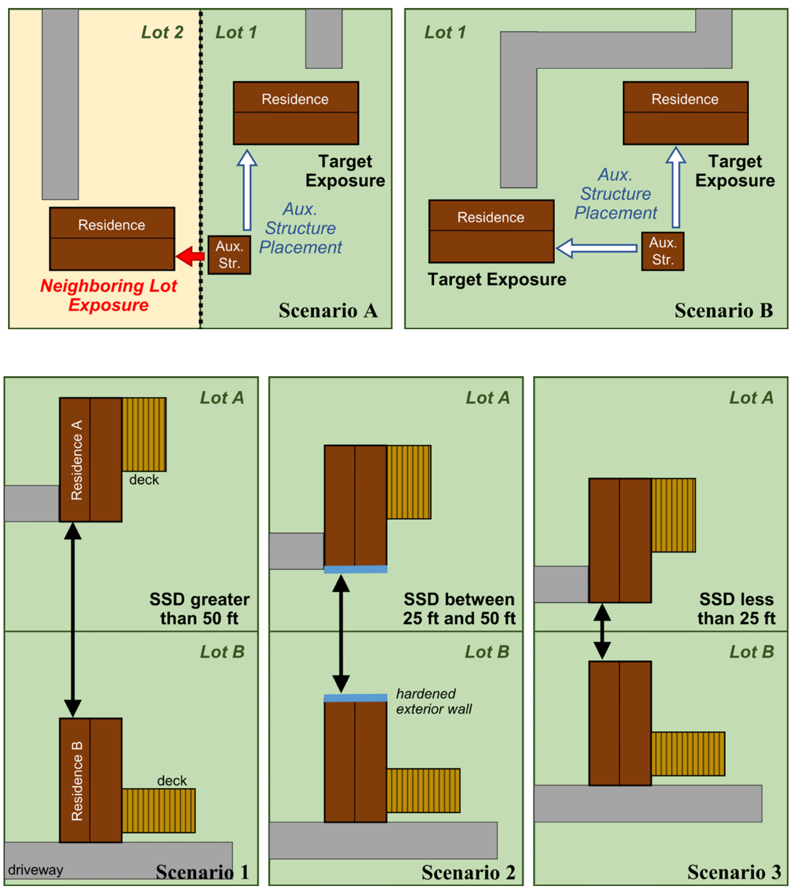
NIST Technical Note 2205

WUI Structure/Parcel/Community Fire Hazard Mitigation Methodology



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National Institute of
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Abstract

In the last twenty years, wildland-urban interface (WUI) fires have grown in severity and size. The structures destroyed by WUI fires have devastated entire communities and have cost billions of dollars while significantly impacting the social fabric and economic well-being of entire regions. Structure losses are attributed to exposures from both embers (firebrands) and fire (radiation and/or convection). As structure losses continue to increase, there is a growing need for a comprehensive hazard assessment and mitigation methodology to harden appropriate structures and parcels effectively and efficiently against ember and fire exposures. To address this need, the National Institute of Standards and Technology (NIST), the California Department of Forestry and Fire Protection (CAL FIRE), and the Insurance Institute for Business & Home Safety (IBHS) embarked on a sixteen-month collaborative effort, culminating in this Hazard Mitigation Methodology (HMM).

The HMM provides an implementable path forward by considering the spatial relationships between fuels, exposures, and hardening at the structure and parcel levels. The HMM demonstrates how complex structure hardening is, and how and why hazards associated with both fire and ember exposures need to be mitigated. By describing the relationships between exposure and hardening within the methodology, HMM highlights situations where structure hardening does not provide sufficient protection in the absence of parcel hardening. The HMM also addresses housing density, structure separation distance, and parcel layouts. The methodology was explicitly designed to address the current building stock, i.e., to solve retrofit challenges, and efforts were made to limit retrofit expenses. While the methodology was developed primarily for retrofits, the presented strategy can also be applied to new construction.

This science-based methodology uses the knowledge collected from post-fire field observations spanning a dozen years and tens of thousands of hours of field data integration and analysis. Additionally, the HMM utilizes the latest technical knowledge gained from laboratory and large-scale research in fire propagation and hazard mitigation in the WUI.

This report documents the methodology and addresses the critical issues of mitigation effectiveness at the parcel and community levels. The impacts of partial mitigation at the parcel and community level were addressed for different types of WUI communities.

Key words
community hazard reduction; disaster resilience; ember; firebrand; hazard mitigation; large outdoor fires; parcel hardening; retrofit; structure separation distance; wildfire; wildland-urban interface; WUI

Table of Contents

List of Tables

List of Figures

Glossary

Abbreviations

AHJ .... authority having jurisdiction

CA Chapter 7A .... a chapter in the California Building Code establishing minimum standards for construction in state-designated areas, titled *Materials and Construction for Exterior Wildfire Exposure*

CAL FIRE.............. California Department of Forestry and Fire Protection

FRAP...................... Fire and Resource Assessment Program (CAL FIRE)

FSD .... fuel separation distance – the spatial distance between a fuel (source) and a target

FSR .... fuel separation range – the spatial distance between a fuel and target in which hardening of the target will significantly reduce target ignition potential

ICC......................... International Code Council

IBHS .... Insurance Institute for Business & Home Safety

NFPA .... National Fire Protection Association

NIST....................... National Institute of Standards and Technology

SSD .... structure separation distance – the distance between two structures (primary or auxiliary)

Terms

cladding.................. the exterior materials or assembly of materials of a structure

ember...................... a hot or burning (flaming or smoldering) particle generated/broken off from the source (due to impact, wind, or the reduced structural integrity of the solid fuel due to burning)

exposure .... the heat energy from flames, radiation, and/or embers that are generated from a burning object, feature, or structure

firebrand................. see ember; particularly an airborne ember

parcel...................... a specific plot of land with delineated boundaries, typically containing a house or building

source .... an object, feature, or structure that, when burning, generates an exposure of heat, flames, and embers

target .... the recipient of an exposure – may be a structure (hardened or non-hardened) or other parcel features

wildlands................ any undeveloped land with vegetative fuels that can generate fire and ember exposures (may also be located on partially developed parcels)

1. Introduction

Fires in the wildland-urban interface (WUI) pose a growing threat to communities across the nation and around the world. Fires have grown in intensity and size in the last 20 years [1-3]. Additionally, a new threat has emerged from fire storms, events where tens of fires can occur simultaneously, creating challenging conditions for first responders that result in reduced response coverages. Recent events include the October 2017 North Bay Fires and the August 2020 lightning fires in California, as well as the September 2020 fires in Oregon. As losses mount, a paradigm shift of the hazard mitigation approaches that have been widely used to date is needed.

Fire and embers vary over small geospatial scales in WUI fire events. Post-WUI fire case studies have identified that these exposures can vary on a sub-parcel scale, on the order of 50 ft to 100 ft, highly dependent on localized fuel, wind, and topographic conditions [4-6]. Embers can travel several miles, and initial low to moderate ember exposures can impact entire communities [7, 8]. These initial wildland exposures can significantly contribute to the spread of fire into the community directly, or through the development of significant fire exposures from the ignition of fuels within the community. Subsequent ignitions within communities can generate localized very high ember exposures. Fire (radiation and convection) exposures can also exhibit significant variations occurring over several feet. This is not only a function of the spatial distribution of fuels but also is associated with the rapid decay in radiation intensity with increasing distance and the limited extent of flaming combustion (i.e., flame length) compared to the widespread extent of ember exposures. National Institute of Standards and Technology (NIST) WUI case studies have repeatedly identified the need to couple exposures to structure hardening [4-6]. A Hazard Mitigation Methodology (HMM) was developed to address this specific need and was a sixteen-month collaborative effort by NIST, the Insurance Institute for Business & Home Safety (IBHS), and the California Department of Forestry and Fire Protection (CAL FIRE).

All WUI communities are not the same. This HMM goes beyond the traditional WUI definitions and introduces the concept of structure separation distance (SSD) for the development and implementation of hazard reduction. The proposed HMM accounts for both ember and flaming exposures in the WUI and addresses the spatial relationships between fuels that drive the ignition of structures and fire propagation. This work represents the technical evolution of the NIST WUI Hazard Scale [9] published in 2013. Scientific developments and field observations have resulted in the increase in spatial resolution of the proposed methodology as compared to the WUI Hazard Scale.

