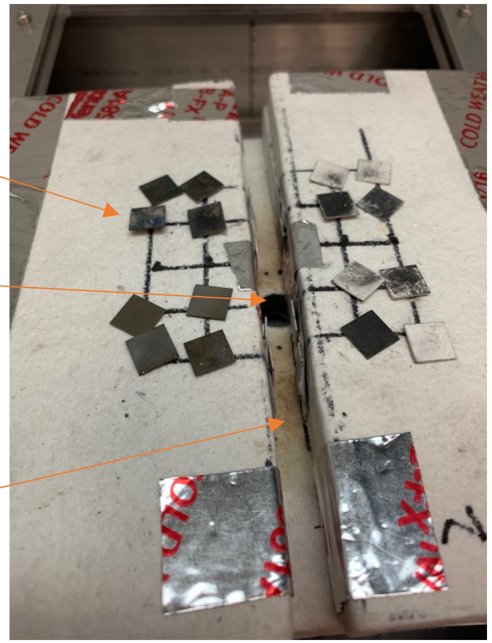
Flat | 90° Crevice | 0° Crevice

Pressure-treated wood

Redwood

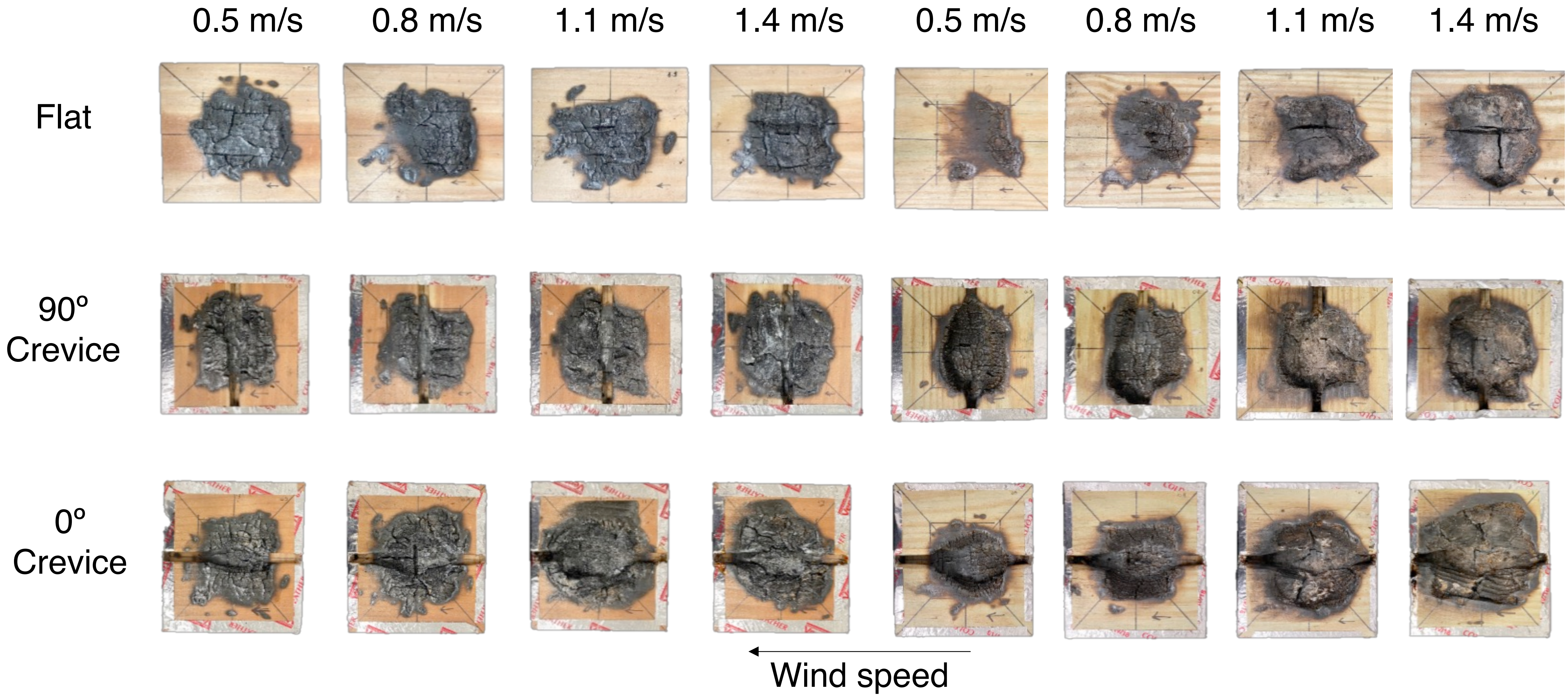


