Wildland-Urban Interface (WUI) Fires: The Next Frontier for Combustion Science During Changes in Climate

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July 20th, 2024

ISF-7 Workshop, Milan, Italy 2024

Special Thanks

Dr. Christopher Shaddix
Combustion Research Facility
Sandia National Laboratories, USA

Prof. Gus Nathan
Department of Mechanical Engineering
The University of Adelaide

Excited to Introduce WUI fires to ISF 7 participants!

We Cannot Look to Future Ignoring Past

Wildland-Urban Interface Fires

Building Resilient Communities of the Future

Why WUI Fires Present Unique Challenges?

WUI Fire Science Remains Elusive

How ISF Initiative May Help?

We Cannot Look to Future Ignoring the Past

Great Meireki Fire – Before USA Existed

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

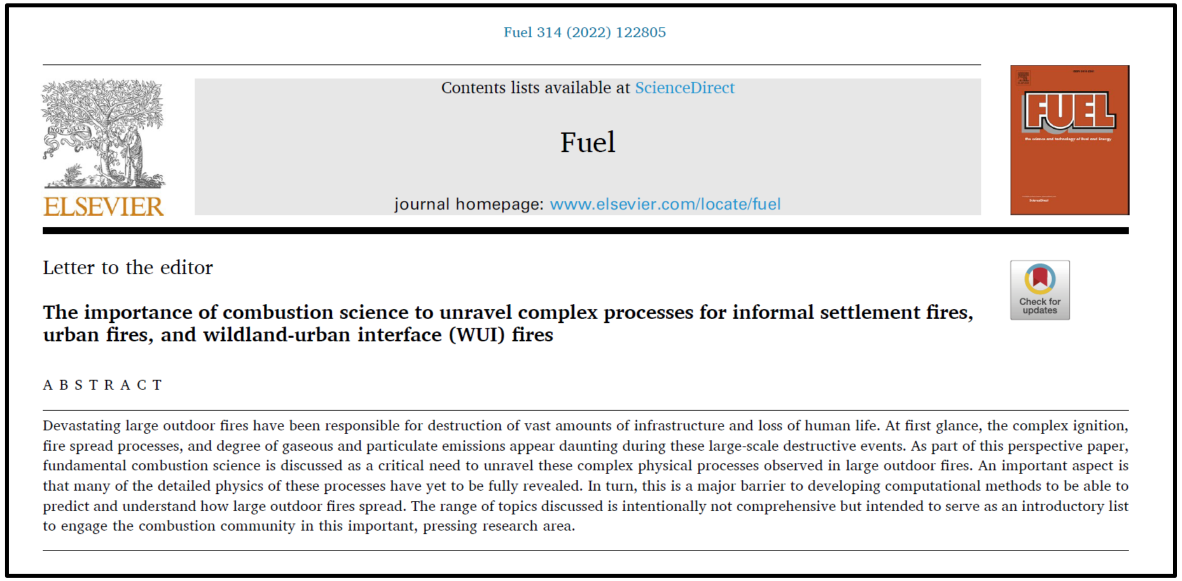
Meireki Fire (1657) Wikipedia

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



Fuel 314 (2022) 122805

Contents lists available at ScienceDirect

Fuel

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

Letter to the editor

The importance of combustion science to unravel complex processes for informal settlement fires, urban fires, and wildland-urban interface (WUI) fires

A B S T R A C T

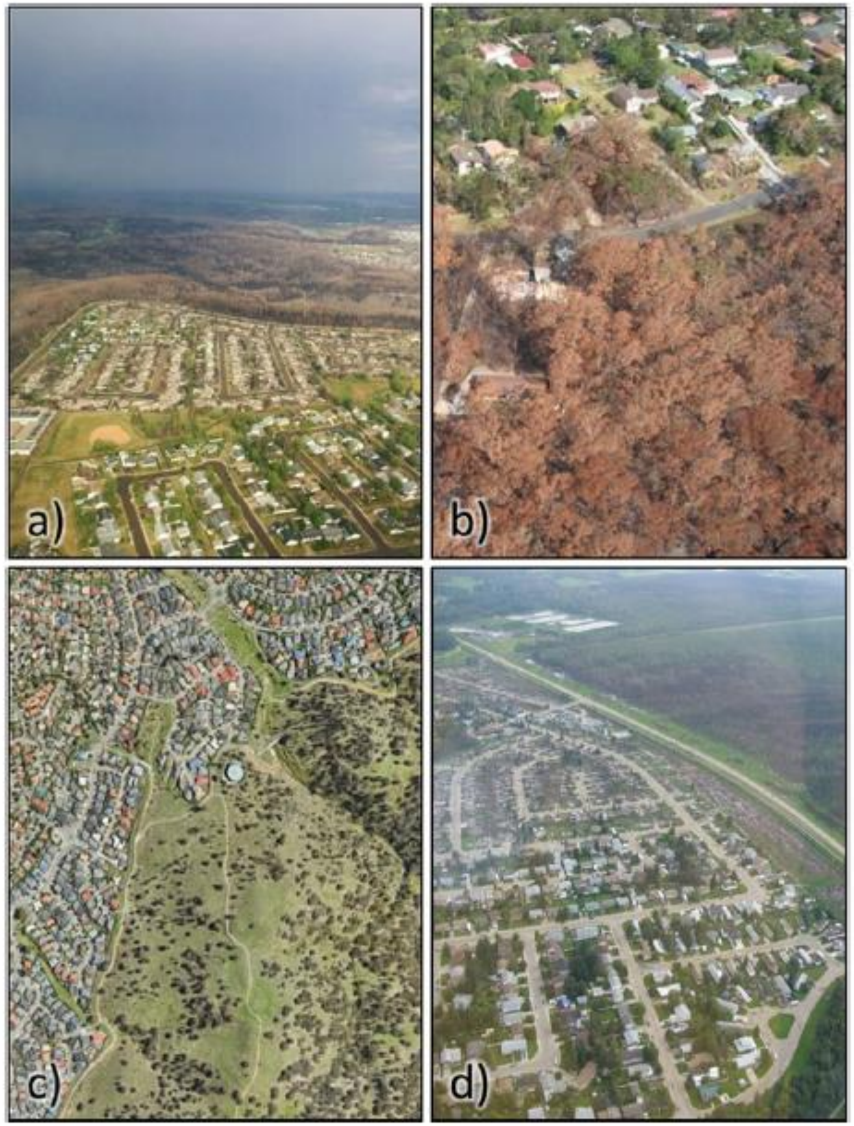
Devastating large outdoor fires have been responsible for destruction of vast amounts of infrastructure and loss of human life. At first glance, the complex ignition, fire spread processes, and degree of gaseous and particulate emissions appear daunting during these large-scale destructive events. As part of this perspective paper, fundamental combustion science is discussed as a critical need to unravel these complex physical processes observed in large outdoor fires. An important aspect is that many of the detailed physics of these processes have yet to be fully revealed. In turn, this is a major barrier to developing computational methods to be able to predict and understand how large outdoor fires spread. The range of topics discussed is intentionally not comprehensive but intended to serve as an introductory list to engage the combustion community in this important, pressing research area.