The goal of the HMM is to reduce the overall implementation burden by assessing local exposures and applying the latest laboratory research findings and knowledge from post-fire field observations to effectively harden structures in a cost-effective way. The HMM is primarily aimed at retrofitting the existing building stock. The proposed methodology also highlights the needs and requirements for implementation at the community level.

HMM was designed to be applied in communities located in hazardous fire prone WUI areas. The benefits of community-wide mitigation can be viewed as proportional to the overall community fire hazard, including fire exposures from surrounding and occluded wildlands. While the implementation of HMM in a high-hazard community will likely substantially reduce losses, significant benefits can also be achieved in lower hazard scenarios. Recent WUI fires have demonstrated that significant losses can occur in low-hazard WUI or urban settings. One example is the impact of the 2017 Tubbs Fire on the Coffey Park community in Santa Rosa, CA.

NIST and IBHS are non-regulatory entities, while CAL FIRE has regulatory authority in the state of California. This HMM was developed to provide authorities having jurisdiction (AHJs) and homeowners with the latest comprehensive understanding of fire behavior and structure response in the WUI. When terms such as "required" and "should" are used, they are only in the context of highlighting the necessary components identified for the HMM to work. AHJs will ultimately choose where to implement any or all of the components presented in the HMM.

2. WUI Definition

The common conceptual definition of wildland-urban interface (WUI) is the geographical area where human development, including structures and other infrastructure, meets or intermixes with undeveloped wildlands [10, 11]. Communities in such areas may be grouped into one of three categories—interface, intermix, or occluded[1]—depending on the density of development, coverage of wildland fuels, and population density [12]. This definition has been adopted by several governing federal- and state-level authorities and codes/standards organizations, including the US Fire Administration, the International Code Council (ICC) International Wildland-Urban Interface Code (IWUIC), and the National Fire Protection Association (NFPA).

Beyond the conceptual definition, establishing a uniform operational definition has proven difficult [13-15]. WUI areas are often delineated using three primary components:

1. human presence, often quantified by housing density or population density
2. wildland vegetation, often quantified by percentage of land coverage
3. proximity to wildlands, often quantified as a buffer distance between wildlands and developed land or structures.

The introduction of an official Federal WUI definition is presented in the Federal Register in 2001 [11] in support of Federal wildland fuel management efforts in response to the fire season of 2000. This definition quantified human presence through either housing density or population density. However, these definitions only qualitatively describe the quantity of wildland vegetation and proximity to wildlands.

The Healthy Forests Restoration Act (HFRA) of 2003 [16] slightly expanded the WUI definition to include "at-risk communities"—groups of homes or structures with basic infrastructure and services where there is a significant threat, to human life or property, from large-scale wildland fires.[2] The WUI extends at least 0.5 mi (0.8 km) from the boundary of such areas and includes any additional area within 1.5 mi (2.4 km) consisting of topography or fuel accumulation conditions with increased potential for elevated fire behavior, or land suitable for effective firebreaks. Furthermore, the HFRA also deemed areas adjacent to evacuation routes from such communities as WUI.

Several studies have implemented the federal definition into practice to identify, quantify, and map WUI areas [14, 17-21]. The generally accepted defining criteria are presented in **Table 1**. However, even while adhering to the spirit of the Federal Register definition, slightly differing assumptions, interpretations of the thresholds, differing data sources, and intermediate data processing steps yield different outcomes [20-23]. Detailing specifics of the

[1] Occluded community refers to a situation where developed areas surround an island of wildland fuels generally < 1000 ac (400 ha) in size [11]. These communities are typically treated and defined similar to interface communities.
[2] Note that both the Federal Register [11] and the HFRA [16] specify communities within or adjacent to federal lands. However, it is important to note that this reflects jurisdictional limitations and should not be understood to limit the broader sense of qualification/definition as WUI.

various implementations are beyond the scope of this document. However, the focus of the mapping studies, and the federal definition in general, is to provide a high-level overview and a sense of scale to help progress to the next step—directing the additional focus needed to hone in on and support direct mitigation efforts in areas where it is needed.

It is important to note that not all communities in the WUI have the same fire risk level, and risk or threat is not quantified or defined in the Federal Register or the HFRA. However, the Federal Register does suggest the consideration of the following three broad categories when evaluating risk factors:

1. Fire behavior potential (e.g., fuel types and distribution, slopes, prevailing winds)
2. Values at risk (e.g., structures, watershed, cultural/historical values), and
3. Infrastructure (e.g., road access/egress, water supply, firefighting capacity).

While the above three risk factors provide useful information for assessing risk, the specific implementation criteria impact the final perimeters of WUI areas determined by local jurisdictions. Historically, WUI fire losses have occurred within these defined boundaries; it has been shown that a significant fraction of buildings destroyed by wildfires are located in the WUI [24]. However, it is also essential to keep in mind that hazardous conditions may extend beyond the "defined" WUI. For example, the Coffey Park neighborhood of Santa Rosa, CA, which was destroyed in the 2017 Tubbs Fire, sits outside the edge of the interface definition implemented by Radeloff et al. [17]. Once into the high-density structures, the fire burned 0.9 mi beyond the interface limit into developed lands. Coffey Park losses illustrate the potential of a WUI fire to morph into an urban conflagration. Similar losses from structure-to-structure fire spread have been observed during many other large-loss WUI fire events whether the locations are designated WUI or not.

HMM was designed to be applied in communities located in hazardous fire prone WUI areas. State and local fire hazard severity mapping systems can be used to identify communities that can benefit from the application of this HMM. Some jurisdictions, such as the State of California, characterize hazard in their definition of WUI. The CAL FIRE Fire and Resource Assessment Program (FRAP) classifies land into Fire Hazard Severity Zones (FHSZ) [25, 26]. There are 3 levels of FHSZ—Moderate, High, and Very High—which are determined by analyzing several factors, including vegetation, fuel loading, topography, weather (temperature, humidity, and wind), fire history, and ember potential. The state uses the defined FHSZs to require building code provisions (i.e., California Building Code (CBC) Chapter 7A [27], California Fire Code Chapter 49 [28]) and hazard mitigation actions [29].

Efforts to define and map WUI hazard areas are necessary to assist local agencies in understanding their jurisdiction's wildfire hazards and to prepare their communities by focusing broad mitigation strategies and land use planning. However, fire behaves at many scales, and fire hazard at the structure or property level is often difficult to quantify using coarse scale data such as LANDFIRE [30].

Structure survivability is the result of the relationship between the structure construction and local intensity and duration of fire and ember exposures. Communities should assess both components in the process of structure and community hardening. As this HMM details, mitigation and hazard assessment distill down to a structure-level issue, and thus, considering structure separation distance as a defining component of WUI fire hazard is a logical progression for determining necessary hazard mitigation.

Table 1. WUI definitions.

	Definition Component	Federal Register	Common Implementation	CAL FIRE
Interface	Conceptual	There is a clear line of demarcation between residential, business, and public structures and wildland fuels; wildland fuels do not generally continue into the developed area	Developed land not dominated (i.e., < 50 %) by vegetation	High-density development adjacent to undeveloped wildland vegetation
	Housing density	≥ 3 structure/ac (741 structure/km^2)	≥ 1 HU/40 ac (6.18 HU/km^2)	>1 HU/20 ac (12.4 HU/km^2) in Moderate, High, or Very High FHSZ
	Population density	≥ 250 people/mi^2 (96 people/km^2)		
	Vegetation cover	Structures directly abut wildland fuels	< 50 %	Not dominated by wildland vegetation
	Buffer from wildland	Up to 1.5 mi (2.4 km) from community border	< 1.5 mi (2.4 km) from land with > 75 % vegetative cover	Wildfire susceptible vegetation up to 1.5 mi (2.4 km) from interface
	Infrastructure	Fire protection of the structures from both an interior fire and an advancing wildland fire provided by the local fire department.		
Intermix	Conceptual	There is no clear line of demarcation; wildland fuels are continuous outside of and within the developed area	Developed land dominated (i.e., > 50 %) by vegetation	Lower-density housing mingled with undeveloped wildland vegetation
	Housing density	≥ 1 structure/40 ac (6.18 structure/km^2)	≥ 1 HU/40 ac (6.18 HU/km^2)	1 HU/20 ac to 1 HU/5 ac (12.4 HU/km^2 to 50 HU/km^2) OR >1 HU/5 ac (50 HU/km^2) when dominated by wildland vegetation, in Moderate, High, or Very High FHSZ
	Population density	(28 to 250) people/mi^2 [(11 to 96) people/km^2]		
	Vegetation cover	Structures are scattered throughout a wildland area	> 50 %	Dominated by wildland vegetation
	Buffer from wildland			Wildfire susceptible vegetation up to 1.5 mi from intermix
	Infrastructure	Fire protection districts provide life and property protection and may also have wildland fire protection responsibilities		

Note: HU = housing units

3. Defining WUI by Structure Separation Distance

The WUI environment is complex and multifaceted. Several definitions of the WUI have been presented and used to meet specific documentation goals or to broadly identify hazard areas. For more focused and effective mitigation efforts, namely the enumeration of required structure hardening, many of these definitions are not sufficient on their own as they do not focus on the parcel-level details that characterize parcel-to-parcel and structure-to-structure fire spread. In this document, the definition of the WUI is subdivided into seven distinct types based on structure separation distance (SSD) and "traditional" WUI categories (i.e., interface or intermix). The Types are listed in **Table 2**. These definitions provide perspective and can help characterize overall community housing density and lot sizes. **Table 2** can be applied at the community or the parcel level; however, **Table 2** is not sufficient to implement the HMM.