Wind speed

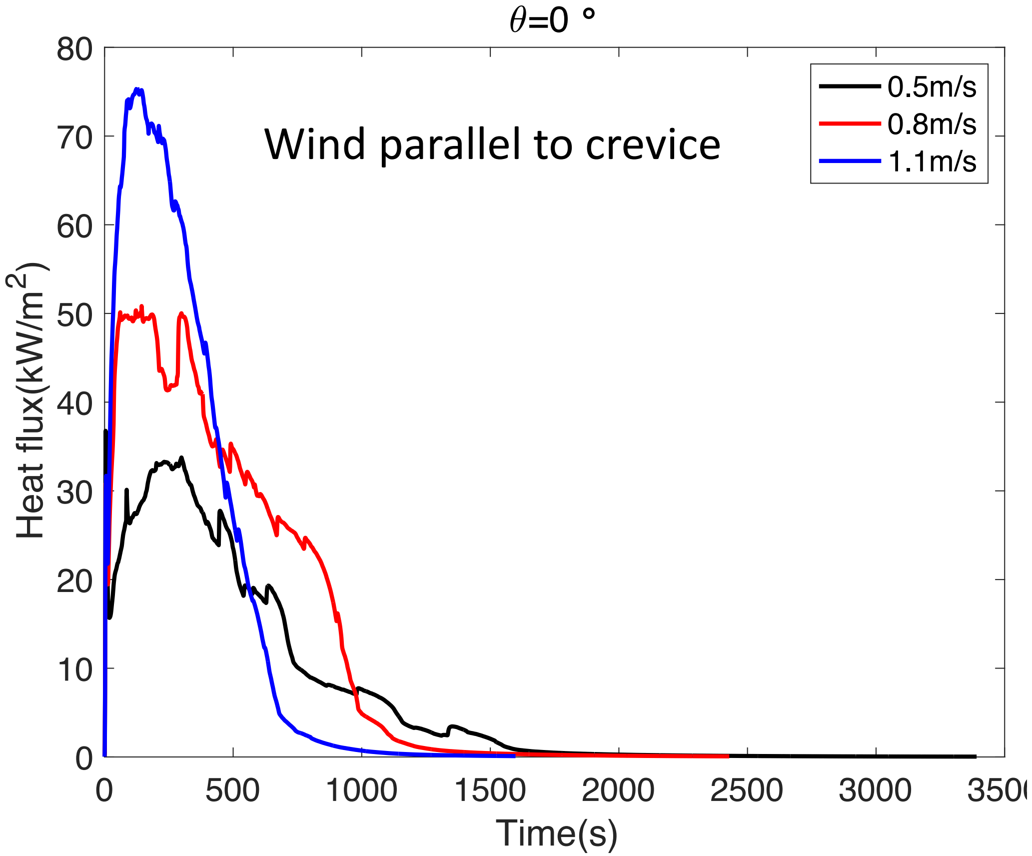


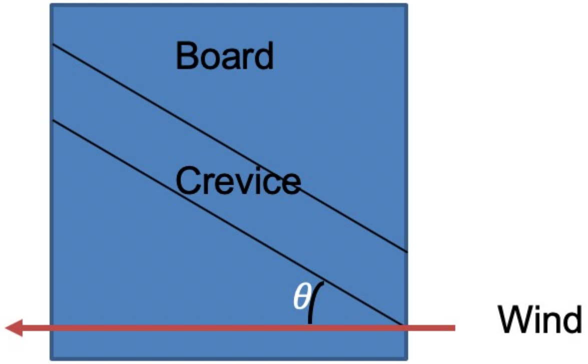
Observations:

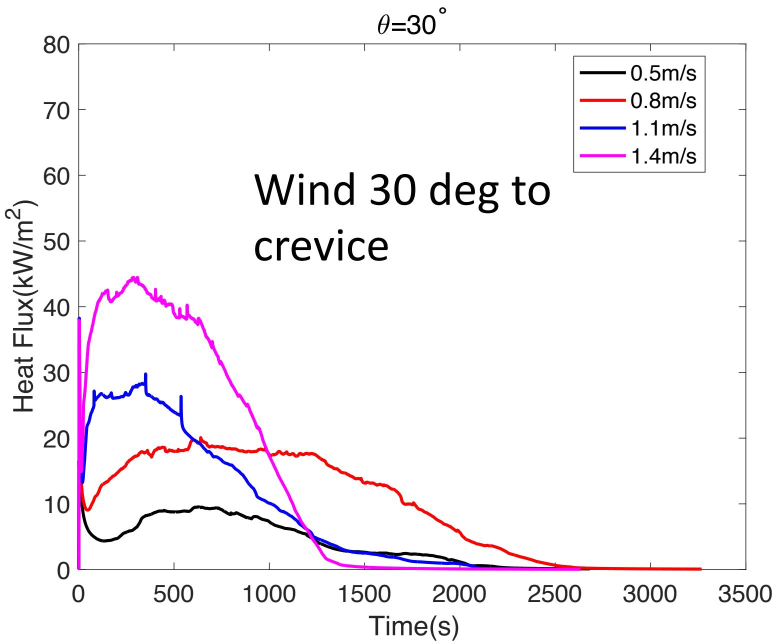
Redwood **Pressure-treated wood**

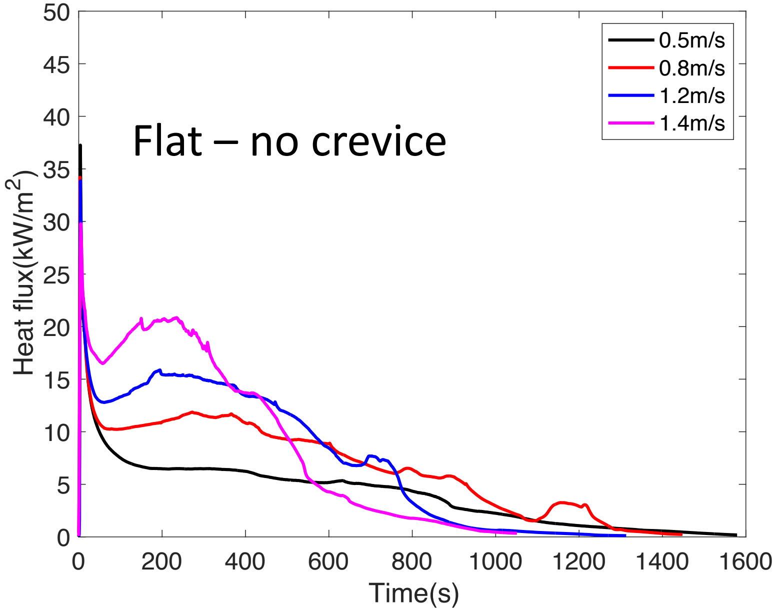


Heat Flux in a Crevice









Heat Flux Measurements

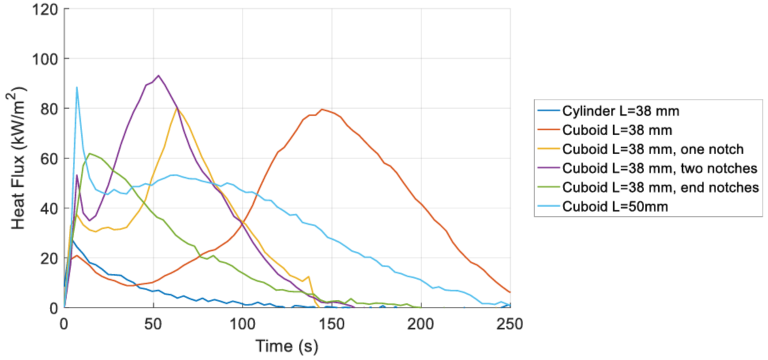


Fig. 8. Heat flux at the peak location with time for different types of firebrands with long side perpendicular to 1.0 m/s of wi