S.L. Manzello and S. Suzuki, *Fuel* 2022

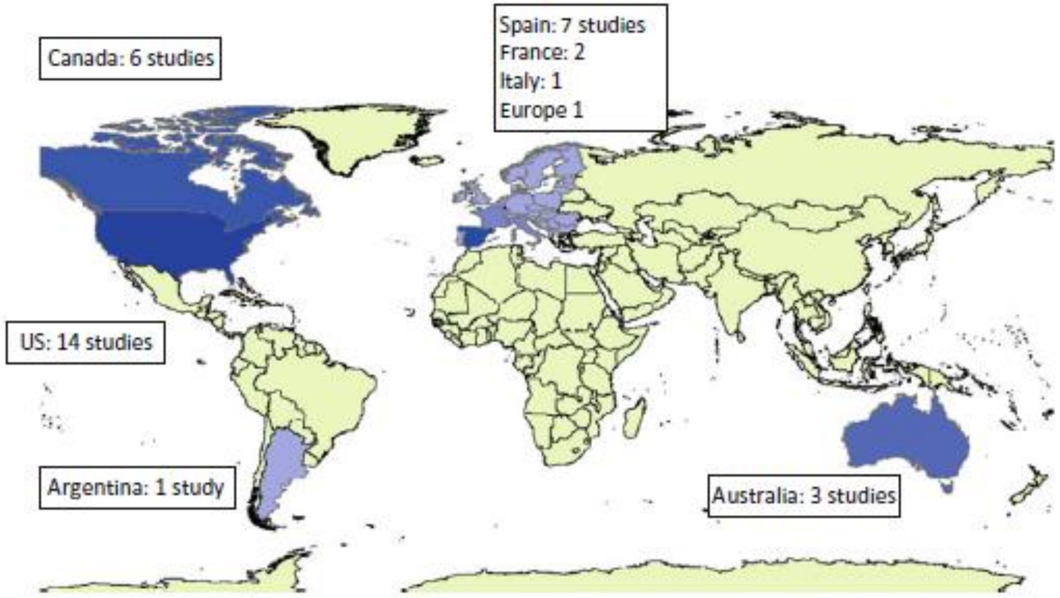
Flame Spread Processes Similar

Wildland-Urban Interface (WUI) Fires

Wildland-Urban Interface (WUI) Fires



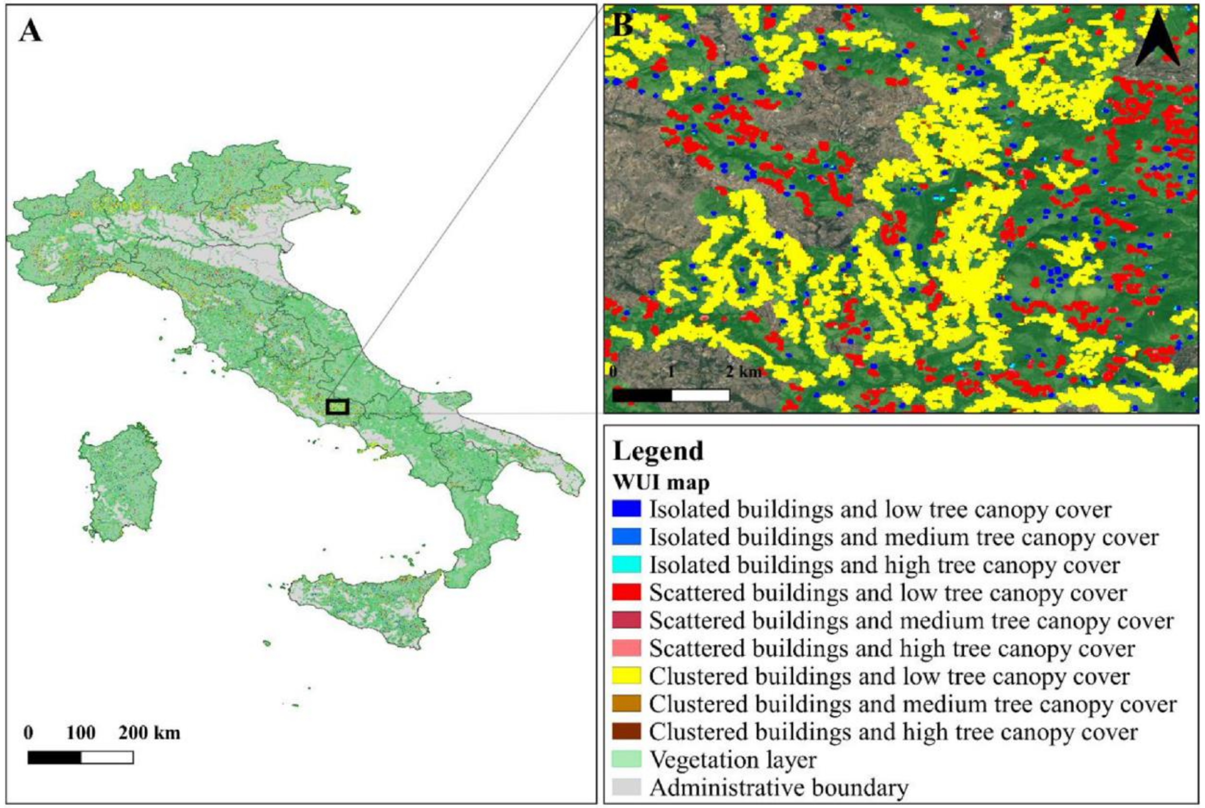
Wildland-Urban Interface, Fig. 1 Examples of interface WUI in (**a**) Fort McMurray, Alberta, Canada (Canadian Forest Service/Wiens B.); (**b**) Sydney, Australia (CSIRO/McArthur N.); (**c**) Australia (Google Maps); and (**d**) Slave Lake, Alberta, Canada (University of Alberta/Flannigan M.)

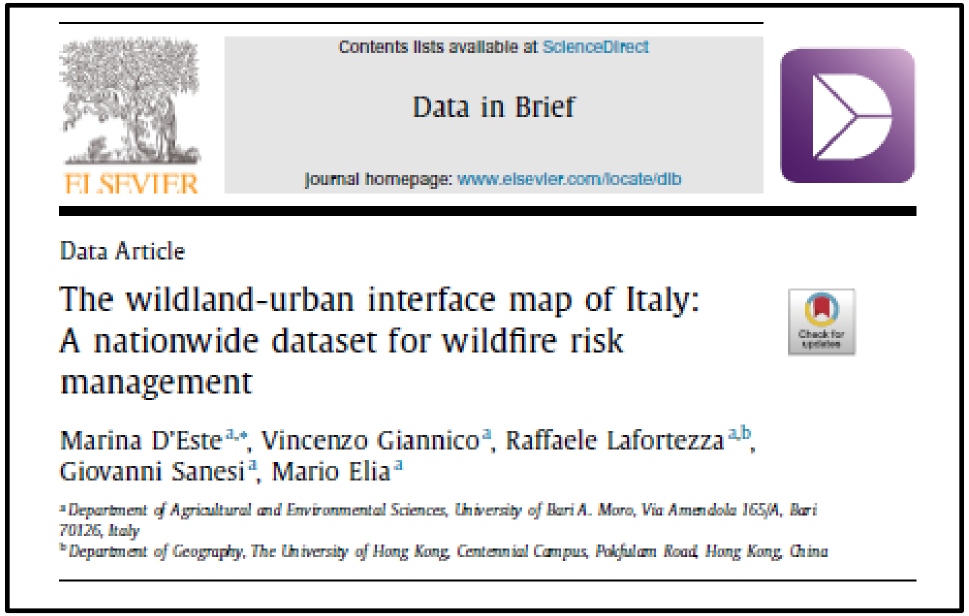


Wildland-Urban Interface, Fig. 4 Number of WUI mapping studies across the world, summarized by country (non-exhaustive numbers)

