Wildland-Urban Interface (WUI) Fires: Perhaps the Greatest Challenge for Fire Safety Science?

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June 8th, 2021
The Chemistry of Urban Wildfires
A Virtual Information Gathering Workshop

ありがとうございます

National Research Institute of Fire and Disaster (NRIFD)
Building Research Institute (BRI)

NRIFD, Japan

Dr. Sayaka Suzuki

Background: Me

- PhD 2000 (University of Illinois – Chicago)
  - Mechanical Engineer (BS/PhD)
  - PhD support by NASA Graduate Student Researcher Fellowship
  - Experiments conducted in Japan in support of PhD
    - In collaboration with University of Tokyo (Hirano/Dobashi) and Princeton University (Dryer)
- Joined NIST in January 2001
  - Post-Doctoral Fellowship from USA National Research Council
  - Awarded JSPS Fellowship in 2008
  - Awarded Department of Commerce (NIST) Individual Bronze Medal in 2012
  - Guest Editor: Fire Safety Journal; Fire Technology, Combustion Science and Technology, Frontiers in Mechanical Engineering
  - Associate Editor: Fire Technology
  - Research Features: Nature and Science
  - Invited Plenary Lecture: 11th IAFSS in 2014, 9th AOSFST in 2012
  - Bigglestone Award 2015, NFPA
  - Tibor Z. Harmathy Award 2016, Springer Nature
  - Best Journal Paper Award Combustion Society of Japan, 2016 and 2020
  - Samuel Wesley Stratton Award 2017, NIST
  - Colloquium Co-Chair, Fire Research 37th , 38th, 39th International Combustion Symposium
  - ISO TC92/TG03 Convener, ISO TC92/WG14 Convener

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日本燃焼学会

Historical Large Outdoor Fires

Wildland-Urban Interface (WUI) Fires

Why WUI Fires Seem Daunting?

Fire Spread from Firebrand Combustion Processes

Gaseous and Particulate Emissions

Thoughts on Research and Standardization Needs

Historical Large Outdoor Fires

Large Outdoor Fires and the Built Environment

- Meireki Fire (1657)
  - 60% of urban area burnt
  - Castle tower burnt -> never reconstructed

Meireki Fire (1657) Wikipedia

Great Chicago Fire of 1871

Currier and Ives, Chicago Historical Society

Modern Times

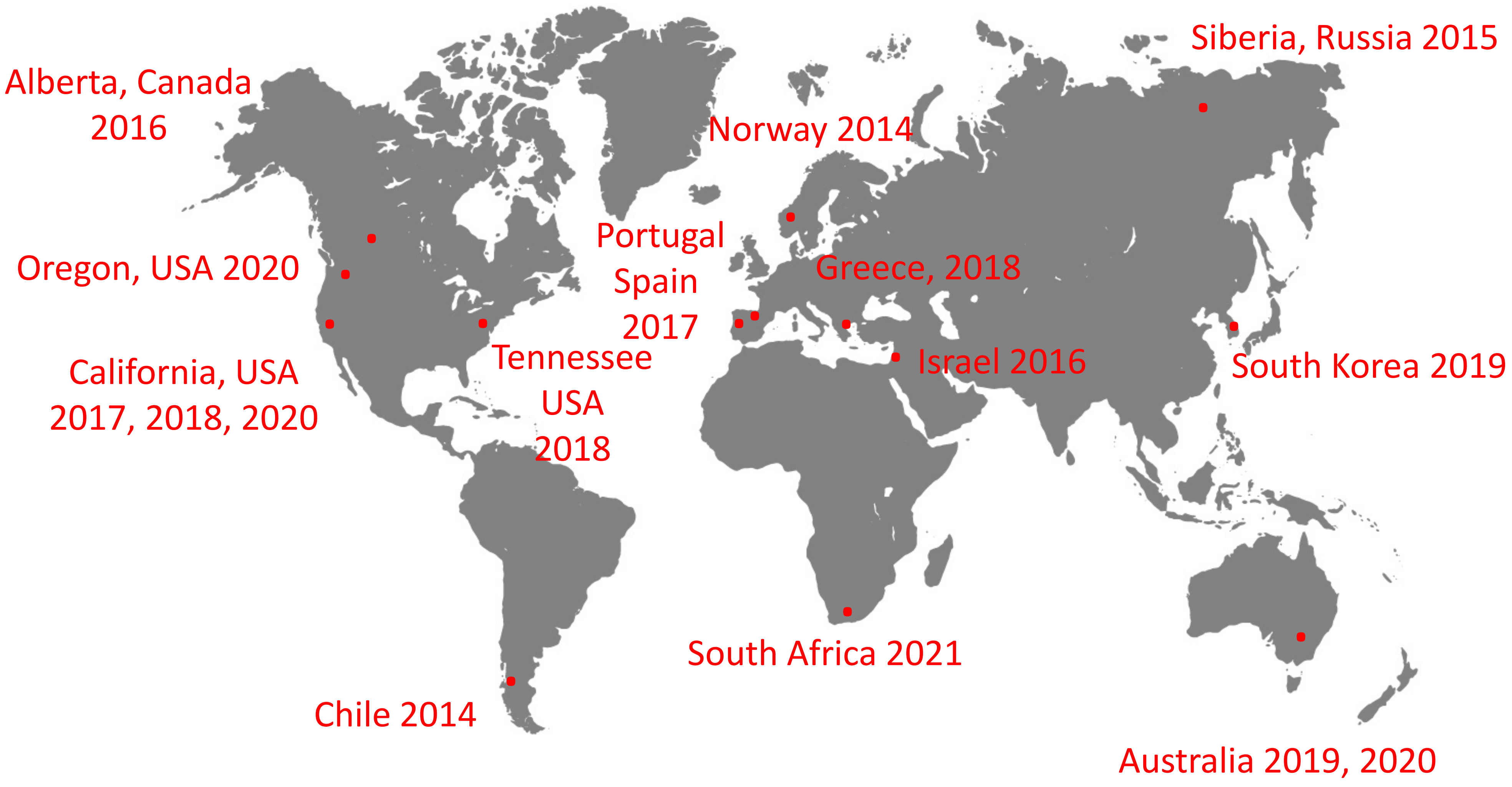
- Wildfires that spread into communities, known as wildland-urban interface (WUI) fires have destroyed communities throughout the world
- Large outdoor fires that pose risk to built environment are urban fires
- Informal settlement fires, common in the developing world, are another important example

Flame Spread Processes Similar

S.L. Manzello and S. Suzuki, 2021

Wildland-Urban Interface (WUI) Fires

WUI Fires Global Problem



Largest U.S. Fire Loss Incidents (NFPA)

Incident	Date	Adjusted Loss (2018 dollars)
1. World Trade Center, NY	2001	$47.4 billion
2. Northern California WUI Fire (2017), CA	2017	$10.2 billion
3. San Francisco, CA Earthquake, CA	1906	$9.7 billion
4. The Camp WUI Fire, CA	1991	$8.5 billion
5. Great Chicago Fire, IL	1871	$3.5 billion
6. The Woolsey WUI Fire, CA	2018	$2.9 billion
7. Oakland WUI fire, CA	1991	$2.8 billion
8. Southern California Fire Storm, CA	2007	$2.1 billion
9. Southern California WUI Fire , CA	2017	$1.8 billion
10. The Valley Fire, CA	1904	$1.6 billion
11. Great Boston Fire, MA	1872	$1.6 billion
12. Polyolefin Plant, TX	2000	$1.5 billion
13. Cerro Grande WUI Fire, NM	2000	$1.5 billion
14. Cedar WUI Fire, CA	2003	$1.4 billion
15. Baltimore Conflagration, MD	1904	$1.4 billion

9 of the top 15 are WUI Fires

Wildland-Urban Interface (WUI) Fires

WUI fire standards and codes are reflection of current physics

Need better comprehensive understanding of the WUI fire physics!