The range of structure densities defined as WUI are extremely broad. A typical high-density community with 8 HU/ac (housing units per acre) is 320 times denser than the lowest density typically considered WUI, 0.02 HU/ac (1 HU on 40 acres). The agglomeration of structures[3] seen in high-density communities (frequently resulting in small SSD) has significant impact on fire behavior [4, 31]. The use of SSD as a key metric in characterizing WUI areas specifically with respect to fire is twofold. First, structures represent a significant density of fuels that impact fire spread and, in many cases, directly contribute to the ignition of additional structures, propagating fire throughout the community. Secondly, existing structures pose a unique challenge in hazard management—they are immobile. While they can be hardened (see Section 5 for mitigation methodology), they cannot be readily removed or displaced like many other WUI fuels.

The traditional WUI categories (interface/intermix) describe the general community classification and hazard profile. However, effective structure-level mitigation must be driven by parcel-level assessments and localized evaluation of potential fire exposures. This can be aided through identification of a parcel-level WUI Type. The Types listed in **Table 2** are primarily defined by SSD, with secondary consideration of parcel size. Even if structures are located on a large lot but are clustered together on the edge of the property with small SSD, the parcel WUI Type would correspond to a smaller SSD.

[3] All structures, not just housing units, including primary (residential and commercial) and auxiliary (e.g., auxiliary dwelling units (ADUs), garages, sheds) structures impact fire spread.

Table 2. WUI Types classified by structure separation distance (SSD) and typical parcel size.

Type #	WUI Type Name	SSD (ft)	Typical Parcel Size (ac)	Typical Housing Density (struct/ac)
1	High Density Interface – Perimeter	6[a] to 30	< 0.5	2 to 8 +
2	High Density Interface – Interior[b]	6[a] to 30	< 0.5	2 to 8 +
3	Medium Density Interface – Perimeter	30 to 100	0.5 to 1+	< 2
4	Medium Density Interface – Interior[b]	30 to 100	0.5 to 1+	< 2
5	Medium Density Intermix	30 to 100	0.5 to 1+	< 2
6	Low Density Interface	100+	1+	< 1
7	Low Density Intermix	100+	1+	< 1

For SI: 1 ft = 0.305 m, 1 ac = 0.4 ha
[a] representative of parcels with a 3 ft setback (common for new construction of sprinklered residences)
[b] interior of community defined as > 0.25 mi (400 m) from wildlands

WUI Type 1 and Type 2

WUI Type 1 and Type 2 represent high-density interface communities. These communities have a high fraction of their fuel load in the form of residential structures. SSDs in these communities are often as little as 6 ft (minimum 3 ft building setback from property line) and up to 30 ft. These types of WUI can be found around the country including in some very high WUI fire hazard areas. These WUI communities typically have parcel sizes significantly less than 0.5 ac (0.2 ha). Communities like Coffey Park in Santa Rosa, CA (shown in **Figure 1**) or the Mountain Shadows area of Colorado Springs, CO are examples of these high-density communities. Typical lot sizes in these two communities are less than 0.15 ac, and typical SSD is 6 ft (see maps and data in **Figure 2** and **Figure 3**). The Mountain Shadows neighborhood can be characterized as Type 1 *High Density Interface – Perimeter* while Coffey Park can be characterized as a Type 2, *High Density Interface – Interior* community.

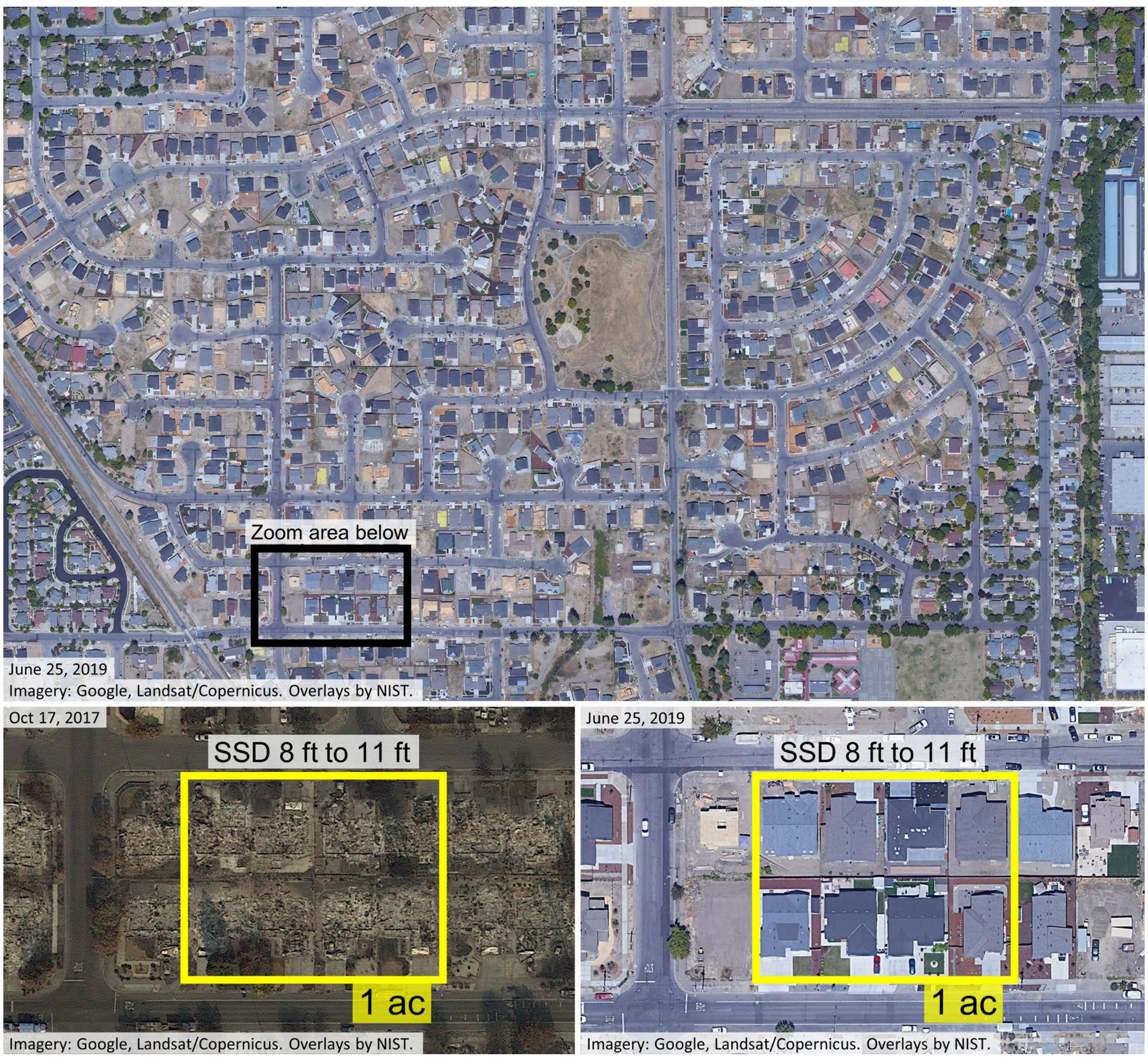

Figure 1. The neighborhood of Coffey Park in Santa Rosa, CA is an example of WUI Type 2 (High Density Interface – Interior). For SI: 1 ft = 0.305 m, 1 ac = 0.4 ha.