Johnston, L., Blanchi, R., Jappiot, M. (2019). Wildland-Urban Interface. In: Manzello, S.L. (eds) Encyclopedia of Wildfires and Wildland-Urban Interface (WUI) Fires. Springer, Cham. https://doi.org/10.1007/978-3-319-51727-8_130-1

Wildland-Urban Interface (WUI) Fires





Contents lists available at ScienceDirect

Data in Brief

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

ELSEVIER

Data Article

The wildland-urban interface map of Italy: A nationwide dataset for wildfire risk management

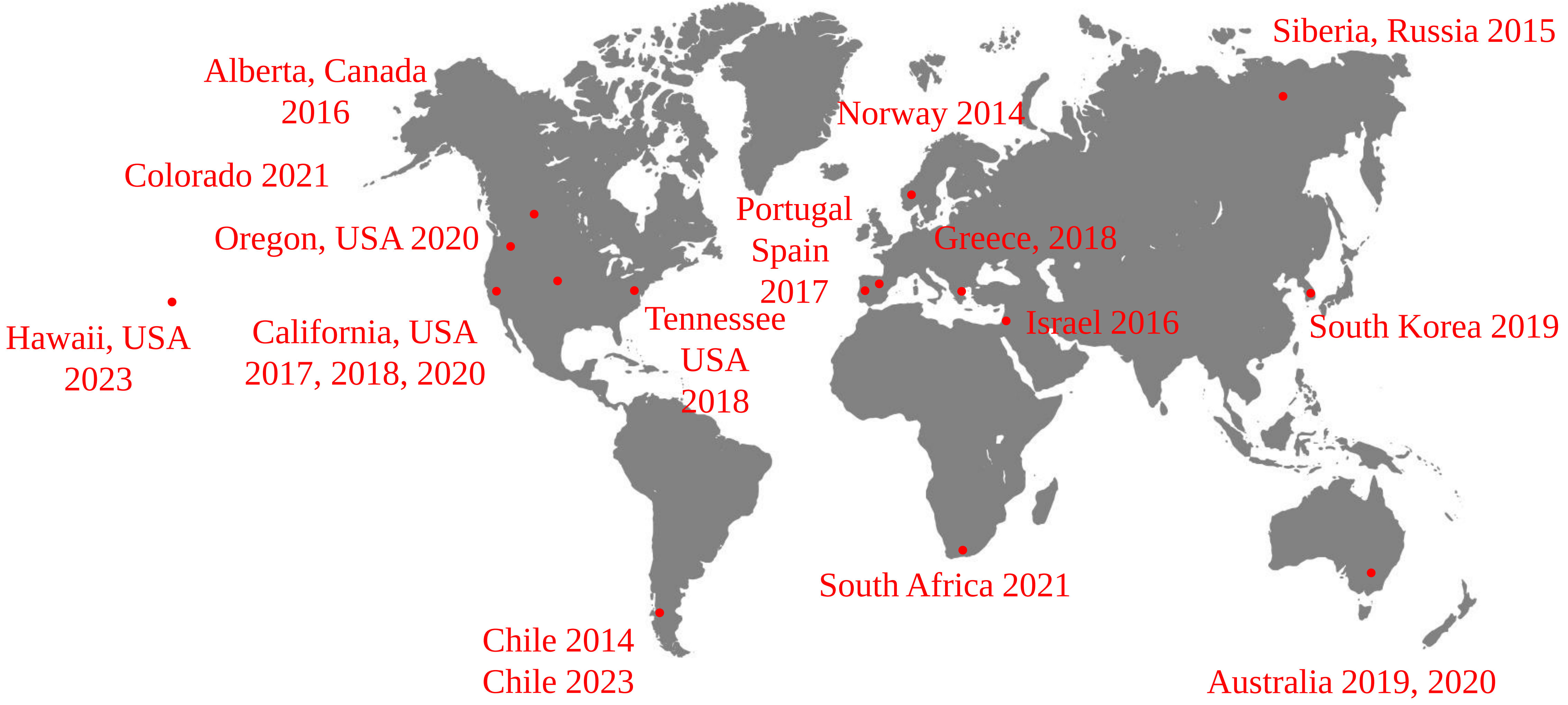
Marina D'Este[a,*], Vincenzo Giannico[a], Raffaele Lafortezza[a,b], Giovanni Sanesi[a], Mario Elia[a]

[a] Department of Agricultural and Environmental Sciences, University of Bari A. Moro, Via Amendola 165/A, Bari 70126, Italy

[b] Department of Geography, The University of Hong Kong, Centennial Campus, Pokfulam Road, Hong Kong, China

More than half of the total area of Italy is occupied by interface areas!

WUI Fires Global Problem



Only a Matter of Time For Your Country?

WUI Fires in Hawaii

Maui 2023

Due to climate change, will WUI fires increase in your country?

Maui fires in pics: Aerial photos show extent of destruction caused by Hawaii wildfires | The Independent

Homes and buildings on the waterfront in Lahaina burned to the ground *(AFP via Getty Images)*

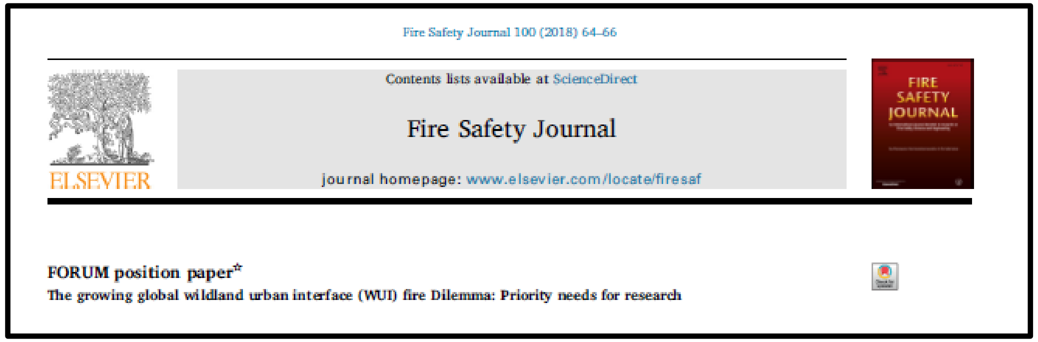
Largest U.S. Fire Loss Incidents (NFPA)

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	2018	$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	2015	$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 – Hawaii not included!