NIST Special Publication 1198

Summary of Workshop on Structure Ignition in Wildland-Urban Interface (WUI) Fires

Sponsored by ASTM International E05 Committee

Samuel L. Manzello
Stephen L. Quarles

This publication is available free of charge from: http://dx.doi.org/10.6028/NIST.SP.1198

INTERNATIONAL
Standards Worldwide

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

Fire Technology, 53, 425–427, 2017
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Editorial

Special Section on Structure Ignition in Wildland-Urban Interface (WUI) Fires

Samuel L. Manzello, Fire Research Division, National Institute of Standards and Technology (NIST), Gaithersburg, MD, USA*

Stephen L. Quarles, Insurance Institute for Business & Home Safety (IBHS), Richburg, SC, USA

Wildfires that spread into communities, commonly referred to as WUI fires, are a significant problem in Australia, Canada, Europe, South America, and the United States. WUI fire spread is extraordinarily challenging and presents an emerging problem in fire safety science. While it is accepted that WUI fires are an important societal problem, little understanding exists on how to contain and mitigate the hazard associated with such fires. The recent WUI fire in Fort McMurray, Canada in 2016 captured the world's attention to the devastation WUI fires may bring to communities.

Hardening, or making structures more resistant to ignition in WUI fires, is an accepted approach to lessen the devastation produced by WUI fire exposures [1]. Building codes and standards already exist that provide requirements for the construction of new buildings in areas known to be prone to WUI fires [2–5]. Proven, scientifically based retrofitting strategies are required for homes, and other buildings, located in areas prone to such fires. The objective of codes and standards is to reduce the risk of structural ignition. They have been developed based on the best information at the time they were developed. The provisions generally focused on flame contact and radiant heat exposures. *Based on current research, are these current codes and standards adequate?*

A workshop entitled *Structure Ignition in Wildland-Urban Interface (WUI) Fires* was held on June 18–19, 2015 in Anaheim, CA. The presentations of the workshop were separated into four topic areas: post-fire studies, structure ignition/firebrand accumulation and generation studies, WUI modeling, and evaluation of mitigation strategies. The interested reader is referred to a NIST Special Publication that documents all the presentations at the workshop [6]. In total, 12 presentations were delivered at the workshop. Authors that delivered accepted presentations were invited to submit papers as part of a special section for publication in *Fire Technology*. As discussed below, 6 papers were ultimately accepted for publication.

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International FORUM of Fire Research Directors Research Needs to Address Growing WUI Fire Dilemma

The Growing Global
Wildland-Urban Interface (WUI) Fire Dilemma:
Priority Needs for Research

NIST, NFPA , CSTB, VTT

NFPA

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

CSTB
le futur en construction

VTT

Fire Safety Journal 100 (2018) 64–66

Contents lists available at ScienceDirect

Fire Safety Journal

journal homepage: www.elsevier.com/locate/firesaf

FORUM position paper*

The growing global wildland urban interface (WUI) fire Dilemma: Priority needs for research

S.L. Manzello *et al*., Fire Safety Journal, 2018

Research into WUI fires *lags* other areas of fire safety science research

Fire safety science community focused on fires inside buildings several decades

Challenge: Wide Range of Scales

900 km (domain) ~8 km (grid cell)

1 km (domain) ~1 m (grid cell)

Regional

Landscape

Community

Combustion Community Critical

Fuel elements

W. Mell, S.L. Manzello, *et al.*,
***Int. J. Wildland Fire*, 2010**

Why WUI Fires Seem Daunting?

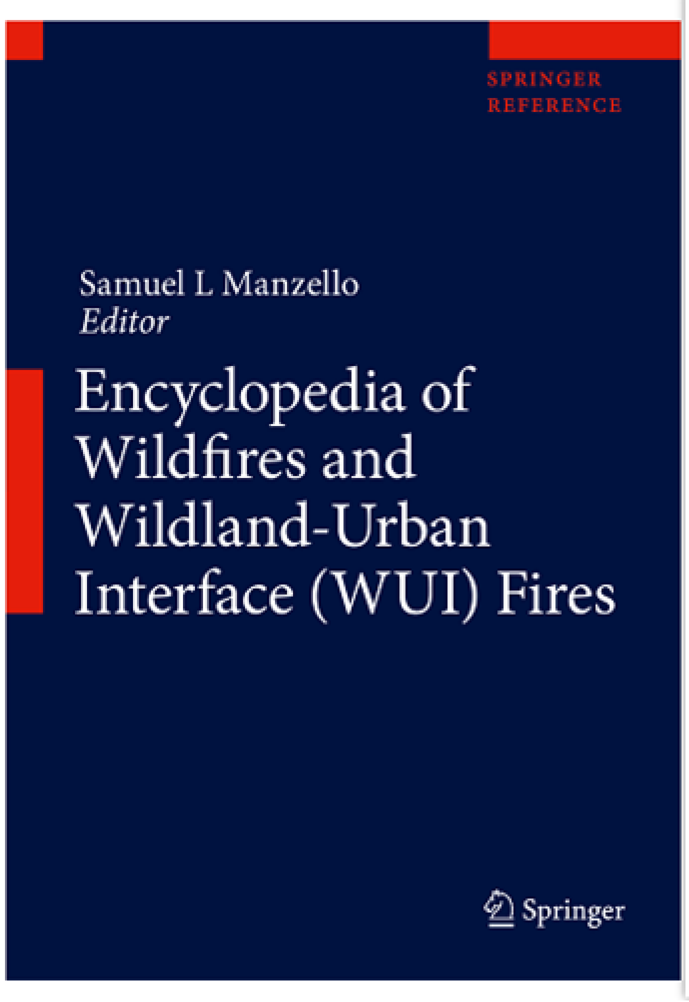
Lack of Resources for Accepted Knowledge