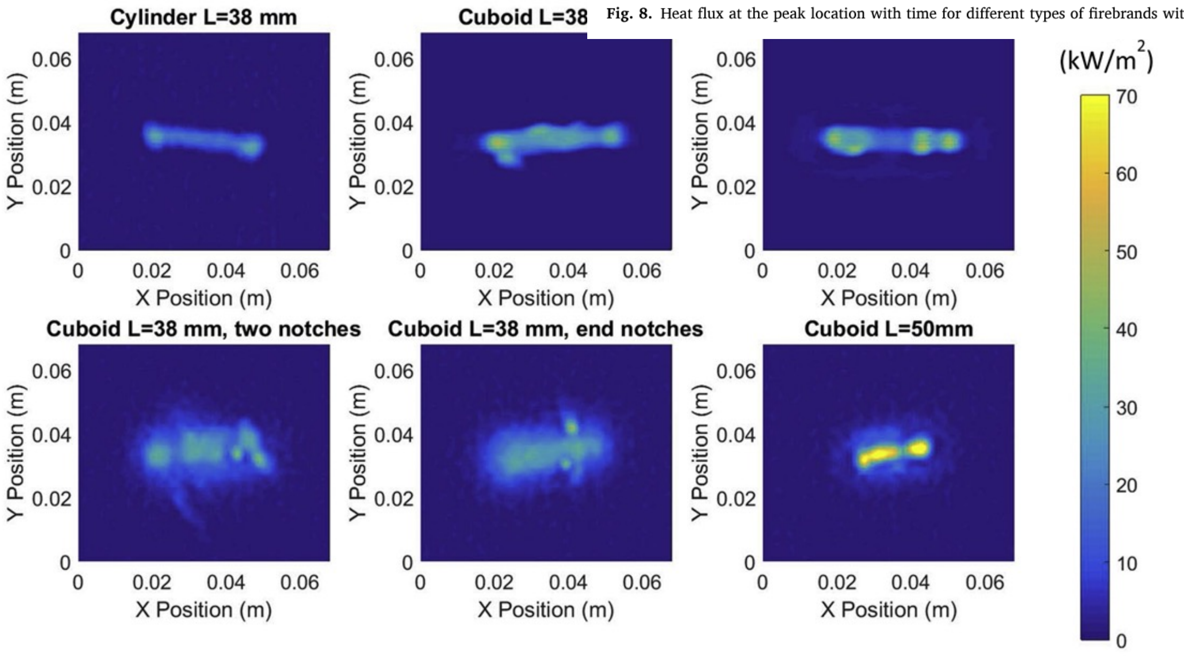


Fig. 5. Heat flux distributions at time of peak for different types of firebrands with no wind.

Description	Wind (m/s)	Wind Orientation	Peak Heat Flux (kW/m^2)		
			High Resolution	Avg. Over Firebrand	12.5 × 12.5 mm Region Avg.
Cuboid – 6.4 mm × 6.4 mm, 38 mm long	None	N/A	49	17.3	13.9
	1.0	Parallel	69.5	16	11.6
	1.0	Perpendicular	79.6	15.6	17.4
Cuboid – 6.4 mm × 6.4 mm, 38 mm long One centered notch	None	N/A	49.3	19.7	11.5
	1.0	Parallel	71.9	16.8	12.9
	0.5	Perpendicular	45.5	13.7	16.5
	1.0	Perpendicular	80.2	19.4	23.4
	1.5	Perpendicular	84.8	15.6	22.7
	2.1	Perpendicular	105.8	22.7	27
Cuboid – 6.4 mm × 6.4 mm, 38 mm long Two centered notches	None	N/A	41.7	18.3	17.4
	1.0	Parallel	73.7	19.4	16.8
	1.0	Perpendicular	93.1	17.7	16.6
Cuboid – 6.4 mm × 6.4 mm, 38 mm long End notches	None	N/A	46.1	19.1	18.7
	1.0	Parallel	71.1	19.8	15.4
	1.0	Perpendicular	61.8	16.2	14.9
Cylinder –6.4 mm diameter, 38 mm long	None	N/A	33.1	13.8	7.4
	1.0	Parallel	51.4	15.4	9.7
	1.0	Perpendicular	28.1	15.8	7.9
Cuboid – 6.4 mm × 6.4 mm, 25 mm long	None	N/A	94.5	27.1	20.8
	1.0	Parallel	85.5	23.5	16.8
	1.0	Perpendicular	88.4	26.1	20.8

Bearinger, E. D., Hodges, J. L., Yang, F., Rippe, C. M., & Lattimer, B. Y. (2021). Localized heat transfer from firebrands to surfaces. *Fire Safety Journal*, *120*, 103037.