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


Fire Safety Journal 100 (2018) 64–66

Contents lists available at ScienceDirect

Fire Safety Journal

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

ELSEVIER

FIRE SAFETY JOURNAL

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

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

Environmental issues related to both suppressing WUI fires, as well the exposure to products of combustion from WUI fires need to be addressed. Research needs in this topic may be delineated as:

- Consequences to residents as well as fire responders from WUI fire and smoke exposures (acute, sub-acute, and long-term effects)
- WUI fires can generate significant amounts of greenhouse gases which exasperate climate change
- WUI fires release inhalable particulates that compromise the respiratory health of exposed population
- Run off during and post fires contaminate water quality
- Cascading damage can result from WUI fires including mudslides in subsequent years

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

Building Resilient Communities of the Future

Building Resilient Communities

2015ASTM E05 (Fire Standards) sponsored a workshop
to study wildland-urban interface (WUI) fire standards and codes issues

INTERNATIONAL
Standards Worldwide

2017 International Association for Fire Safety Science (IAFSS) also sponsored a workshop to look at large outdoor fires from a global perspective

THE INTERNATIONAL ASSOCIATION
FOR FIRE SAFETY SCIENCE

Creation of IAFSS LOF&BE

2017 ISO TC92 TG03 was setup with the intent to propose a path forward for the topic Large Outdoor Fires and the Built Environment for ISO TC92
This led to the establishment of ISO TC 92/WG14

Current WUI fire standards and codes are reflection of current (**or lack thereof**) science

ISO TC92/WG14 Team

France
Six (6) members

Germany
Two (2) members

Sweden
Two (2) members

USA
Three (3) members

China
Two (2) members

Netherlands
Two (2) members

Convener of ISO TC92/WG14
Samuel L. Manzello

Austria
One (1) member

Japan
Four (4) members

Korea
Two (2) members

United Kingdom
Two (2) members

Trinidad and Tobago
One (1) member

Hungary
One (1) member

Greece
One (1) member

Canada
Four (4) members

Australia
One (3) members

ISO TR 24188:2022

Global Overview of Different Approaches to Standardization

← ICS ← 13 ← 13.220 ← 13.220.01

ISO/TR 24188:2022

Large outdoor fires and the built environment — Global overview of different approaches to standardization

Abstract

Preview

This document provides a review of global testing methodologies related to the vulnerabilities of buildings from large outdoor fire exposures. It also provides information on land use management practices. Some of the test methods outlined in this document have been developed in the context of building fires and extrapolated to external fire exposures.

General information

Status : Published	**Publication date** : 2022-06
Edition : 1	**Number of pages** : 19
Technical Committee : ISO/TC 92 Fire safety	
ICS : 13.220.01 Protection against fire in general	

SUSTAINABLE DEVELOPMENT GOALS

This standard contributes to the following Sustainable Development Goals:

9 15

Buy this standard

Format	Language
✓ PDF + ePub	English
Paper	English

CHF 118 Buy

ISO Standard Firebrand Generator (ISO 6021:2024)

<u>Published</u> International Standard March, 2024

Fire Safety Journal 91 (2017) 784–790

Contents lists available at ScienceDirect

Fire Safety Journal

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

IAFSS 12th Symposium 2017

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

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

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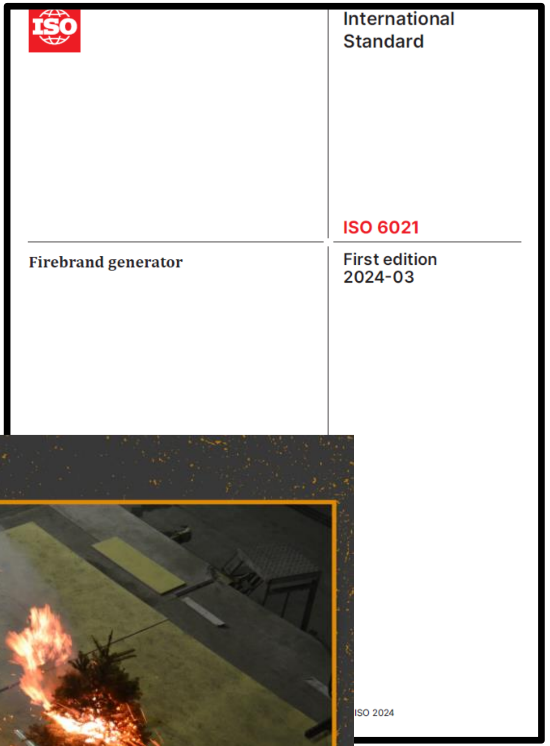
[b] Fire Research Division, Engineering Laboratory National Institute of Standards and Technology (NIST), Gaithersburg, MD 20899-8662, USA



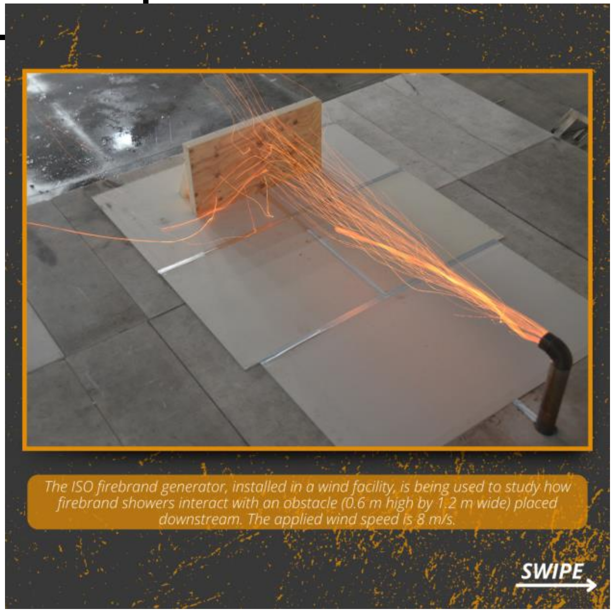
International Standard

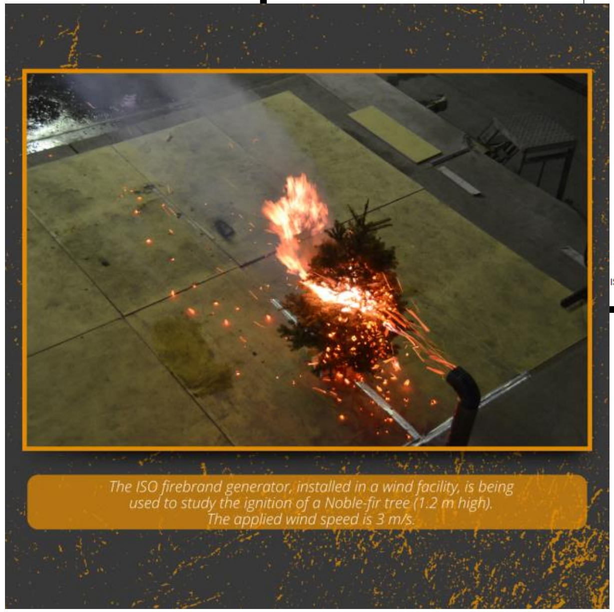
ISO 6021

Firebrand generator

First edition 2024-03

© ISO 2024





ISO Standardized Post-Fire Data Collection – NWIP Approved by Global Ballot

N 1424

ISO Form 6
RESULT OF VOTING ON NEW WORK ITEM PROPOSAL (NP)

Date: 2024-05-30	ISO/TC 92 N 1424
Title of TC/SC concerned: Fire safety	

Please attach the results and comments of the NP ballot from CIB to this form.

ISO/TC 92 **N 1424**	**Circulation** 2024-03-01	**Deadline** 2024-05-25
Title: **English title:** Standardized Post-Fire Data Collection Methods from Large Outdoor Fires **French title:** Titre manque		

RESULTS (detailed results are in the attached Annex)

The following criteria for acceptance have been met:

☒ Approval by a 2/3 majority of the voting P-members; and

☒ A commitment to participate actively in the development of the project by at least 4 P-members in committees with 16 or less P-members and at least 5 P-members in committees with 17 or more P-members (ISO/IEC Directives, Part 1 Clause 2.3.5), that have approved the proposal and nominated an expert.