Book Printed July 2020

Living Edition

171 contributions published
More than 200 authors from all over the world

https://link.springer.com/referencework/10.1007/978-3-319-51727-8



Detailed Physics Yet to be Revealed

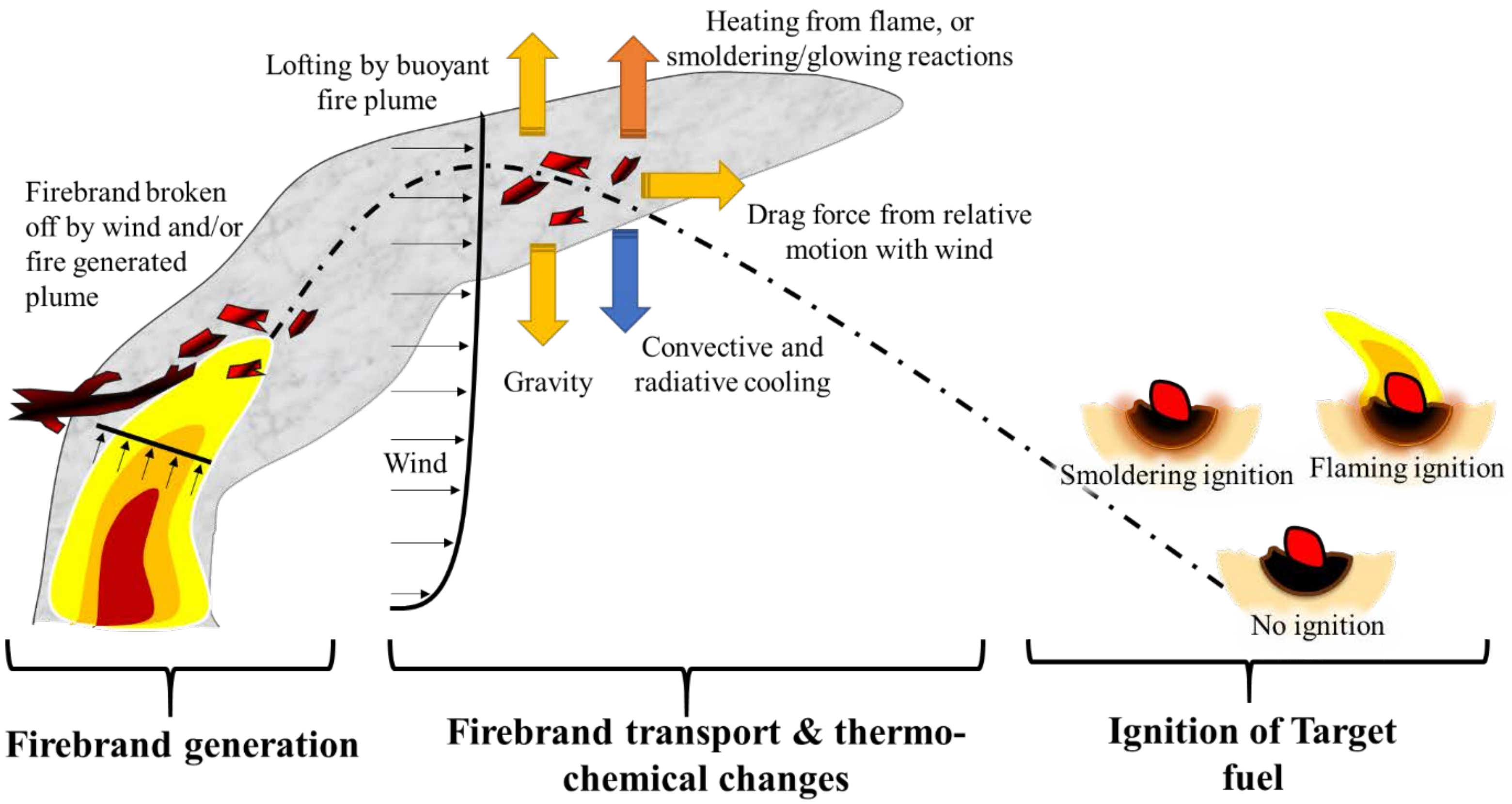
- The complex ignition, fire spread processes, and degree of gaseous and particulate emissions appear daunting during WUI fire events
- Some needed studies relevant to WUI fire processes:
  - Firebrand combustion processes
  - Gaseous and particulate emissions
  - Transition from smoldering combustion to flaming combustion
  - Initial ignition of vegetative and structural fuels, subsequent flame spread
  - Fire whirl combustion processes

Detailed physics of these processes have yet to be fully revealed

Barrier to develop computational methods to predict/understand WUI fires

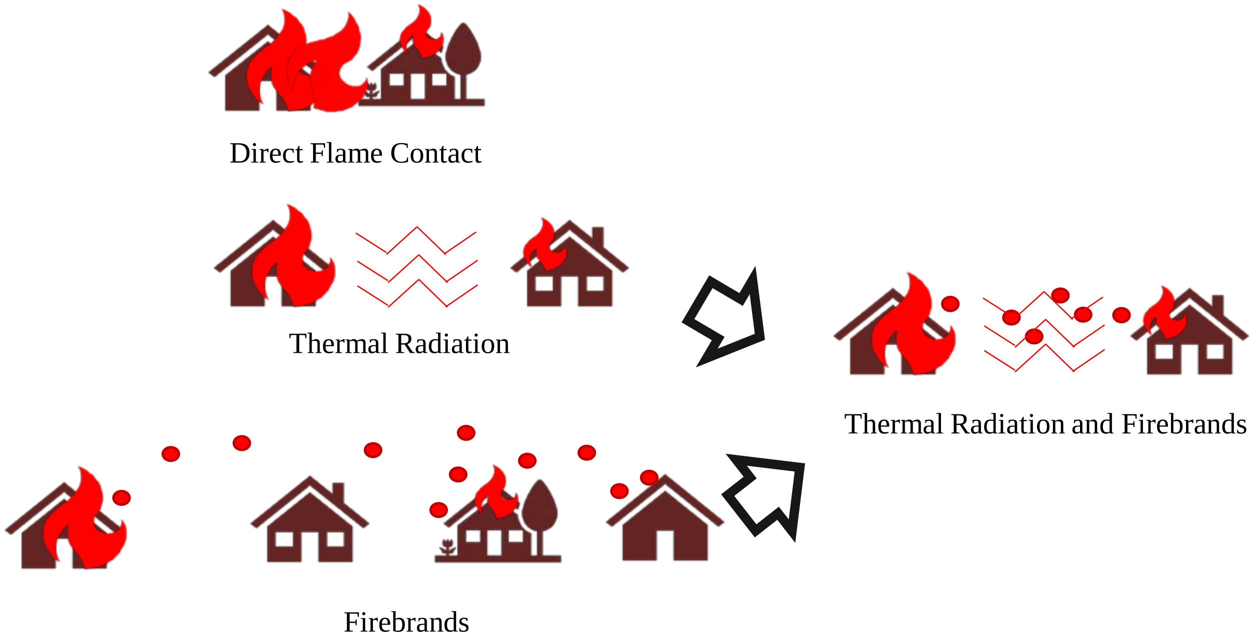
S.L. Manzello and S. Suzuki, 2021

Firebrand Combustion Processes in WUI Fires



S.L. Manzello, S. Suzuki, *et al*., Progress in Energy and Combustion Science, 2020

Structure Ignition Mechanisms in WUI Fires



S. Suzuki and S.L. Manzello, *Fire Technology* 2021

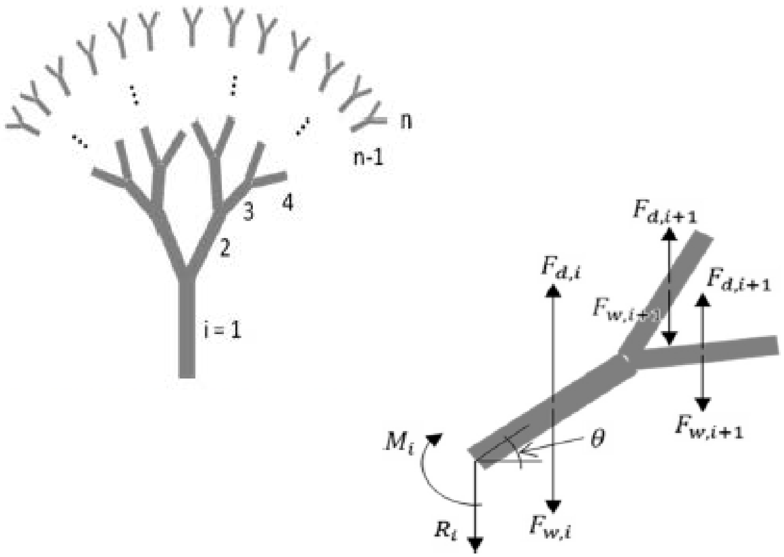
Fire Spread from Firebrand Combustion Processes

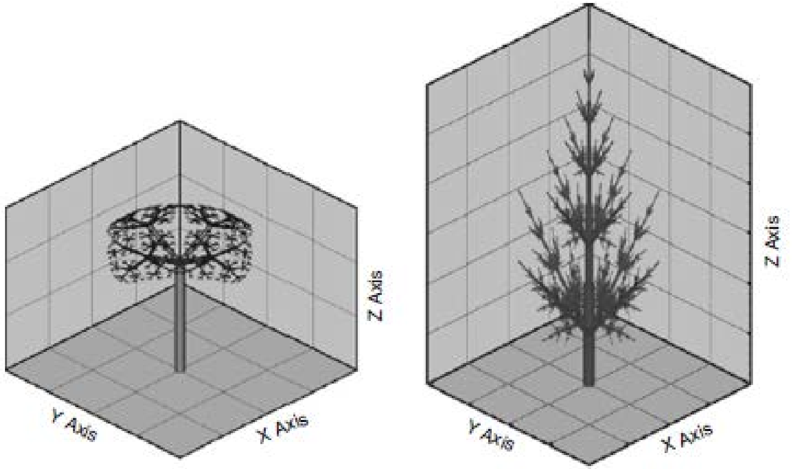
Firebrand Generation from Vegetation Combustion

- Pyrolysis of fuel elements is an important mechanism
- During vegetative combustion process, wind flow around fuel elements generates and imposes aerodynamic forces
- These forces produce moments and stresses along fuel elements while pyrolysis simultaneously thermally degrades them and reduces their structural integrity
- Firebrands are formed when a critical point is reached

Conifer Tree Combustion
Manzello *et al*.,
***Int. J. Widland Fire*, 2007**

B. Barr and D.K. Ezekoye
***Proc. Comb. Inst.* , 2013**





D.K. Ezekoye and S. Weisses
Encyclopedia of Wildland Fires and WUI fires, 2020
(S.L. Manzello, Editor)

Firebrand Yields vs Tree Species

Table I. Summary of firebrand masses collected (m_{fb}) and ratio of mass collected as firebrands to mass lost during burning as well as ratio of mass collected as firebrands to total tree mass.