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

Improve Response

- Notification
- Evacuation
- Response Coordination
- Planning & Communication

Reducing Exposure

- Community Design
- Fuel Reduction
- Prescribed Fire

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

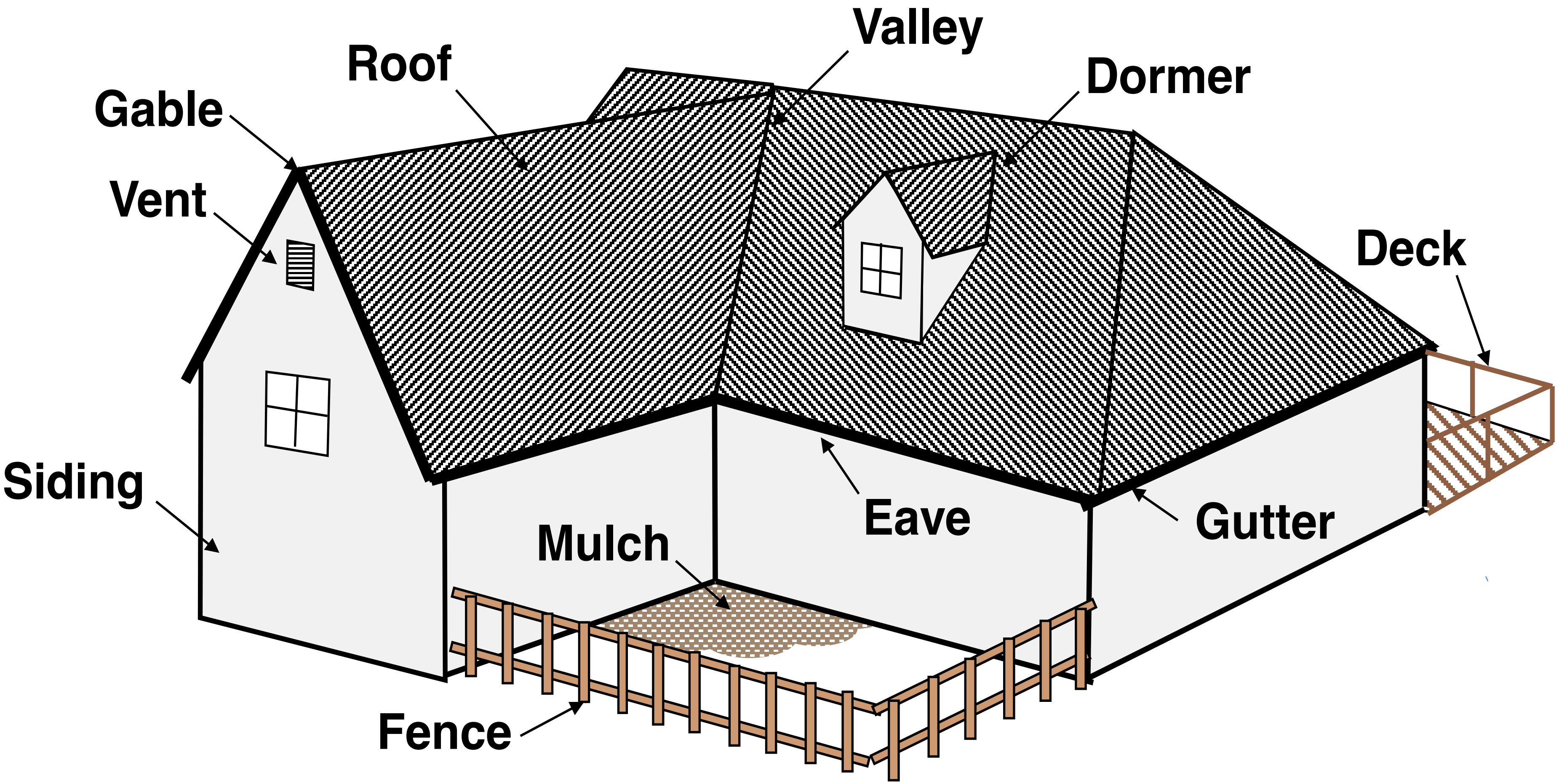
Vinyl gutters and mulch and debris ignite and burn at a test in the IBHS research center