☒ Justification statements have been checked (all negative votes must be accompanied by a statement justifying the decision, or they shall not be counted. See ISO/IEC Directives Part 1, Clause 2.3.4)

Appointed Project Leader of NWI
Also serve as convenor of ISO TC92/WG14

Standards Sectors About ISO News Taking part Store Search

← TC ← ISO/TC 92

ISO/AWI 24944

Standardized Post-Fire Data Collection Methods from Large Outdoor Fires

WORKING DRAFT

Under development
A working group has prepared a draft.

Abstract

Post-fire data collection for large outdoor fires will be reviewed based on available studies conducted for wildland-urban interface fires, urban fires, including post-earthquake urban fires, and informal settlement fires. These studies will be used to develop a standardized data collection methodology for large outdoor fires that may be used in the event of future large outdoor fire disasters. A standardized approach, at the international level, will is required to be able to assess and compare fire spread and damage across all these large outdoor fire types.

General information

Status : Under development
Stage : New project registered in TC/SC work programme [20.00]

Edition : 1

Technical Committee : ISO/TC 92

RSS updates

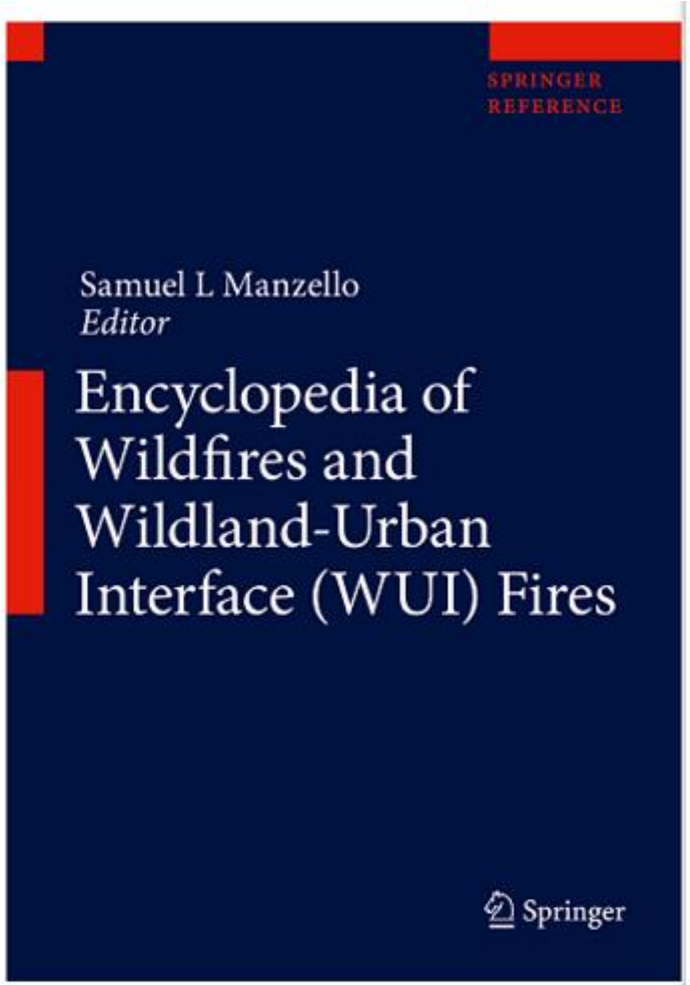
Why WUI Fires Present Unique Challenges?

Lack of Resources for Accepted Knowledge

Book Printed July 2020

Also a Living Edition!

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



SPRINGER NATURE

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

WUI Fire Science Remains Elusive

- 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 chemistry and 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, *Fuel* 2022

Structure Ignition Mechanisms in WUI Fires

Direct Flame Contact

Thermal Radiation

Firebrands

S.L. Manzello and S. Suzuki, *Frontiers in Mechanical Engineering* 2023

Challenge: Wide Range of Scales

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

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

Combustion Community Critical

Regional

Landscape

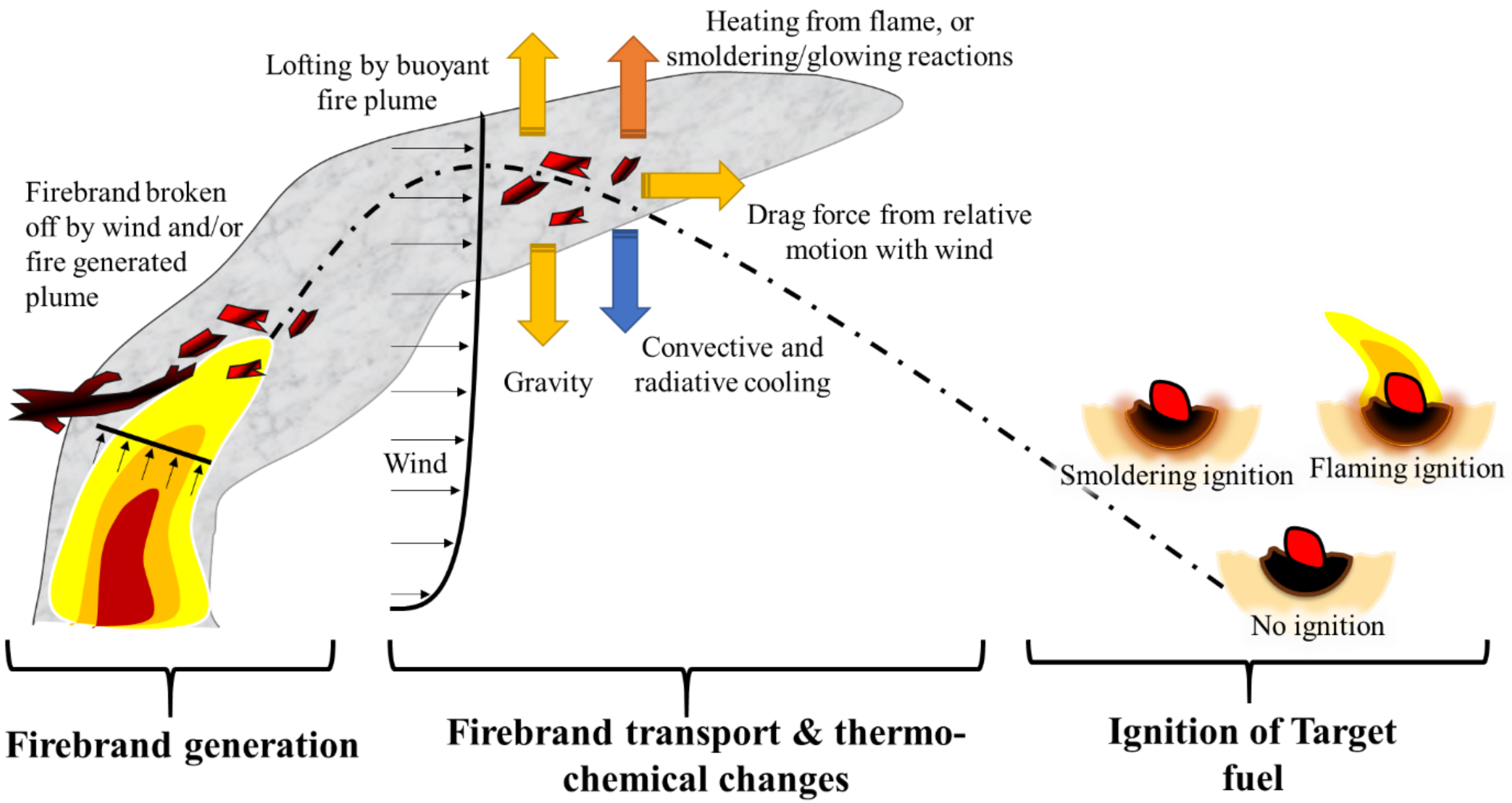
Photo by JOHN GIBBINS / Union-Tribune
Cedar Fire about to engulf the Scripps Ranch residential community