Tree species	Mass of firebrands, m_{fb} (g)	Mass of firebrands/mass lost during burning (%)	Mass of firebrands/total tree mass (%)
Korean pine (4.0 m)	33±15	2	0.28
Douglas-fir (2.6 m)	18±4	0.45	0.15
Douglas-fir (5.2 m)	50±5	0.2	0.08

Notes: Initial moisture content of all trees tested was similar.

Firebrand Yields from Conifer Trees

No wind

S.L. Manzello *et al.*, *Fire and Materials*, 2009

Douglas-fir

Korean Pine

Experimental studies needed under wind

Burner Ignition – Wind

S.L. Manzello, S. Suzuki
12th Joint US Combustion Meeting, 2021

1.5 m Noble-fir
No wind
Burner Ignition

Different combustion dynamics!

1.5 m Noble-fir
3 m/s
Burner Ignition

Firebrand Generation Processes
Structural Fuel Combustion

Actual structure experiments are expensive (takai)

Full-scale 3 story school house burn
3,000,000,000 Japanese Yen ~ $26,000,000 for one test!!

Tsukuba, Japan

Laboratory-Scale Insights Required

- Full-scale structure experiments to investigate firebrand production are expensive
- What can we learn from simplified building components?
- Simple-minded approach
  - Design structures to produce less firebrands?
  - Develop test methods that compare and evaluate (screen) a materials propensity to produce firebrands, suggesting a mitigation strategy may be possible by simply limiting a buildings propensity for firebrand production
  - At same time, develop fundamental understanding of firebrand production mechanisms

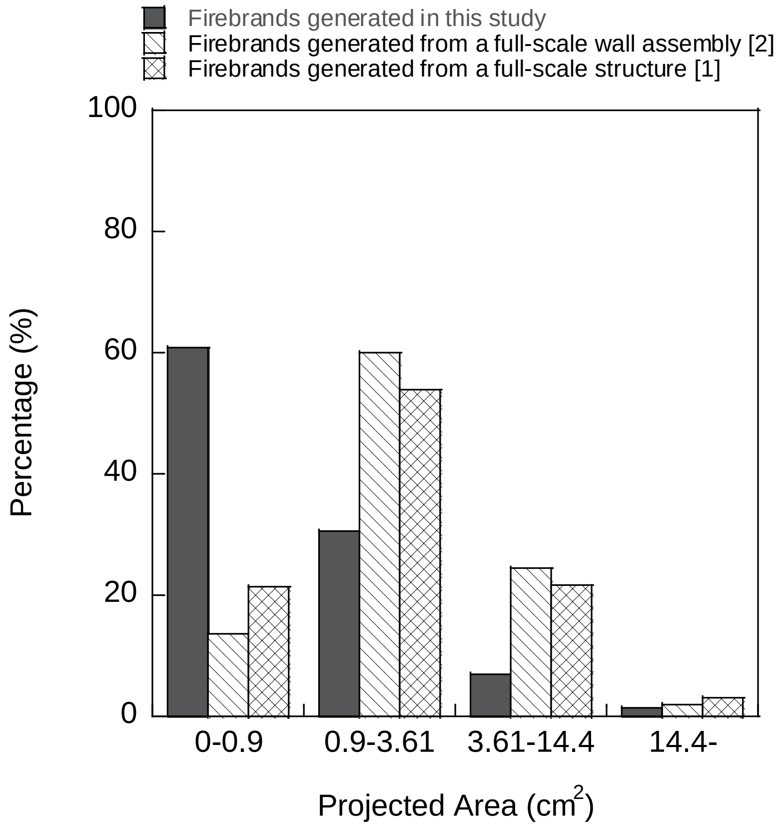
Can we go even simpler?

Experimental Complexity (Actual Situation to Simplified Components)

S.L. Manzello, S. Suzuki, *Proc. Comb. Inst.*, 2017

Comparisons to Full-Scale Experiments

Comparison of size distribution for mock-ups to full-scale corner wall assembly and full-scale structure 6 m/s

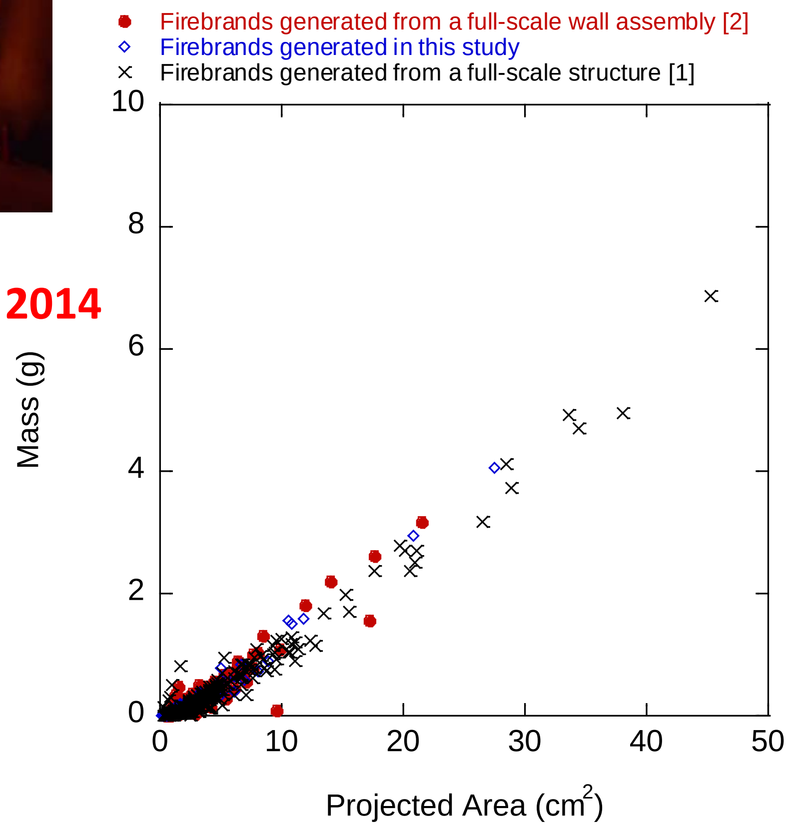


Full-scale structure [1]

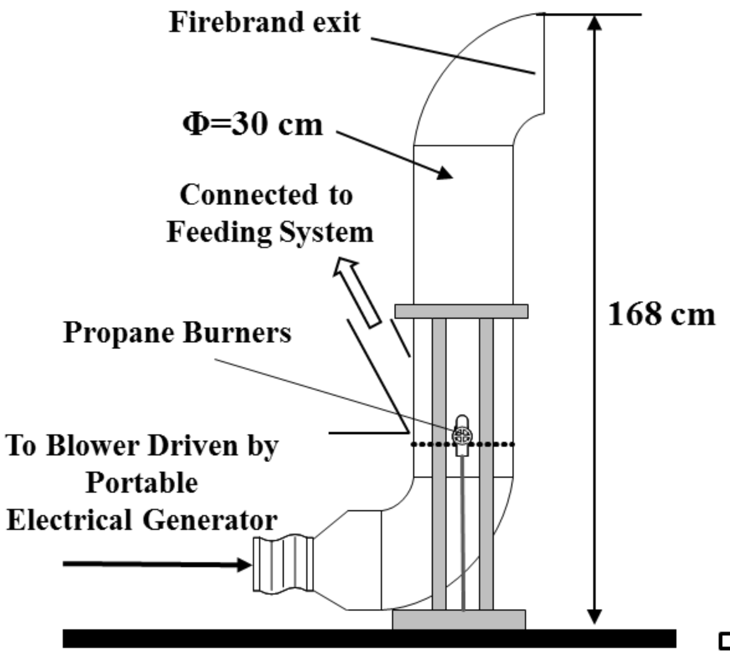
Suzuki et al., *Fire Saf. J.* 63: 43, 2014