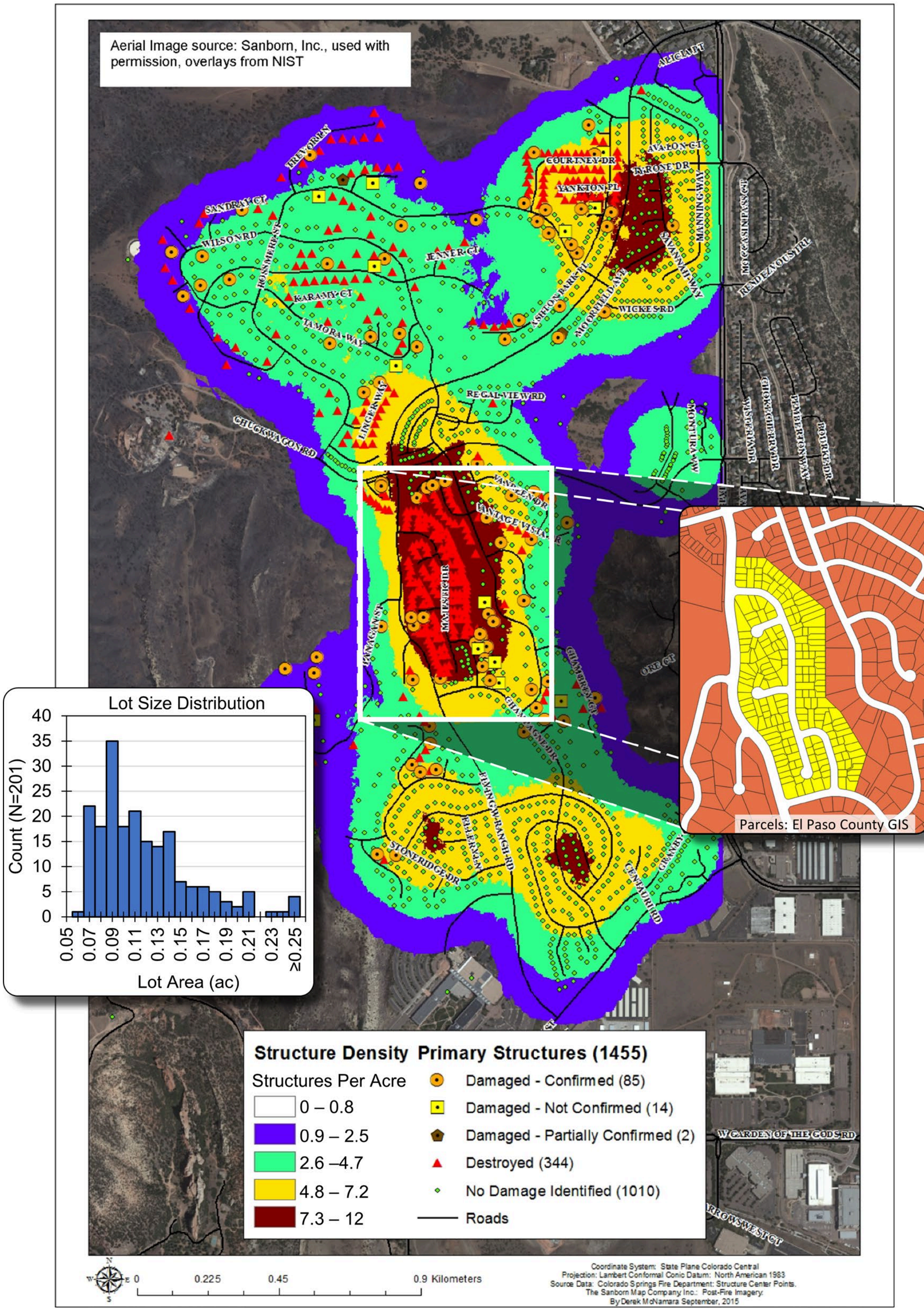

Figure 2. An example of structure density of the Mountain Shadows neighborhood in Colorado Springs, CO is shown in Map Figure 13 from NIST TN 1910 [4] (units modified). Insets show the highest density area (yellow) and associated lot size distribution.
For SI: 1 ac = 0.4 ha; 1 structure/ac = 2.47 structure/ha.

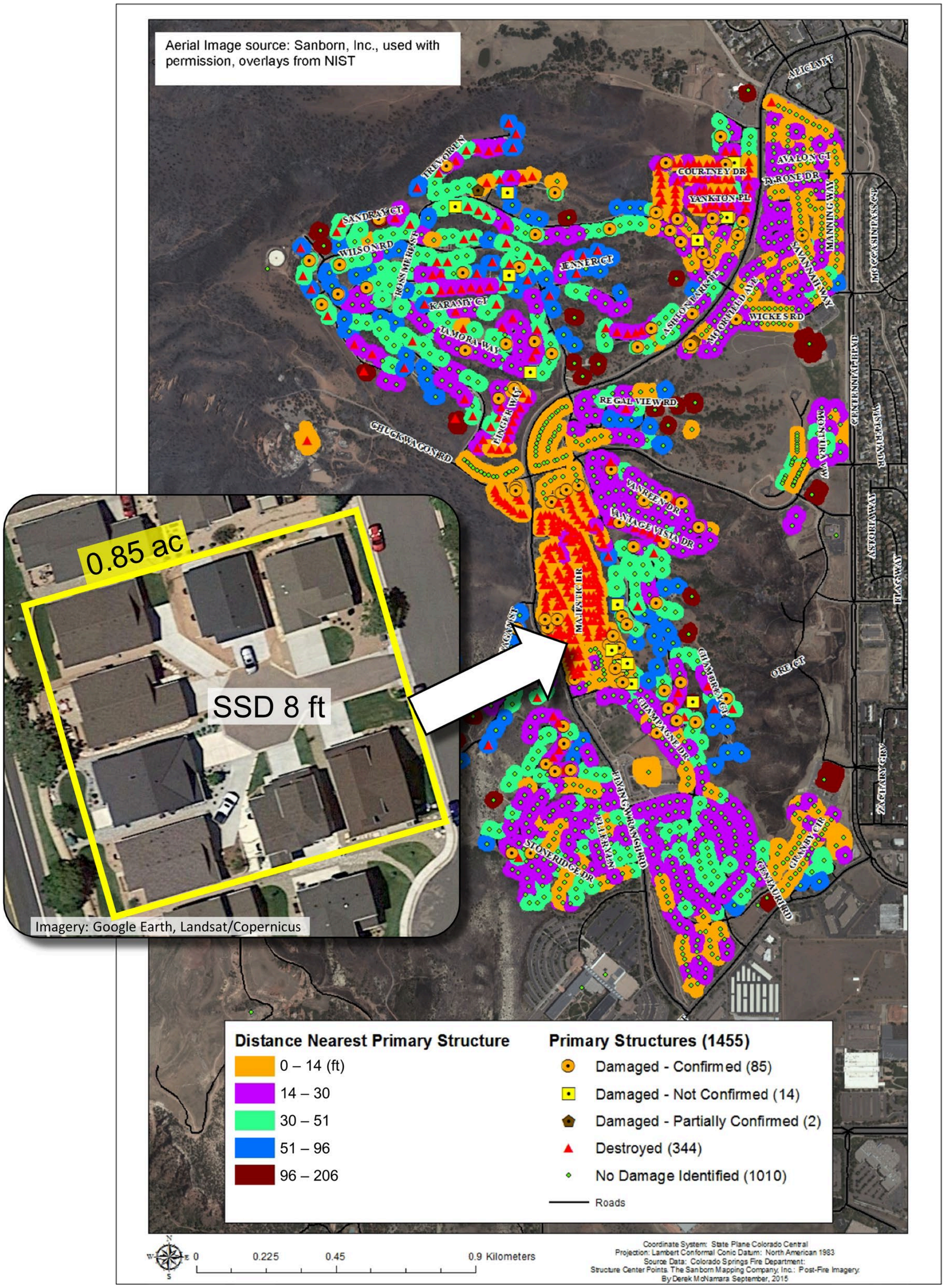

Figure 3. Varying structure separation distances in the Mountain Shadows neighborhood of Colorado Springs, CO are shown in Map Figure 14 from NIST TN 1910 [4] (units modified). The inset highlights an area of very low SSD. For SI: 1 ft = 0.305 m, 1 ac = 0.4 ha.