Community

Fuel elements

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

Firebrand Processes in WUI Fires



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

Wildland Fire Fighters

Smoldering Combustion

Flaming Combustion

McAllister S., Hollingsworth L.T., Apuzzo G., Grob I. (2020) Hand Tools, Chain Saw, Leaf Blower, and Backpack Pump. In: Manzello S.L. (eds) Encyclopedia of Wildfires and Wildland-Urban Interface (WUI) Fires. Springer, Cham. https://doi.org/10.1007/978-3-319-51727-8_265-1

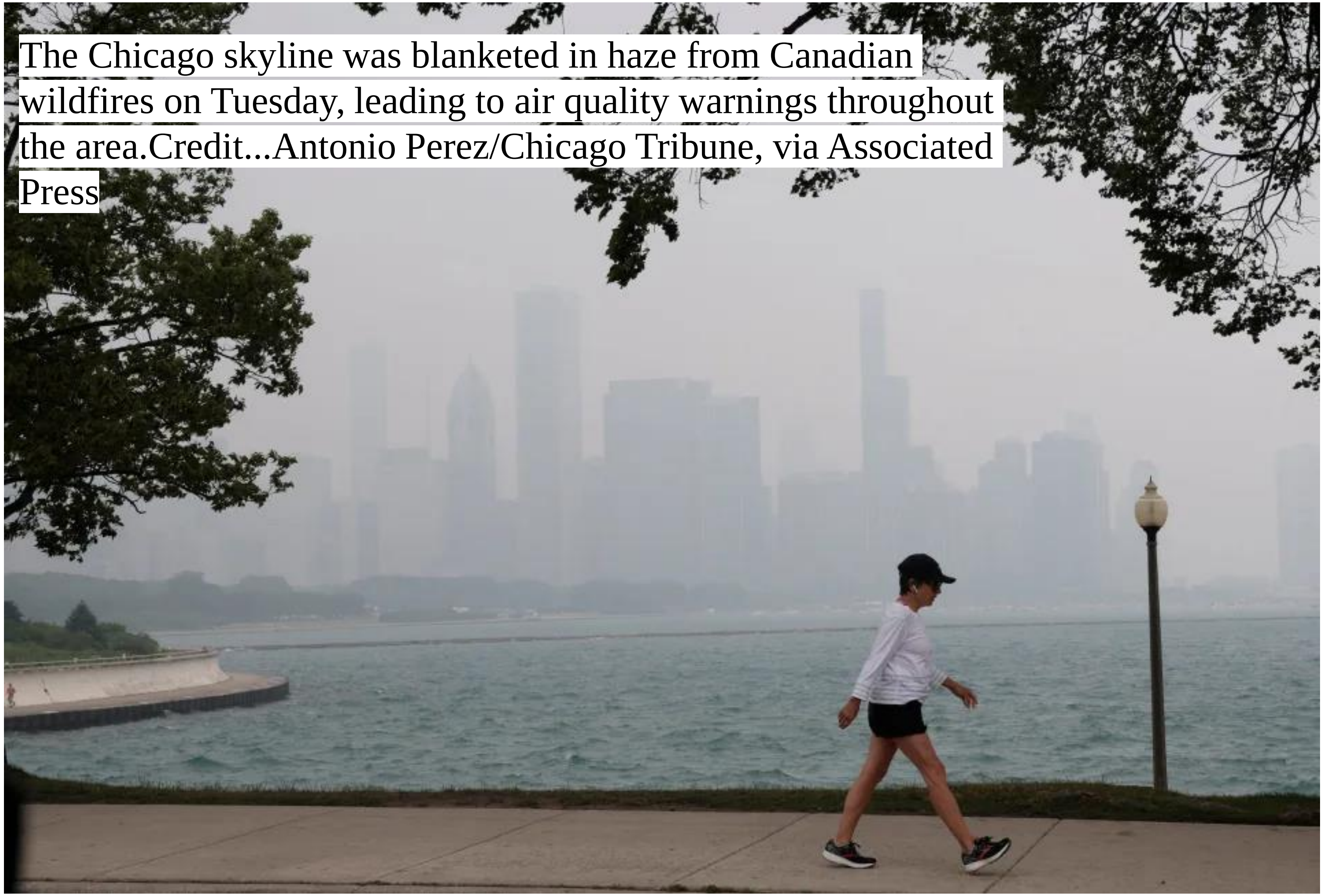
How ISF Initiative May Help?

Gaseous and Particulate Formation from WUI Fires

- Combustion products are known to cause extreme visibility issues and worries about health
- Globally, the combustion of vegetative fuels is thought to be the prime supplier of particulate emissions and the second most supplier of gaseous emissions (S.K. Akagi *et al*., Atmos. Chem. Phys., 2011)
- Particulate emissions from WUI fires in California in 2018 resulted in almost a complete closure of San Francisco

S.L. Manzello and S. Suzuki, *Fuel* 2022

Gaseous and Particulate Formation from WUI Fires



The Chicago skyline was blanketed in haze from Canadian wildfires on Tuesday, leading to air quality warnings throughout the area.Credit...Antonio Perez/Chicago Tribune, via Associated Press

Chicago, IL
USA

Summer 2023

Chicago and Midwest Air Quality Declines as Canada Wildfire Smoke Lingers - The New York Times (nytimes.com)

National Academies of Science, Engineering, and Medicine WUI Fire Workshop

The National Academies of SCIENCES ENGINEERING MEDICINE

NAE Workshop (June 2021)

- How do fires at the wildland-urban interface (WUI) differ from wildland fires?
- And how does understanding these differences change how we mitigate fires and their impacts on families and communities?
- The study *The Chemistry of Urban Wildfires* examined these questions.
- The specific goals of this workshop were to hear from leaders in the field in order to better understand:
  - The composition of residential materials and their combustion products
  - The sources of emissions and potential exposures
  - The chemical processes involved
  - Data gaps and research needs that remain

All talks and slides are on-line

Report published in 2022

The National Academies of SCIENCES ENGINEERING MEDICINE

Gaseous and Particulate Formation from WUI Fires

- Quantifying emissions from wildland fires have focused on the premise of developing emission factors (EF)
- EFs determine the ratio of a particular species emitted based on a known amount of combusted mass
- EFs are most often 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
- The combustion process from structures, automobiles, and other human-made materials (i.e. plastics) only add to the multitude of emissions

S.L. Manzello and S. Suzuki, *Fuel* 2022

Gaseous and Particulate Formation from WUI Fires

- Another limitation - most EF for vegetative fuels based on prescribed burning, or controlled outdoor burns conducted for various fire management purposes
- Prescribed burning conducted over realistic scales, but fire exposure conditions do not mimic 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