Full-scale corner wall assembly [2]

Suzuki et al., *Proc. Comb. Inst.* 32: 2479, 2013

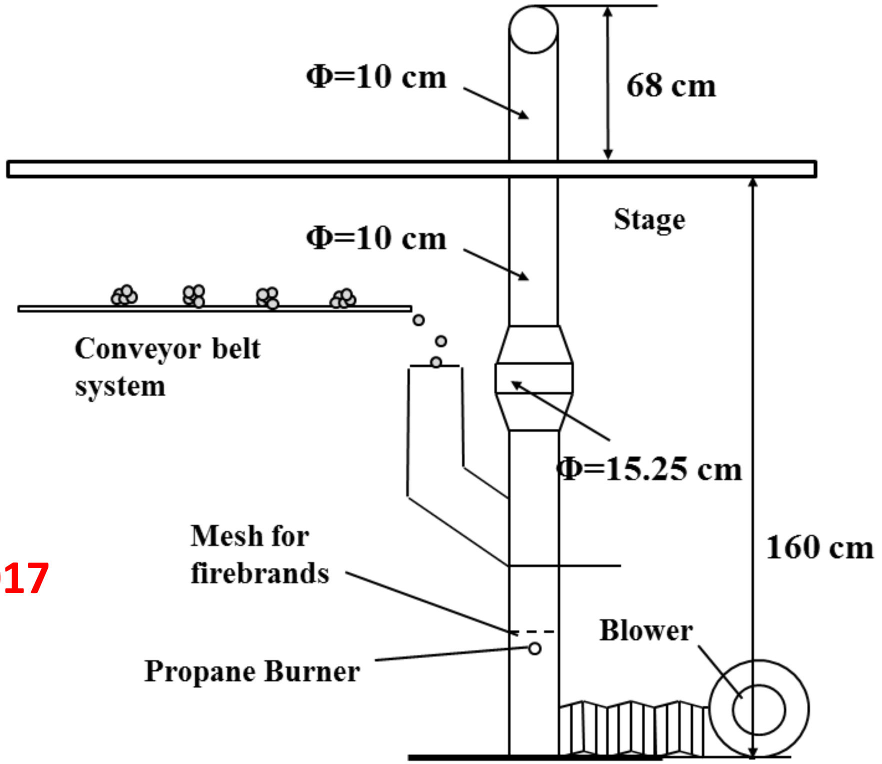


A Tale of Two Dragons 龍



Full-Scale

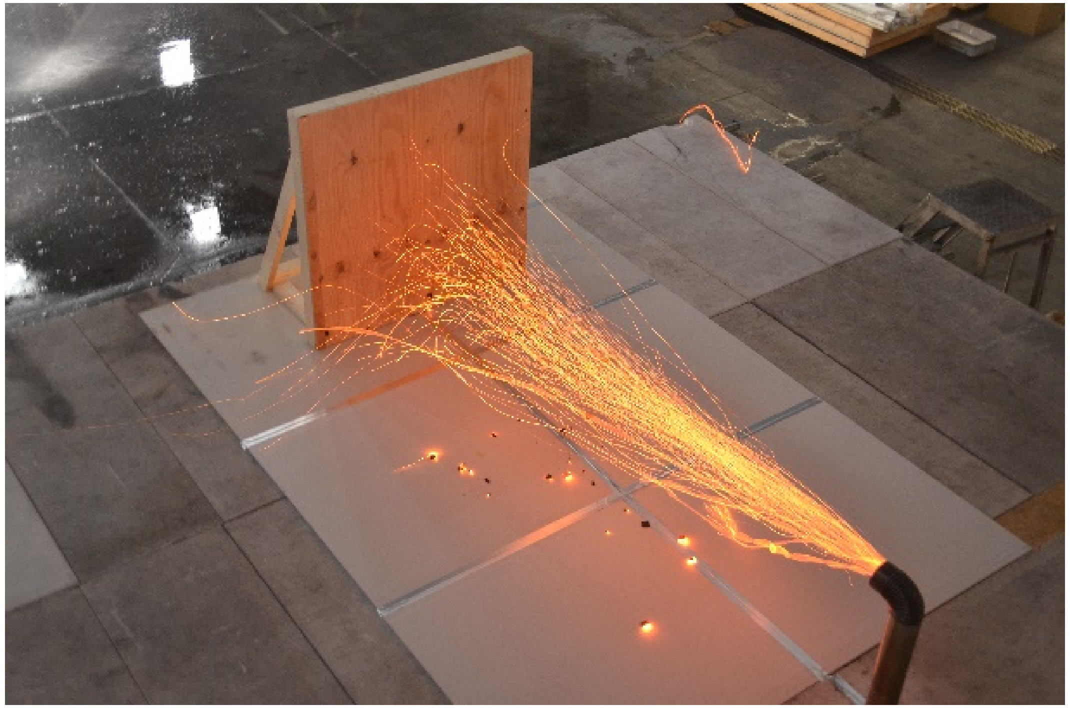
Bench-Scale



S. Suzuki and S.L. Manzello, *Fire Safety Journal*, 2017

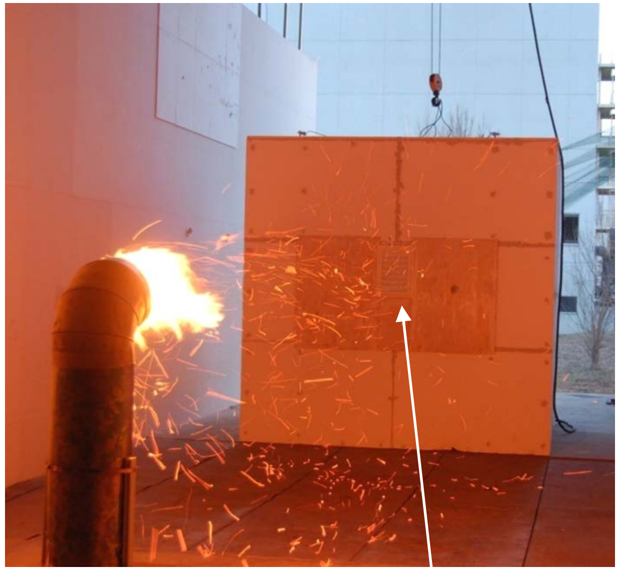
From Full-Scale to Laboratory Scale

Accumulation Processes
S.L. Manzello, *et al*., *Fire Safety Journal*, 2011

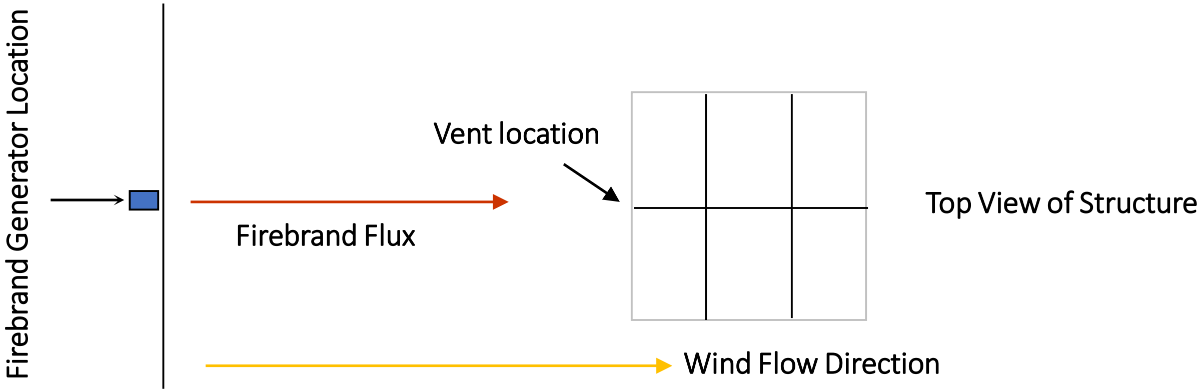


Transport Processes
S. Suzuki and S.L. Manzello, *Fire Technology*, 202

Firebrand Penetration Through Vents



Gable Vent



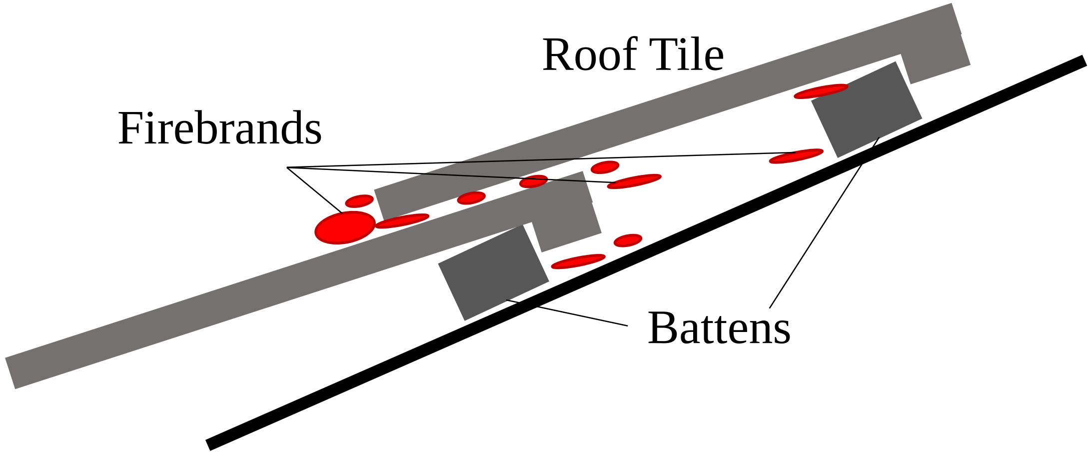
Firebrand Goes Through

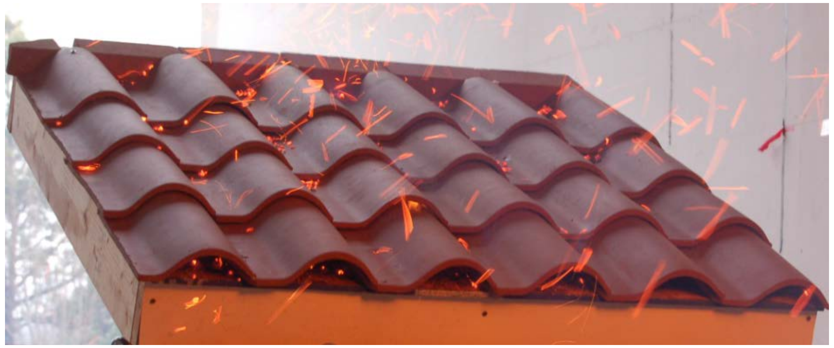
Screen Behind Vent

Three mesh sizes tested 6 mm , 3 mm , and 1.5 mm

S.L. Manzello *et al*., Interflam, 2007

Roofing Assemblies and Firebrand Showers

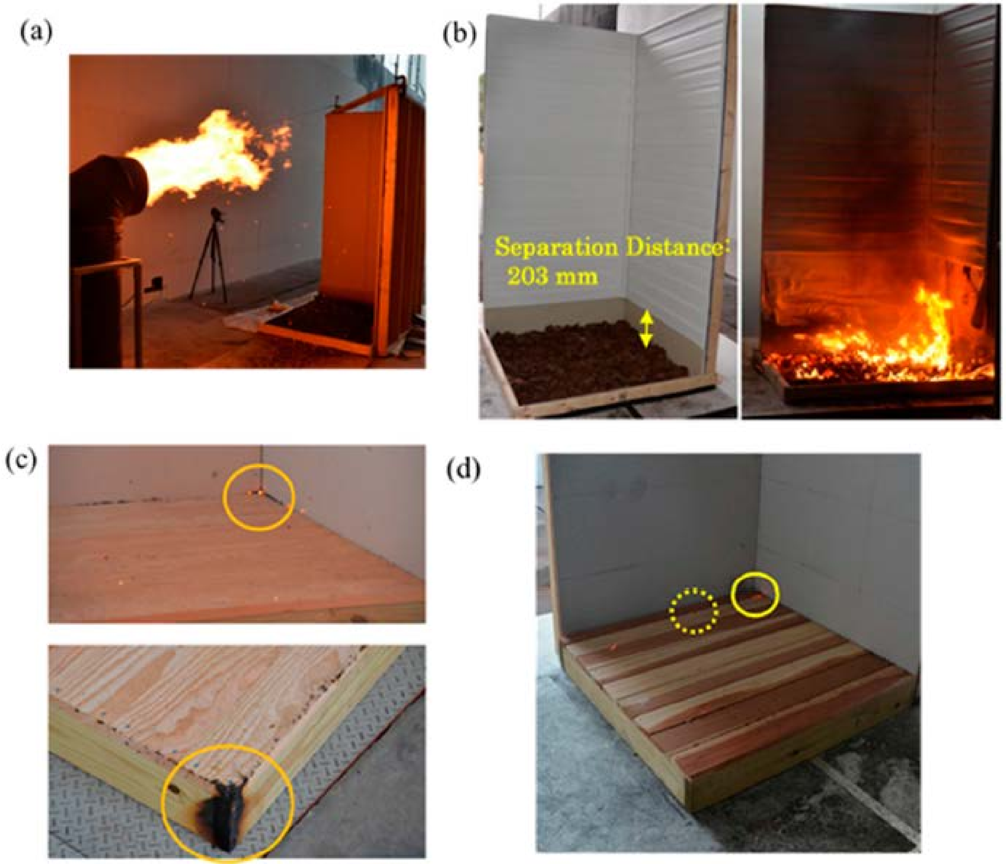




S.L. Manzello et al., *Fire Safety Journal*, 2010

Dangers of Various Materials to Firebrand Exposure

Comprehensive Review of Various Experimental Series