WUI Type 3, Type 4, and Type 5

WUI Types 3, 4, and 5 are all characterized by medium-density construction with SSD ranging from 30 ft to 100 ft. Parcels are typically larger in the medium (or moderate) density WUI, with many being over 1 ac. These WUI Types are further subdivided; interface (Types 3 and 4) and intermix (Type 5). Like WUI Type 1 and Type 2, Medium Density Interfaces can be located on the perimeter abutting wildlands (Type 3) or in the interior of WUI interface communities (Type 4). WUI Type 5 represents medium density intermix communities with similar SSD found in Types 3 and 4 of 30 ft to 100 ft.

WUI Type 6 and Type 7

WUI Types 6 and 7 are characterized by low structure density at the interface and intermix, respectively. These are low structure density locations where residential structures are typically over 100 ft apart.[4] These communities are comprised of larger lots, typically over 2 ac. Note that even within a WUI Type, structure and vegetation characteristics may be quite different. **Figure 4**, **Figure 5**, and **Figure 6** show different examples of low-density intermix.

Figure 4. WUI Type 6: Low Density Intermix Rancho Santa Fe, CA.

[4] Auxiliary structures may be present and can have significant impact on fire spread. These local SSD (between all structures and other fuels) are explicitly addressed through the HMM.

Figure 5. WUI Type 6: Low Density Intermix, The Trails, Rancho Bernardo, CA. Note irrigated lawns, long paved driveways, pools and tennis courts. Some structure-to-structure distances are representative of Moderate Density Intermix (lower part of image). Also note limited high density non-irrigated vegetative loading.

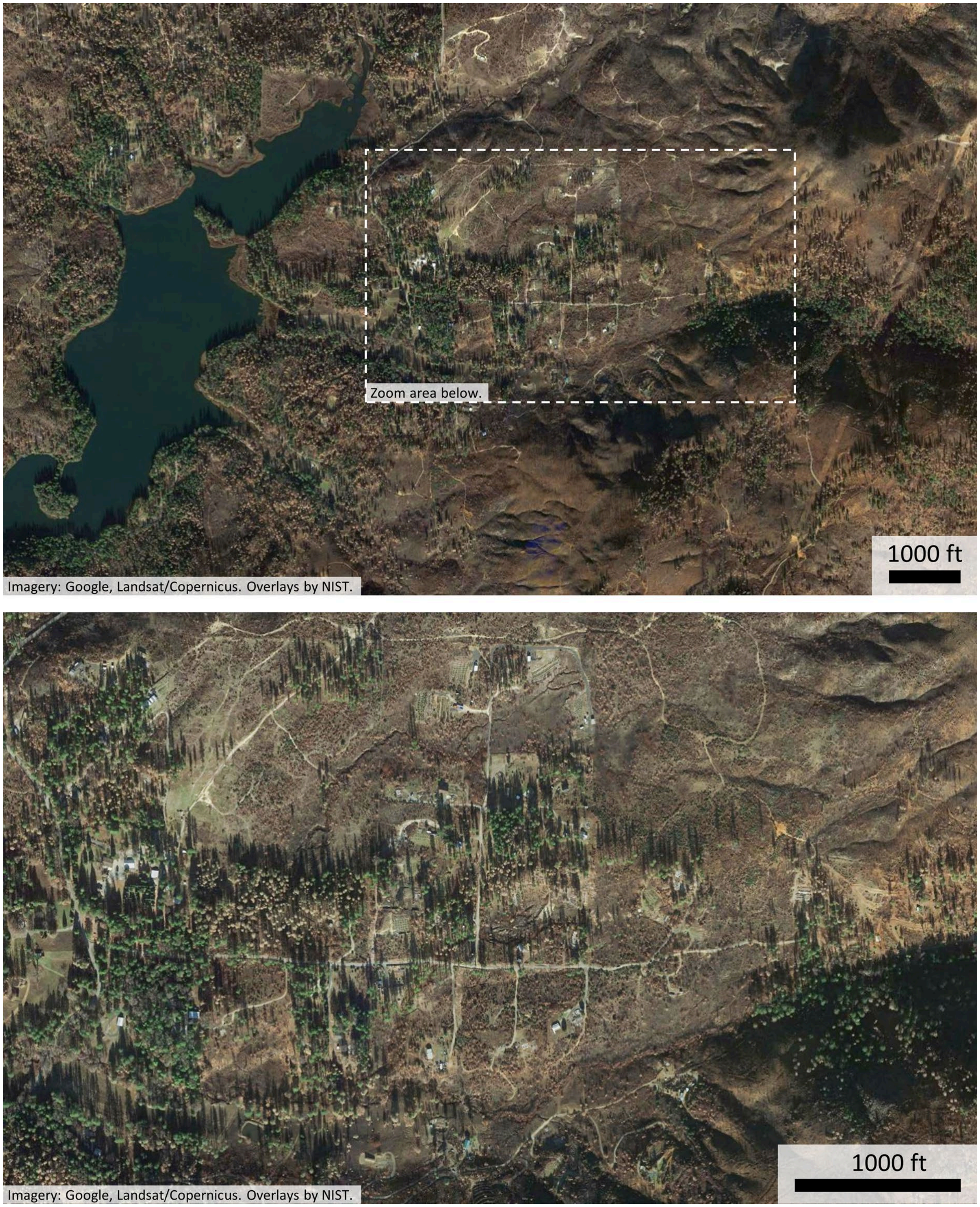

Figure 6. WUI Type 6: Low Density Intermix: Concow, CA. Note the overall large SSD and structures located within the wildland vegetation. Note the imagery is taken after the 2018 Camp Fire.

The seven WUI types described above can be used to help characterize WUI communities. These definitions are intended to provide general structure spacing information for a community or part of a community. The hazard mitigation and retrofit guidance provided in this document is parcel-centric and specifically accounts for local fuel spacing conditions. SSD and vegetation type, quantity, and location also relate to potential fire exposure. Exposures in the WUI are a combination of two components—fire and embers. These two exposure types are further discussed in Section 4.2. The impacts of fuel densities on exposures are discussed in Section 4.3, and the mitigation methodology to address the varying fire and ember exposures is described in Section 5.

4. WUI Hazard Mitigation Methodology

4.1. Introduction

The proposed methodology was developed to meet two primary objectives:

1. Reduce structural losses in WUI fires by hardening structures and parcels, and
2. Prioritize mitigation efforts to reduce overall mitigation costs.

WUI fire hazard mitigation is often thought of as either an "every little bit helps" or a "one-size-fits-all" voluntary endeavor. The first approach is a good start and can provide realized benefits in low-exposure conditions where defensive actions[5] are also very effective [4, 32]. However, such an approach often leaves significant gaps and a false sense of security (see Sections 5.4.2 and 5.4.3 on partial compliance). This approach has significant shortcomings in conditions where defensive actions are not possible due to high exposures or limited resources. There is a fundamental difference in communication for public awareness and hardening for standalone protection. Public education is a critical component of a hazard communication strategy but does not go far enough to solve the larger-scale problem. The second approach, "one-size-fits-all" mitigation, is very expensive if all vulnerabilities are to be addressed. The goal of the methodology developed in this document is to bridge the gap through selective hardening actions in response to potential exposures at the parcel level, while considering exposures to/from neighboring parcels. This quasi-performance-based design approach can reduce the overall burden of mitigation in both effort and expense.

The mitigation strategy outlined in this document was primarily developed to address the needs for retrofit hardening of existing communities; however, the information can also be used for the design and construction of new communities. The proposed methodology is designed to augment defensible space [33]. The strategy relies on defensible space principles specifically related to the removal and maintenance of vegetative fuel and other combustible materials. The strategy was developed over a period of 16 months through a collaborative effort between NIST, CAL FIRE, and IBHS and leverages the most current science and data together with more than ten thousand hours of pre- and post-WUI fire field data collection conducted by the collaborating agencies. Discussions with the building industry were necessary to clarify and improve different implementations for retrofit solutions. The HMM will continue to be adapted and revised as additional science and technical findings become available.

Structures in the WUI can experience two different types of hazardous exposures—embers and fire (i.e., flames via radiation and/or convection) [34]. To survive without contributions of defensive actions (see Section 5.4.1 on the impact of defensive actions in the WUI) structures must be able to withstand both ember and fire exposures. This adaptive methodology is designed to harden the structure and the parcel against both hazards.

[5] Defensive actions include fuel displacement, fire suppression, fire containment, and exposure protection by first responders.