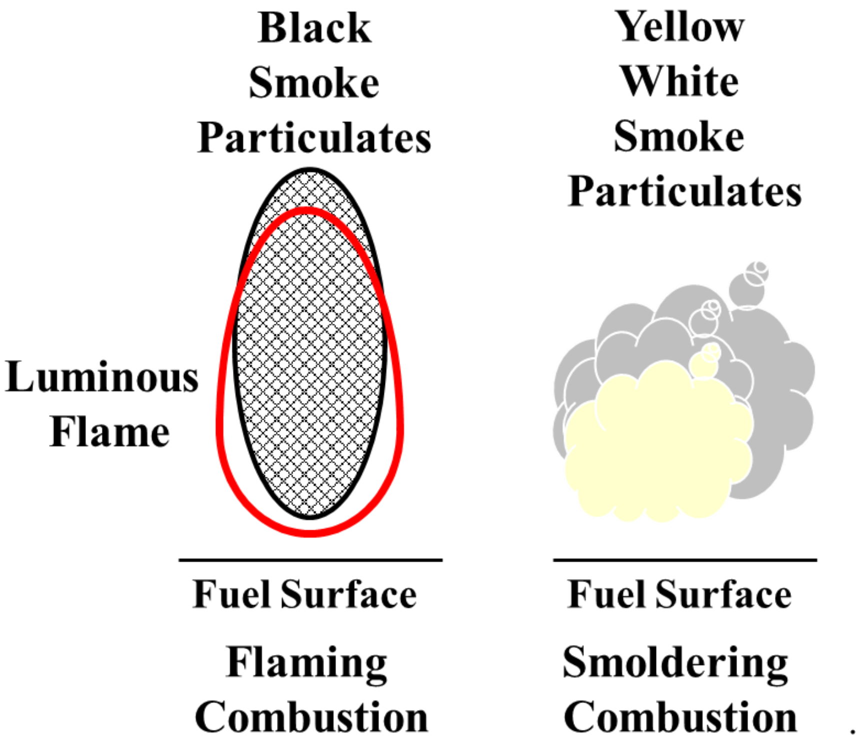
S.L. Manzello and S. Suzuki, *Fuel* 2022

Little Fundamental Understanding of PM Processes from Fuels in WUI Communities

Smoldering Combustion vs Flaming Combustion

Smoldering combustion is described as a propagating non-flaming exothermic surface reaction

Flaming combustion represents a fast, exothermic gas-phase reaction



S. Suzuki and S.L. Manzello, *IJWF* 2023

Results reported that for wildland fires or biomass that are in a state of smoldering combustion, the combustion processes are generally dominated by lower temperature regimes and therefore the collected particles have a liquid-like structure

For wildland fires or biomass that have higher temperatures, and are in a state of flaming combustion, these fires produce particles with more well-known fractal agglomerates and structure often seen in most soot formation studies in a state of flaming combustion

No information for fuels in WUI communities

One Example - 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 other countries

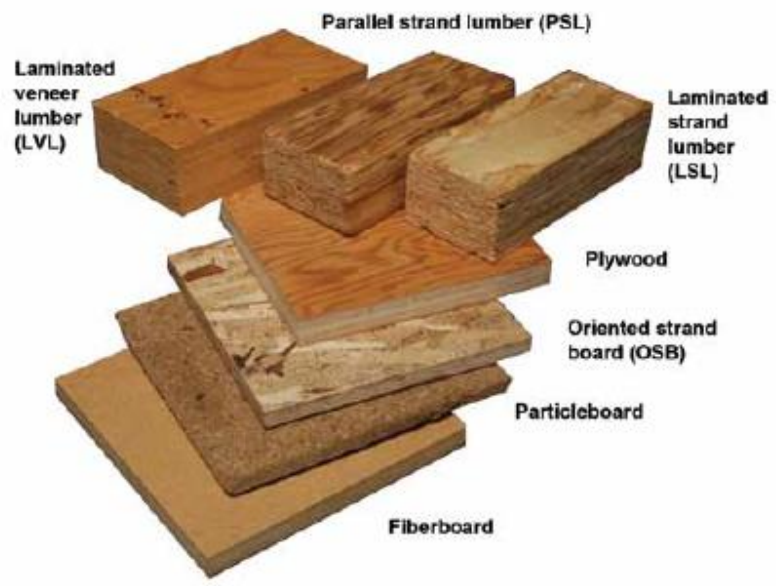


Figure 11–4. Examples of various composite products. From top left, clockwise: LVL, PSL, LSL, plywood, OSB, particleboard, and fiberboard.

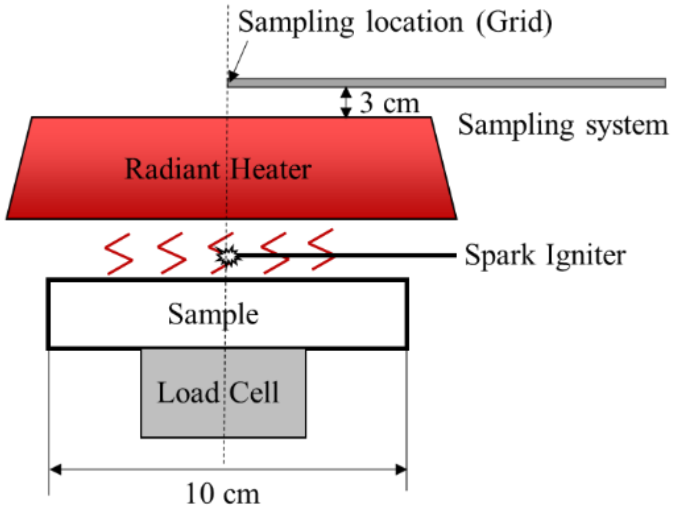
Stark *et al.*, 2011

Experimental Approach

- 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
- Noble-fir branches cut into 50 mm length
- Initial proof of concept study - radiant heat flux of 25 to 30 kW/m^2 was applied
- For flaming combustion spark was operated continuously
- For smoldering combustion spark was not activated