Combustible Element Investigated	Parameter		Other Information	Wind Speed [m/s]	Reference
Shredded hardwood mulch	FMC	oven-dry, wet (9–40%) and super wet (over 40%)	Mulch dimension (see Figure 1e)	6, 8	[30]
Shredded hardwood mulch, Japanese cypress chip mulch, Pine bark nugget mulch	Separation Distance between mulch surface to sidings	102 mm and 203 mm	Mulch was oven-dry, mulch dimension (see Figure 1e)	8	[31]
Fencing assembly	Fence/mulch configuration	See Figure 1a–d	Mulch was oven-dry FMC of fencing assembly was approximately 10%	8	[29]
Decking assembly	Decking materials	Douglas-fir, Redwood, Cedar	Decking dimension (see Figure 1e) Gap 5 mm FMC of decking assemblies was around 10% (6 m/s) and 12% (8 m/s)	6, 8	[26,27]
Decking assembly	Gap between deck boards Decking materials	Douglas-fir (0 mm), Redwood (0 mm and 10 mm), Cedar (0 mm)	Decking dimension (see Figure 1e) FMC of decking assemblies was from 10% to 16%	8	[28]

S. Suzuki and S.L. Manzello, Sustainability, 2021

Firebrand Shower Ignition

New studies needed under wind!