Response of Components and Systems

Mitigation Strategies

- Buildings are engineered to passively protect people
  - WUI environment relies on non-standardized practices and active measures by homeowners
- Large flames must be within 100-200 feet of the structure (the home ignition zone) in order to ignite them
- Because this distance is rarely met for sufficient duration, small flames or firebrands ignite most homes
  - WUI fires can be thought of in terms of potential for home ignition
  - ***The goal of decreasing home ignitability places much responsibility on the homeowner***

Building Components



Many areas addressed in codes/standards and HIZ assessments

Response of Components

- Roofing
  - Some Class A roofing ignite, testing with firebrands ongoing
- Gutters
  - Need to test/standardize waves to eliminate debris accumulation
- Mulch and Debris
  - Various ignition and flaming tests performed (no standard)
- Eaves and Vents
  - Embers can still penetrate small mesh, but less likely to ignite
  - New test for mesh size (ASTM E2886)
- Fences
  - No experimental verification, but has been cited as possible structure ignition source
  - Research ongoing at NIST

Response of Components

- Decks, Porches, and Patios
  - Significant source of ignition in post-fire investigation
  - Need better national tests for brands, flame (CA has CBC 12-7A-4)
- Siding, Windows, and Glazing
  - Ignition on exterior walls a concern
    - Firebrand accumulation or debris ignition
  - Double pane glass effective
  - Plastic skylights have no testing, but could be risk

Reactions of Components

- Sidings, Windows and Glazing
  - Windows will shatter under high enough radiant heat flux
  - Double glazed windows help
- Use NON FLAMMABLE SIDING

a

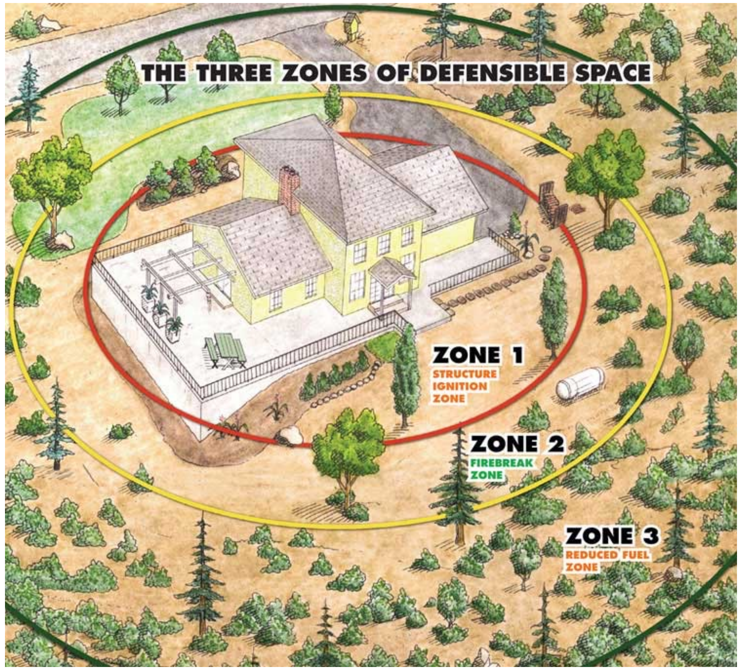
a

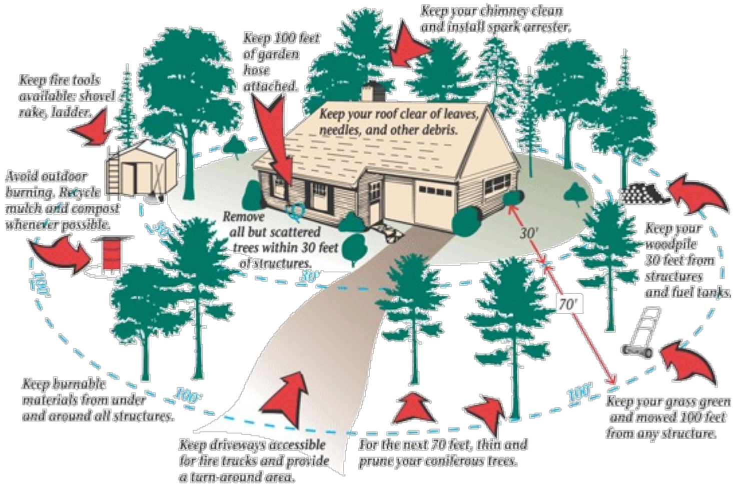
b

Accumulation of Debris

Debris (pine needles)

Zone Concept & Defensible Space





Several diagrams showing the three zones recommended by Firewise and other standards and programs

Firewise, NFPA 1141 and the ICC WUI Code all define the home ignition zone within the first 200 feet of a home.