S. Suzuki and S.L. Manzello, *IJWF* 2023

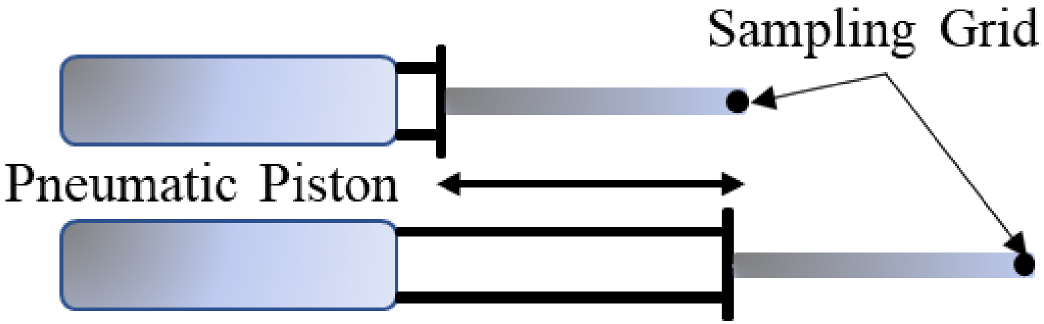
OSB



Noble-fir Branches

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 for these times

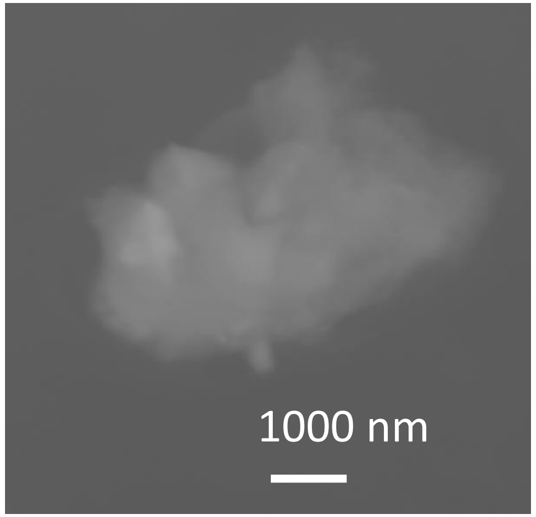


S. Suzuki and S.L. Manzello, *IJWF* 2023

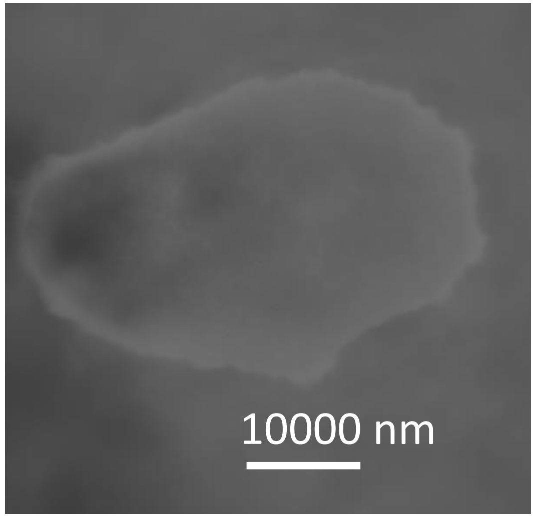
Ignited OSB Sample Flaming Combustion

Smoldering Combustion

Noble-fir

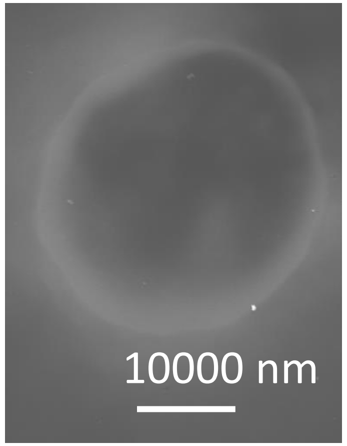


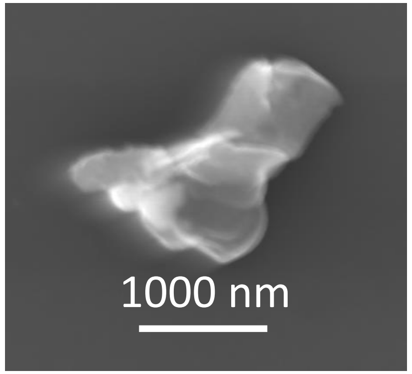
SEM images of liquid like particles collected from Noble-fir branches in a state of smoldering combustion (25 kW/m^2)

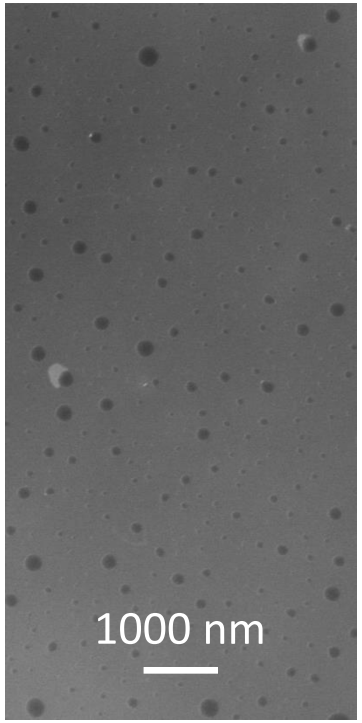


S. Suzuki and S.L. Manzello, *IJWF* 2023

OSB







SEM image of liquid like particles collected from OSB in a state of smoldering combustion (25 kW/ m^2)

Second Example: Plastics

Cribs contained wood, gypsum, and plastic

Small amount of plastic dominated soot yields

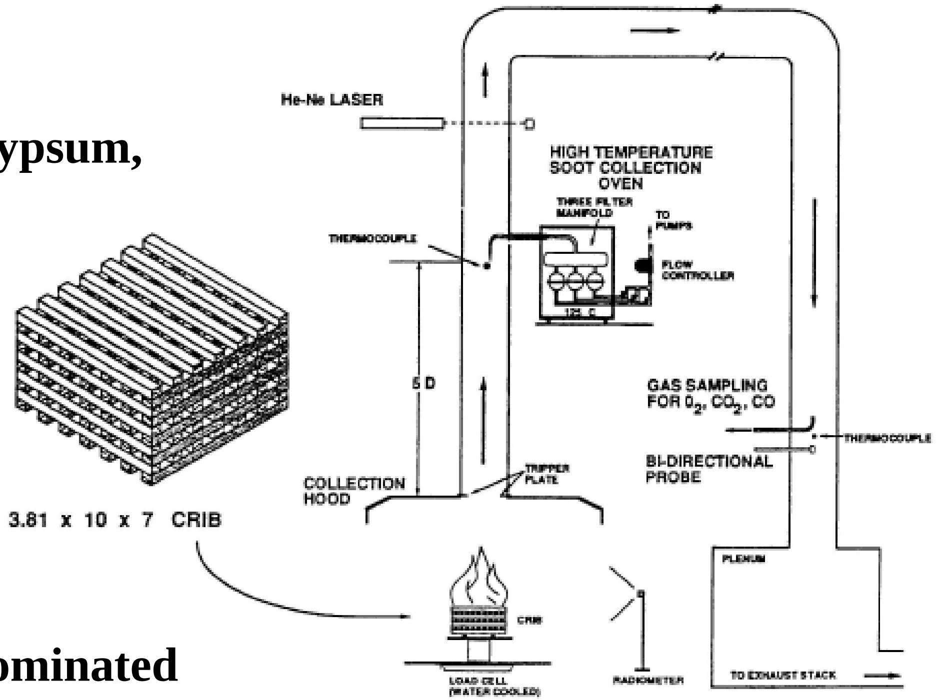


Fig. 1. Large scale burn facility and 3.81 × 10 × 7 crib.

No measurement of soot morphology

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

Third Example:Lithium Ion Batteries (LiB)

- Due to increasing concerns of climate change and associated global warming, the adoption of electric vehicles (EV) has been increasing at a rapid pace
- Changes have been further pressured by various regulations proposed to phase out internal combustion engines in passenger vehicles
- Electric Vehicles (EV) contain vast amount of LiB cells
- Thermal runaway of LiB battery cells is studied much recently
- There is little or no understanding regarding the emissions generated in the event EV vehicles are destroyed during large outdoor fire disasters or even if there a fire inside a home or building containing EV vehicles

Vehicles after 2023 Hawaii WUI Fires

Maui fire death toll rises to 93 as officials warn scale of losses not yet known | Guernsey Press

Vehicles destroyed by wildfires in Lahaina (Stephen Lam/San Francisco Chronicle/AP)

S.L. Manzello *et al.*, ICFD Conference, Sendai, Japan 2023

Summary

- Combustion science needed to address global WUI fire problem
- Members of the ISF community are needed!
  - **WUI fire problem too complex to continue down current path**
  - **ISF community – come up with targeted experimental setup to delve into the chemistry and physics of WUI fuels**