There is a direct relationship between exposure and the structure hardening required for survival, and effective mitigation is a tuned balance of the two components. This relationship is illustrated in **Figure 7**, where the two knobs or dials represent exposure level and structure hardening. There are as many relationships that will result in structure ignition as there are relationships or settings that will result in no ignition. At the extreme, if the exposures (both fire and embers) are eliminated then no hardening is required. Conversely, if a structure is hardened to a windowless concrete bunker, it could survive an extreme exposure. It is acknowledged that the bunker approach is not realistically implementable or desirable, highlighting the need for a balanced strategy between exposure reduction and structure hardening.

Figure 7. WUI fire hazard mitigation is a balance between two input dials—reducing exposure and increasing structure hardening.

4.2. Quantifying Ember and Fire Exposures

4.2.1. Embers

In a WUI fire, structures will likely experience ember exposures. Embers can cause direct ignitions of structures and parcels. Ignitions of parcel-level features may result in fire exposures to the structure and generation of additional embers. Structure ignition will depend on the vulnerabilities present on the structure and the intensity/duration[6] of local ember exposures.

Ember exposures can vary over several orders of magnitude in number flux (count/m^2/s) and in energy content, as embers can range from sub-millimeter scale to many centimeters in size [4, 35, 36]. In WUI fire events the initial embers arriving to a structure often originate from beyond the parcel that is being protected/hardened. Depending on the origin of the embers and the ownership of the ember generating fuels, options may be available to limit ember generation. While ember exposures can be reduced locally by defensive actions, the presence of first responders cannot be relied upon particularly during large incidents. Therefore, structures must be hardened to withstand various ember exposures ranging from very low to very high. Because the exposure intensity and duration cannot be controlled, or in many cases even predicted, ember hardening must address significant ember exposures and

[6] Intensity of ember exposures will be a function of several factors including size distribution, number density, and energy content, which all vary in both space and time.

associated local ember accumulations. While scientific work is in progress to measure and quantify ember fluxes (e.g., [37-39]), visual observations and ignition occurrences are the best documentation at this time. The technical goal is to prevent ignition, not merely delay it. This is accomplished through the use of noncombustible materials in vulnerable areas of the structure. A detailed list of ember hardening requirements is discussed in Appendix A.

On the parcel, embers can cause the ignition of different parcel-level features. The hardening of these features can fall outside the current regulatory practices of fire departments and local AHJs. One example is recreational vehicles (RVs). The ignition resistance of RVs to embers will impact the potential contributions of RVs to fire spread within and across parcels in the WUI. RVs and other parcel-level features will generate both ember and fire exposures.

4.2.2. Fire

Fire exposures can originate from within the respective parcel or from adjacent parcels or wildlands. Like ember exposures, fire exposures can vary in intensity and duration. However, unlike embers that can travel several miles, fire exposures impact potential fuel in the range of tens of feet, as radiation and convection decay rapidly with distance.

There is a significant connection to be made between fire exposure and hardening. A structure with limited hardening can tolerate a low fire exposure relatively easily. Examples of low fire exposures are a mulch fire or a shrub fire. While these exposures can generate heat fluxes of 15 kW/m^2 locally, these exposures are very limited in space and have short finite durations. These types of low exposures are not a challenge to hardened structure cladding (e.g., stucco, cementitious board) and do not cause cladding failure as current test methods (e.g., ASTM E2957) are designed to accommodate them. While non-threatening to hardened structure cladding, these exposures can still pose a significant ignition hazard to other non-hardened exposed combustibles, which may further increase the total exposure to the structure. Depending on materials and assembly construction, a low fire exposure can result in local ignition and subsequent structure loss.

Hardening for these types of exposures requires localized changes in building cladding and reinforcement of the assembly. As an example, raising the combustible cladding from the ground[7] uncouples potential exposures from a mulch bed or an accumulation of wind-blown flammable materials (e.g., pine needles and leaf litter). This strategy is easier and more cost effective to implement than replacing the entire siding for that very targeted low intensity fire exposure. It should be noted that while low intensity fire exposures can be treated with local hardening solutions of exposure uncoupling (e.g., fuel displacement) or structure hardening, they must be addressed if structure survivability is to be achieved.

Fire exposures are a continuum in both intensity and duration. The above example illustrates the low end of that continuum. An example at the other end of the fire exposure spectrum

[7] **Table A**, item 10, in Appendix A requires a noncombustible cladding for the first 2 ft from ground level. Field observations frequently identify wind-blown debris piles exceeding 1 ft in height.

may be encountered in a high-density construction environment where structures are separated by 6 ft (i.e., 3 ft setback from property line). A fully involved residential structure will expose the neighboring residence to very high heat fluxes for a prolonged duration. High-exposure fires can also be generated by auxiliary structures. Such high heat fluxes will challenge almost all typical residential construction. A structure that can withstand these types of exposures can be thought of as built like an inside-out furnace. While this is technically achievable with current construction materials, this level of hardening is very difficult to retrofit existing construction.

It should be noted that wildland vegetation at the edge of an interface community can also generate very high heat fluxes with very long flame lengths (much longer than what is generated from a residential structure). These wildland fire heat fluxes can be very large and easily result in structure ignition even if they are not as long lived as fluxes from a fully involved residence. These impacts can be further accentuated in the presence of complex terrain (i.e., slope, aspect, canyons).

In between these two fire exposure extremes are scenarios where hardening the cladding of the primary residence will provide increased resilience and significantly reduce or eliminate the structure's ignition potential. This is further described in Section 5.2.

The primary technical approach to dealing with the fire exposure problem is to uncouple the exposure by implementing fuel displacement (e.g., moving firewood away from other combustibles) or fuel removal (e.g., remove a shed from a property) if space is not available for fuel displacement.

4.3. Structure Ignition Pathways

There are multiple structure ignition pathways from both ember and fire exposures in the WUI [4, 5, 7, 34, 40]. **Figure 8** illustrates the parcel-level combustible features that can contribute to fire spread within a parcel as well as across parcels. The list is not all-inclusive but is used here to illustrate the potentially large number of combustibles. Fire can move across one or multiple combustible features (becoming new sources of fire and embers) and across multiple parcels. The NIST Camp Fire Case Study [7] showed 16 different pathways that resulted in structure ignitions during that event.

The ignitability and energy release (in terms of both embers and fire) of these combustible features is a function of materials, assembly and design particulars, and size. Of the features in **Figure 8**, only firewood (wood piles), vegetation, and mulch have inherent combustible characteristics. To some extent, all of the other features can either be made of, or utilize cladding of, noncombustible materials. This is readily achievable for simply assembled features like fences but is significantly harder or impossible to achieve for complex fuels like RVs and other vehicles (e.g., cars and boats).

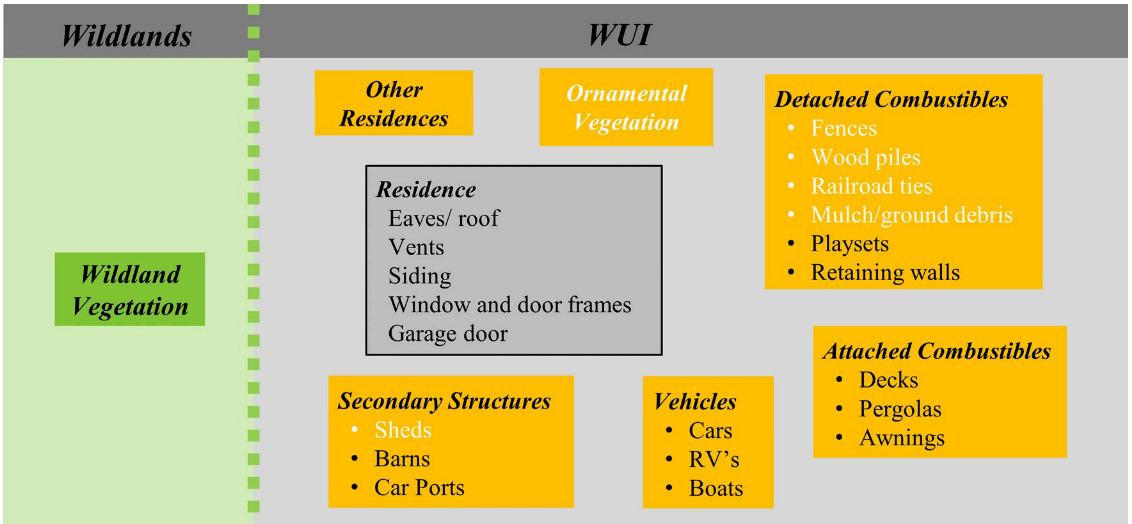

Figure 8. Parcel-level combustible features that can contribute to various structure ignition pathways. Highlighted in white are hazards that NIST and IBHS have performed extensive study of.