Defensible Space

- NIST investigation of the Witch Creek and Guejito Fires

Zone	Destroyed Structures With Wildland Vegetation	Destroyed Structures Without Wildland Vegetation
0 – 30 ft from the structure	67%	32%
30 – 100 ft from the structure	59%	27%
100 – 200 ft from the structure	54%	27%
Beyond 200 ft	64%	17%

Percent structure destroyed with and without wildland vegetation

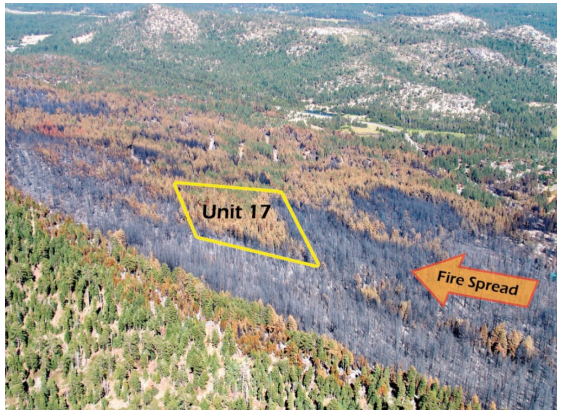
- Many Firewise recommendations effective in reducing ignition
- *Firewise does not explicitly recognize the hazard that an <u>untreated property</u> can have on an <u>adjacent properties</u>*
  - e.g. homeowners pushed fuel piles away from their homes, but in effect pushed closer to neighbor's house
- Recent study: structures were more likely to survive a fire with defensible space immediately adjacent to them

Syphard, A.D., Brennan, T.J., Kelley, J.E., 2014. Int. J. Wildland Fire

Maranghides, A., McNamara, D., Mell, W., Trook, J., Toman, B., 2013. NIST Report #2

Fuel Treatments

- Physically altering vegetation (e.g. removing, thinning, pruning, mastication, etc.)
  - Reduce intensity of fire (flame length, ROS)
  - Remove ladder fuels & space fuels to prevent crowing in tree canopy
  - Mechanical treatments: (hand/machine, chipping/pile burning or grazing) or prescribed burning
  - Continued maintenance important to retain effectiveness.
- General concensus on effectiveness of lowering fire intensity
  - Shown in 2007 Angora Fire
- Southern California study
  - Did not stop fires on own, but improved firefighter access & effectiveness



Fuel treatment area which met the full force of a crowning head fire. It transitioned to a lower intensity surface fire at the fuel treatment area.