We had visitors (trees that is) from Oregon



1.5 m Noble-fir
3 m/s
Firebrand Showers Capable to Ignite Vegetation

S.L. Manzello, S. Suzuki
12th Joint US Combustion Meeting, 2021

Gaseous and Particulate Formation from WUI Fires

Gaseous and Particulate Formation from WUI Fires

- Quantifying emissions from wildland fires have focused on the premise of developing emissions factors (EF)
- EFs determine the ratio of a particular species emitted based on a known amount of combusted mass
- EFs are reported for CO_2, CO, and $PM_{2.5}$
- The range of reported EF does not consider the combustion of structural fuels of importance to WUI fires, urban fires, and informal settlement fires
- The combustion process from structures, automobiles, and other human-made materials (i.e. plastics) only add to the multitude of emissions

S. Suzuki and S.L. Manzello, *58th Japanese Combustion Symposium*, 2020

Gaseous and Particulate Formation from WUI Fires

- Another limitation - most of EF for vegetative fuels are based on prescribed burning, or controlled outdoor burns conducted for various fire management purposes
- Prescribed burning has the advantage that it is conducted over realistic scales, but the fire exposure conditions do not mimic what is seen in actual large outdoor fires
- Sheer intensity and scale of actual fire events cannot be conducted safely, these prescribed fires are undertaken, for example, under low ambient wind conditions
- Laboratory-scale experiments do not mimic actual large outdoor fire events as well
- Yet advantage is that laboratory-scales provide opportunities to benchmark and develop new and improved diagnostic methods that may lead to improved fundamental understanding of the physics of these emissions processes

S. Suzuki and S.L. Manzello, *58th Japanese Combustion Symposium*, 2020

Little Fundamental Understanding of Soot Processes from Engineered Materials in WUI Communities

Engineered Wood Products

- The use of engineered wood products has been common worldwide
- There has been a dramatic shift to the use of OSB; historically plywood was the dominant material used
- The reasons - economic in nature; OSB is manufactured from smaller trees as compared to plywood and consists primarily of wood fragments
- Similar trends have been seen in Japan

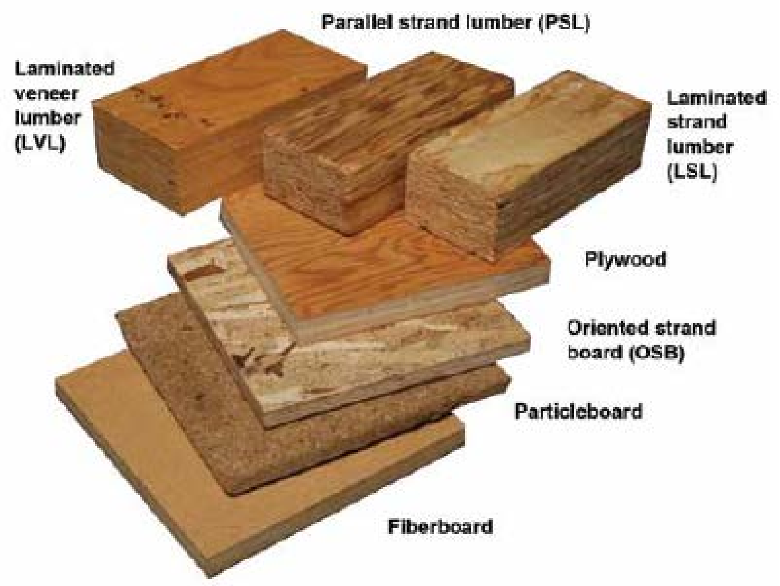


Figure 11–4. Examples of various composite products. From top left, clockwise: LVL, PSL, LSL, plywood, OSB, particleboard, and fiberboard.

Stark et al., 2011

Plastics

Cribs contained wood, gypsum, and plastic

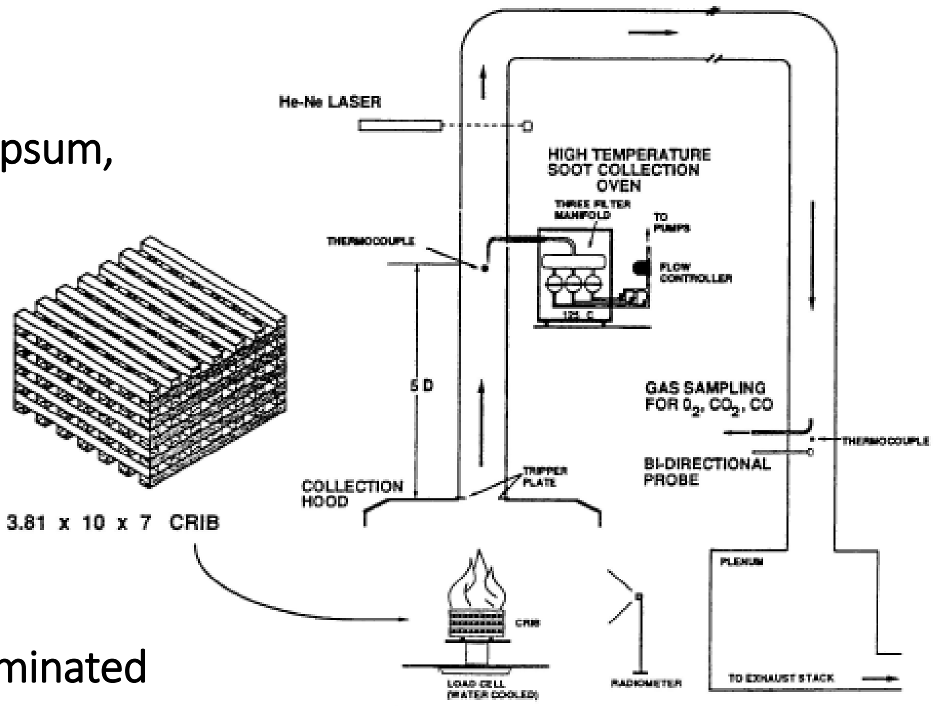


Fig. 1. Large scale burn facility and 3.81 × 10 × 7 crib.

Small amount of plastic dominated soot yields

No measurement of soot morphology

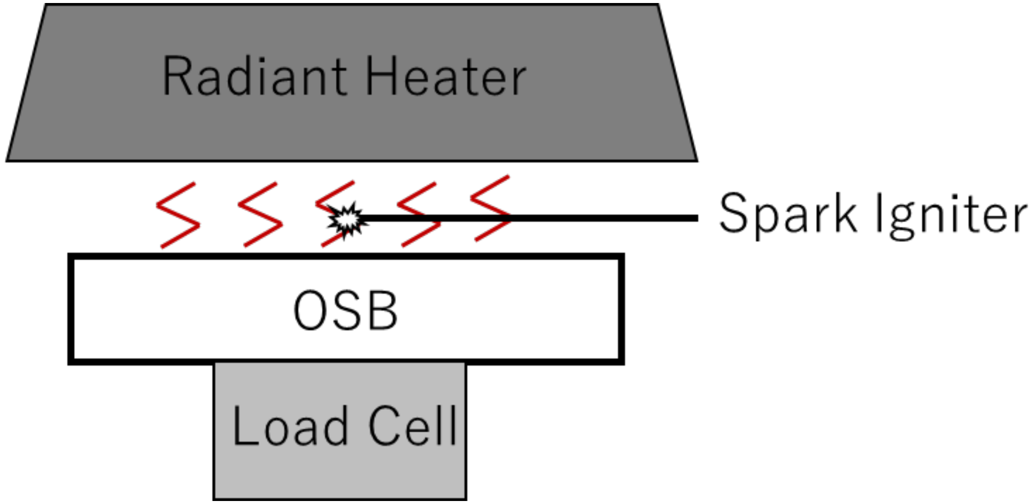
OSB contains wood as well as glue

What is the effect?