There are three technically important considerations when assessing fire spread within and across parcels. These are that:

1. parcel boundaries typically limit the continuity of protection between parcels,
2. linear features[8] can carry fire very efficiently within and between parcels, and
3. fuel agglomeration has significant impact on energy release and fire spread.

4.3.1. Impact of Parcel Boundaries on Code Application

Historically, codes have been parcel-centric and address exposures in the context of protecting a residence from the exposures on the same parcel. An example of how code compliance is typically interpreted/applied is illustrated in **Figure 9**, which shows a diagram of the placement of an auxiliary structure (e.g., a shed). Codes provide a minimum separation distance requirement for auxiliary structures. In some cases, the code requirement places the auxiliary structure at a minimum distance from the residential structure (30 ft), however, it provides very little for the protection of structures in adjacent parcels as the auxiliary structure setback from the property line does not reflect the potential hazard to adjacent parcels. A 5 ft setback is often allowed if the auxiliary structure is not sprinklered, placing the auxiliary structure as close as 10 ft from a non-sprinklered residence on the other side of the property line, seen in **Figure 9a**. Both structures are protected by the necessary SSD when the two residences are located on the same lot, as in Scenario B. When property lines are considered as a limit of code application, the hazard imposed from the auxiliary structure to the neighboring residence in Scenario A is unmitigated.

[8] combustible features such as fences, retaining walls, and landscaping railroad ties

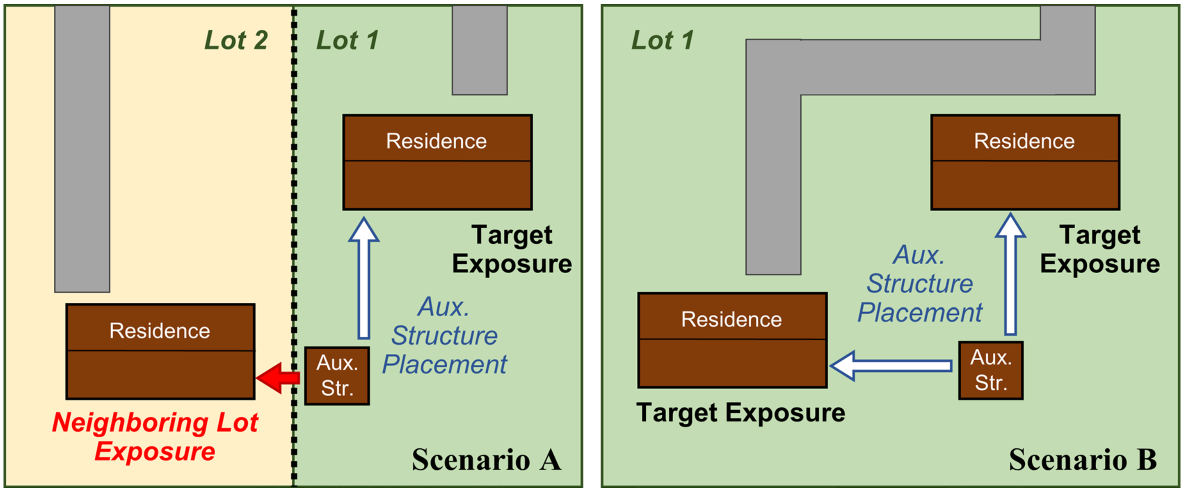

Figure 9. Existing codes are parcel centric. Residential structures are similarly located in Scenario A and B; however, the parcel division in Scenario A allows placement of an auxiliary structure too close to the neighboring primary structure when the parcels are considered independently.

4.3.2. Impact of Linear Features on Fire Spread

The impact of linear features was first documented in the Witch/Guejito Case Study [8, 32] and quantified during the Amarillo Case Study [5, 6]. This was further observed during the Waldo Fire Case Study [4]. Based on these field observations, NIST has conducted over 100 experiments to assess fire spread among fences and the impact of fences on fire propagation [41].

Figure 10 illustrates how fire can burn along linear features to spread from a single ignition point to multiple lots and impact multiple residences. For example, following ignition and fire spread pathway *B* shows that a single ignition on a fence line can carry fire to 6 lots and destroy (directly or indirectly) 3 residences depicted within the extent of the figure. It is also important to note that even with a partial improvement, such as removing the fence's direct connection to *Residence 3*, the result is still 2 destroyed residences within the figure: *Ignition B* → *shed* → *Structure 3* → *Structure 4*.

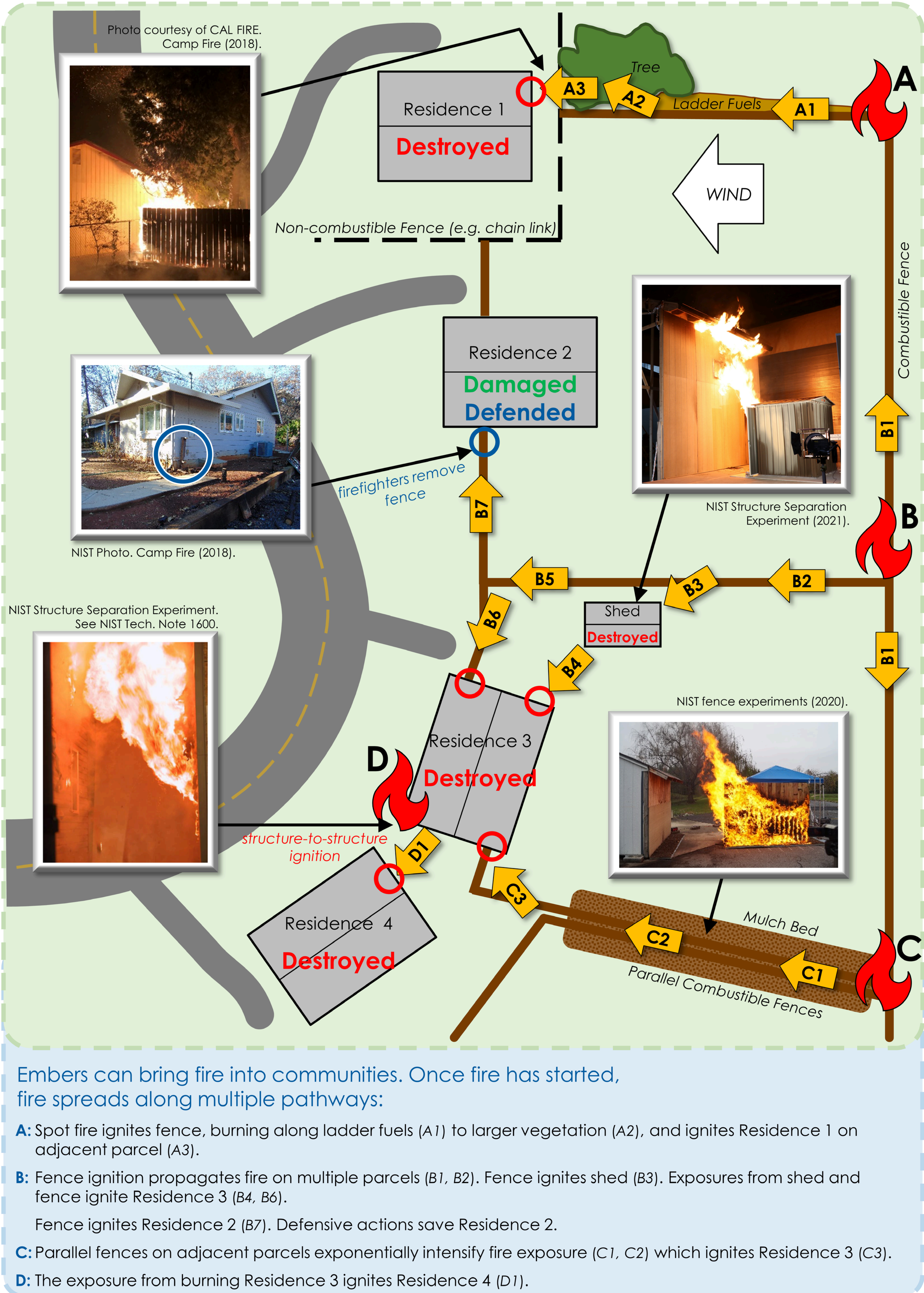

Figure 10. Illustration of numerous fire spread pathways among neighboring parcels via linear features and other combustibles. Inset photographs are from field observations and experiments.