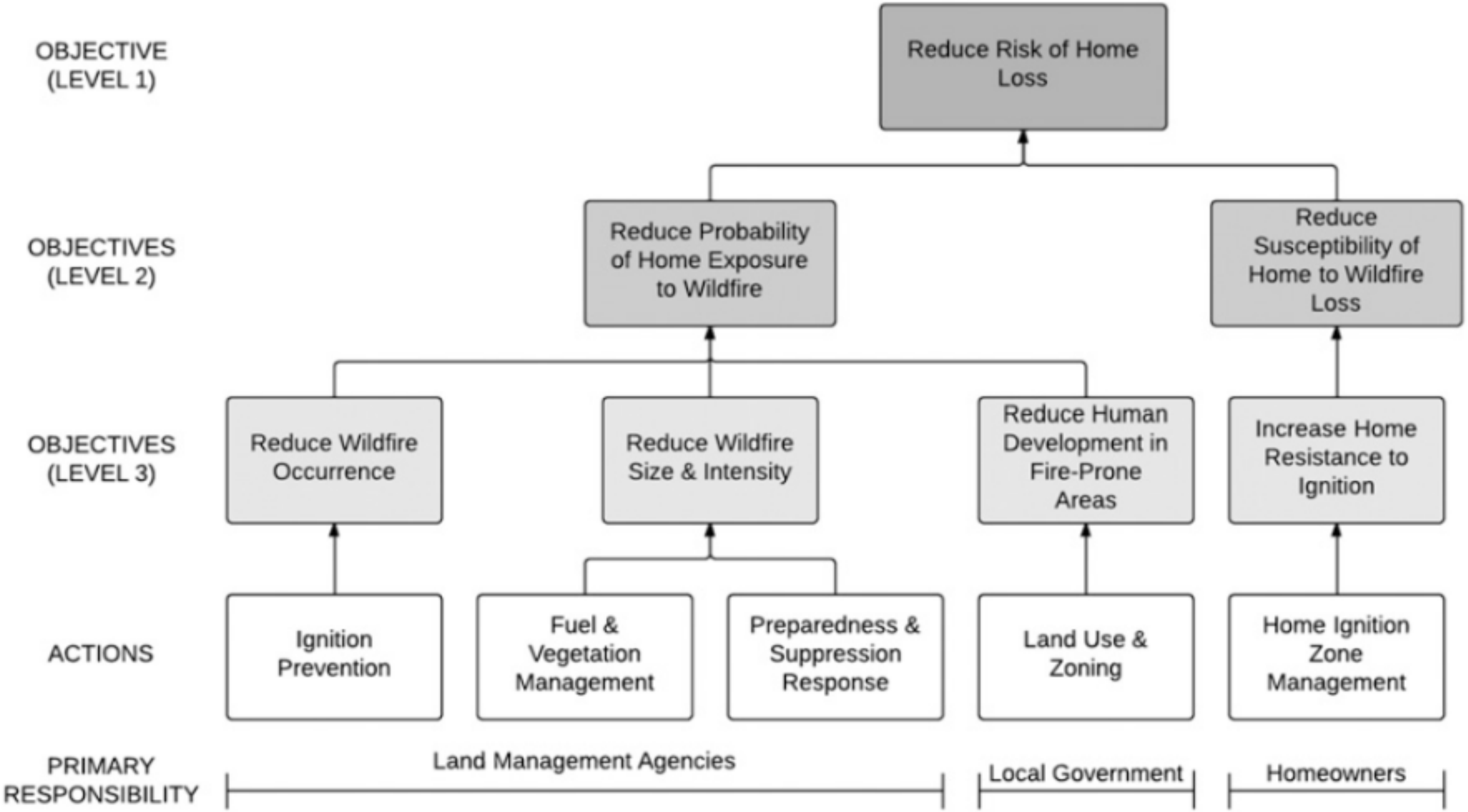
Hudak et al. Gen. Tech. Rep. RMRS-GTR-252. USFS
Murphy, K., Rich, T., Sexton, T., 2007., USFS Tech. Pap. R5-TP-025

Wetting/Covering Agents

- Exterior sprinklers, gel and foam agents, exterior blankets, etc.
  - Some mentioned in 2012 ICC WUI Code
  - Most not evaluated in actual-scale WUI event
- Bench-scale tests focus on radiant heating
  - Unrealistic conditions (flame contact, firebrands)
- Some gel and foam coatings delay ignition
  - Benefit is short term (hours after application)
  - Note the benefit is short term (hours) and it *must not blow off*! (*typical hot, dry, windy conditions*)
- Only 2 published studies on exterior sprinklers
  - One where all but one structure with a working sprinkler system survived ***a*** fire
  - Does not *PROVE* this works – no record of individual exposure conditions - ***Water availability issues if implemented at large scale***
  - Other in San Diego, single house, used to douse embers, 3 hr suppy

Urbas, J., 2013. Fire Mater. 563–580. *Johnson, J.F., Downing, T., Nelson, K.C., 2008.*

Conceptual Model for Risk of Home Loss



Calkin, D.E., Cohen, J.D., Finney, M.A, Thompson, M.P., 2014. Proc. Natl. Acad. Sci. 111

Note on HIZ

- One important note mentioned in the study was that Firewise does not explicitly recognize the hazard that an untreated property can have on an adjacent properties
- Focuses on the home.

- Based on NIST study of San Diego Community after the Witch and Guejito fires