Soot yields determined from wood cribs (Atmospheric Environment 25 A, 1991)

Soot Formation from Engineered Building Materials

- Samples of OSB were cut into sizes of 100 mm by 100 mm
- As commercial samples of OSB was used - thickness fixed at 11 mm
- Initial proof of concept study - radiant heat flux of 50 kW/m^2 was applied and spark was operated continuously
- Under these conditions - OSB samples ignited with sustained flaming ignition within 10 sec

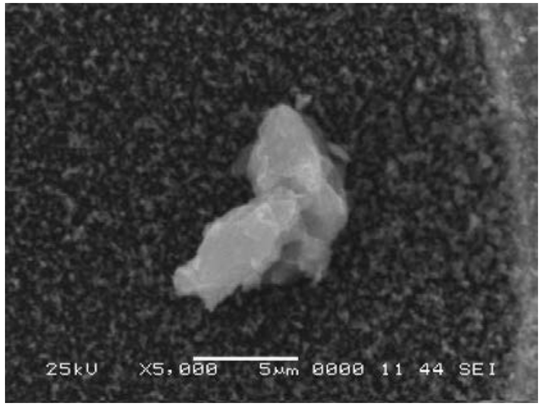


S. Suzuki and S.L. Manzello, *58th Japanese Combustion Symposium*, 2020

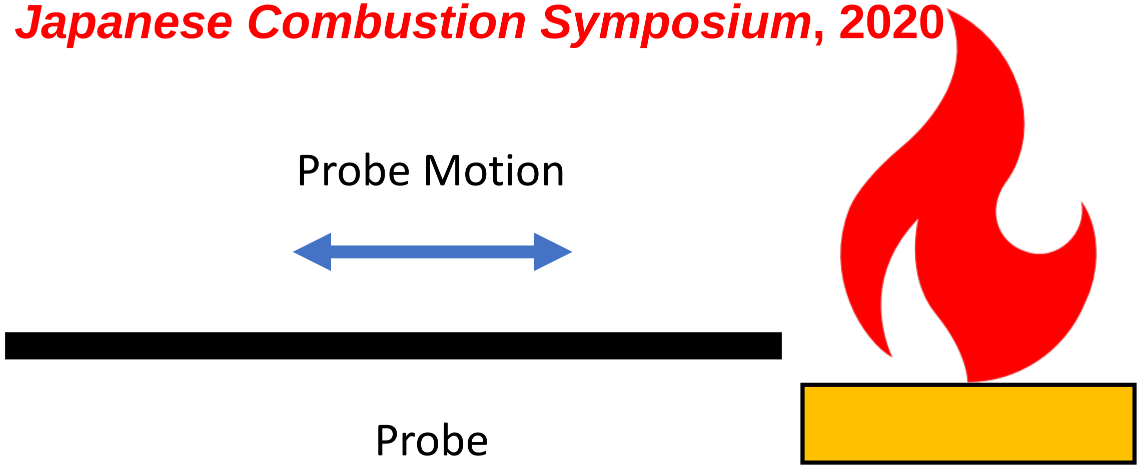
Thermophoretic Sampling
Scanning Electron Microscopy (SEM)

- The well-known principle of thermophoretic sampling was used
- In the presence of a temperature gradient, the hot soot particles will be collected using cold grids that may be used for Scanning Electron Microscopy (SEM) and Transmission Electron Microscopy (TEM) analysis
- SEM was used a first step to image the overall structure of the particulate samples
- In this study, the sampling time used was varied from 1 sec, to 2 sec, to 3 sec
- The grid was inserted in the flame for these times

S. Suzuki and S.L. Manzello, *58th Japanese Combustion Symposium*, 2020



SEM Image Soot Agglomerate Grid Insertion Time 1 sec



Some Emissions Research Needs

- Combustion community has developed a suite of laser diagnostic capabilities to quantify gaseous and particulate emissions from traditional combustion sources, such as engines and gas turbines
- Diagnostic methodologies may be used to quantify particulate emissions from a range of fuel types seen in WUI fires
- Dearth of measurements on the details of particulate sizes from the combustion processes of both vegetative, structural fuels, and other human-made fuel types
- Detailed measurements could be conducted for particle size distributions
- To date, emission measurements from mainly vegetative fuels have been performed using only bulk filter collection techniques, and the full suite of spatially and temporally resolved diagnostics developed by the combustion community remain largely unapplied
- Informative to investigate the morphology of the particulate matter to understand its chemical composition and nature of the particles

S.L. Manzello S. Suzuki, 2021

Thoughts on Standardization Needs

ISO TC92/WG14
Large Outdoor Fires and the Built Environment

- ISO TC92/Task Group (TG) 03 (Large Outdoor Fires and the Built Environment) was formed to advise ISO TC92 on a path forward for the topic *Large Outdoor Fires and the Built Environment*
- As result of ISOTC92/TG03 activities, including a workshop at the ISO TC92 Plenary meetings in Delft on October 2018, and a subsequent special section of papers from this workshop guest edited in the journal *Fire Technology*, the task group proposed the formation of a new working group (WG) under TC92
- This new working group (WG), entitled ISO TC92/WG14 (Large Outdoor Fires and the Built Environment) has been formally approved with Manzello as convener

ISO Standard Firebrand Generator (ISO/AWI 6021)

Added to ISO TC92 Work Program by Global Ballot

We have three years to develop into global standard

Approved on NIST Dragon Design

ISO

Form 4: New Work Item Proposal

Circulation date: 2020-10-09 Closing date for voting: 2021-01-04	Reference number: ISO/NP 6021 (to be given by Central Secretariat) ISO/TC 92 N 1291
Proposer (e.g. ISO member body or A liaison organization) ISO/TC 92	
Secretariat BSI	

A proposal for a new work item within the scope of an existing committee shall be submitted to the secretariat of that committee with a copy to the Central Secretariat and, in the case of a subcommittee, a copy to the secretariat of the parent technical committee. Proposals not within the scope of an existing committee shall be submitted to the secretariat of the ISO Technical Management Board.

The proposer of a new work item may be a member body of ISO, the secretariat itself, another technical committee or subcommittee, an organization in liaison, the Technical Management Board or one of the advisory groups, or the Secretary-General.

The proposal will be circulated to the P-members of the technical committee or subcommittee for voting, and to the O-members for information.

☒ The proposer has considered the guidance given in the Annex C during the preparation of the NP.

Resource availability

☒ There are resources available to allow the development of the project to start immediately after project approval (e.g. project leader, related WG or committee work programme)

Note: If resources are not available, it is recommended that the project be first registered as a preliminary work item (a Form 4 is not required for this) and when the development can start, Form 4 should be completed to initiate the NP ballot.

Proposal (to be completed by the proposer)

Fire Safety Journal 91 (2017) 784–790

Contents lists available at ScienceDirect

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Fire Safety Journal

journal homepage: www.elsevier.com/locate/firesaf

FIRE SAFETY JOURNAL

IAFSS 12th Symposium 2017

Experiments to provide the scientific-basis for laboratory standard test methods for firebrand exposure

CrossMark

Sayaka Suzuki[a], Samuel L. Manzello[b,*]

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[b] Fire Research Division, Engineering Laboratory National Institute of Standards and Technology (NIST), Gaithersburg, MD 20899-8662, USA

Manzello
Project Leader
Convener

iso.org/committee/50492/x/catalogue/p/0/u/1/w/0/d/0

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ISO/TC 92/SC 4	Fire safety engineering	28	12

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Global Overview of Different Approaches to Standardization

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ISO Technical Report (TR)-24188

ISO TC 92/WG14

Secretariat: ANSI (United States)

Large Outdoor Fires and the Built Environment: Global Overview of Different Approaches to Standardization

DRAFT

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To help you, this guide on writing standards was produced by the ISO/TMB and is available at https://www.iso.org/iso/how-to-write-standards.pdf

A model manuscript of a draft International Standard (known as "The Rice Model") is available at https://www.iso.org/iso/model_document-rice_model.pdf

Manzello – Project Leader
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Thank you for time!

Fire science can be quite interesting!