4.3.3. Impact of Fuel Agglomeration on Fire Spread

NIST experiments [41] have confirmed field fire observations about the role of fuel agglomeration on fire and ember exposures generated from combustibles in close proximity to one another. **Figure 11** illustrates the intense burning and significant energy release from two fences placed 8 in (20 cm) apart. The observed increase in intensity compared to the burning of a single fence remained even when fences were spaced by 36 in (92 cm).

Figure 11. Parallel western red cedar fences burning with an applied wind of 13 mi/h (6 m/s) (left two images) compared to a single burning fence (right).

The impact of this increase in fire intensity on structure ignitions in the WUI is explicitly addressed in the methodology outlined here by requiring spacing between combustibles. This strategy decreases exposures to the asset to be protected (i.e., residence or other WUI feature), increases life safety of the public during evacuation, and creates a more defensible space for first responders to conduct rescue and firefighting operations.

Fuel agglomeration can occur unintentionally, as in the case of two neighbors putting up fences, significantly increasing the fire and exposure potential (see *Ignition C* in **Figure 10**). However, another path to fuel agglomeration has been observed to be an indirect result of mitigation guidance to WUI residents—when fuel relocation is encouraged rather than fuel removal. This becomes a significant fire hazard in moderate- and high-density construction on medium to small parcels ranging from 1 ac down to 0.2 ac or less. One observed example is firewood piles moved as far away from the residence as possible to the edge of these small properties, typically near combustible fences, creating high energy pathways for fire to move through these high-density communities. Fuel relocation is a valid hazard reduction approach; however, it should not be used as the default approach on small parcels. This approach is better suited to larger lots that can adequately separate all combustibles.

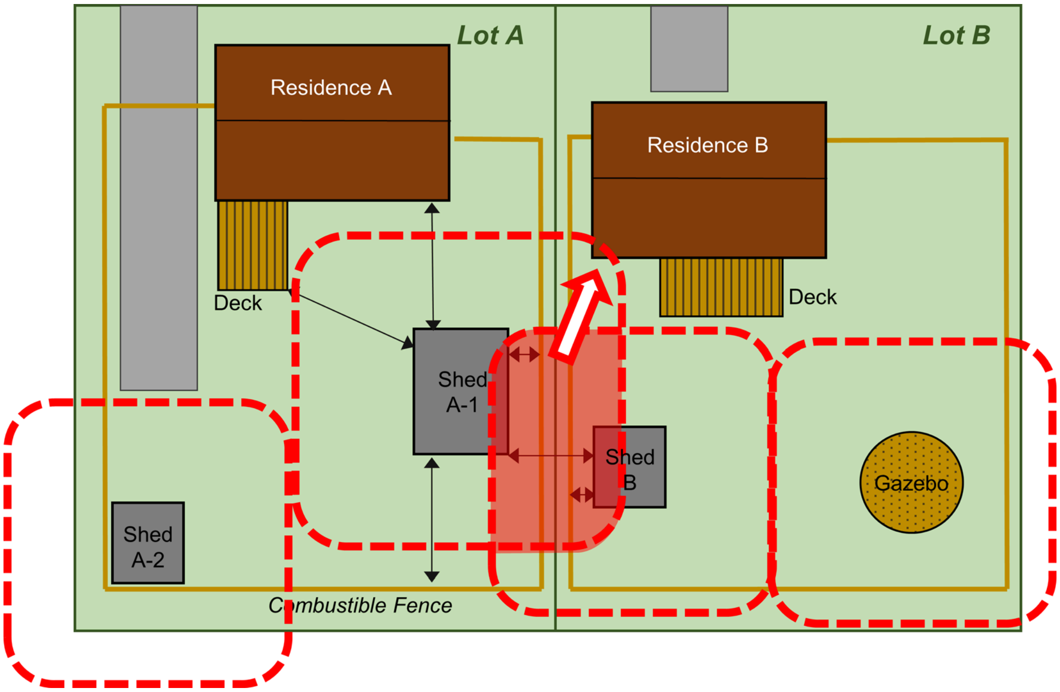

Figure 12. Spatial relationships between fuels on two adjacent parcels. Sheds are spaced appropriately from the residences and other fuels, except fences, on their respective lots. However, *Shed A-1* is too close to *Residence B*, and both sheds act as an agglomerated fuel package along the property border. The sheds and fences will substantially increase the exposures from the red highlighted area, igniting the structures.

Figure 12 illustrates how the issue of fuel agglomeration and increased exposures is particularly important in high- and moderate-density construction. The two red dashed outlines represent areas of high fire exposure potential from the sheds and illustrate the challenge from the fire exposures of high fuel loading on small parcels. The area represented by the overlapping dashed outlines represents an area of potential high energy release, and the red/white arrow illustrates the direct impact from this high energy release to the primary residence. Backyards like those illustrated in **Figure 12** represent a significant defensible space challenge to first responders. The highlighted example of the interactions between the two sheds[9] and the combustible fences is one of several possible similar scenarios in *Lots A* and *B* in **Figure 12**.

Fuel agglomeration can present fire spread challenges even if the fuel spacing on individual parcels is adequate to prevent fire spread within the parcel. **Figure 13** illustrates a scenario where the gazebo on *Lot B* (right) is located sufficiently far from the primary residential structure. However, agglomeration on the edge of the lot increases the fire spread hazard. Combined with the linear fence feature, a fire spread pathway to the neighboring parcel exists, even in this case where both structures have noncombustible fence attachments to the

[9] Note: smaller sheds (e.g., under 120 ft^2 in CA) are typically not as spatially regulated in terms of their placement as larger sheds. Current codes often allow these smaller sheds to be as close as 5 ft from a residence and/or property line.

primary structure. Additional fuel agglomeration on *Lot A* presents a hazard to the primary residence, indicated by the red and white arrows. The inclusion of an RV is to illustrate how combustible components that do not require a building permit can impact fire spread. RV owners may consider spatial separation distances similar to those for auxiliary structures to mitigate exposures to other combustibles.

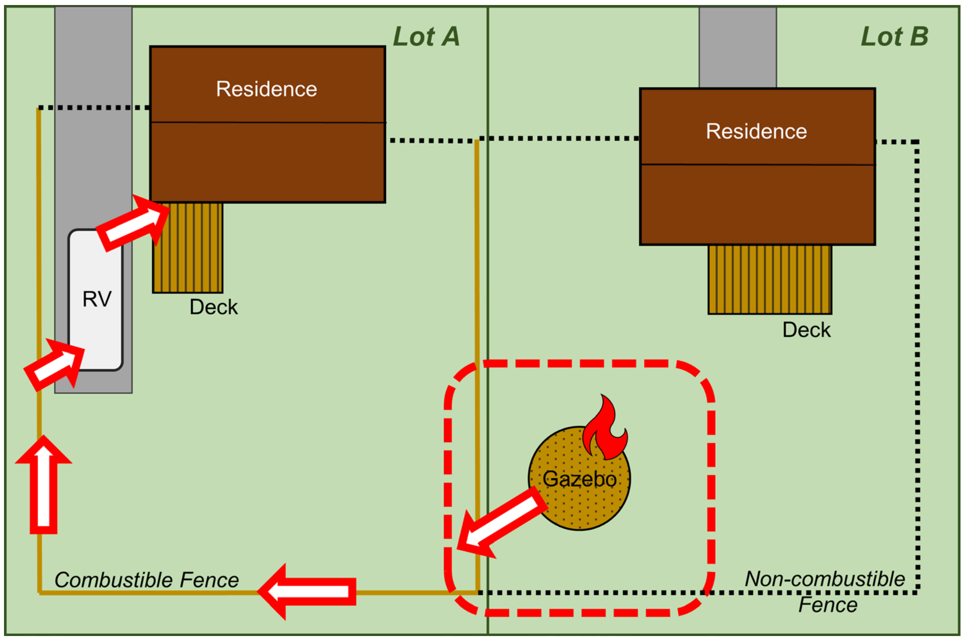

Figure 13. Fuel on *Lot B* is adequately spaced from *Residence B*; however, fuel is agglomerated at the fence, which opens the pathway to *Residence A*. Ignition on *Lot B* may still result in pathway shown, *gazebo→fence→RV→Residence A*, despite noncombustible fence attachments on both residences.

Figure 14 depicts the agglomeration of residential structures and other fuels in a high-density community. This figure illustrates an actual WUI community and is drawn to scale. No fuel breaks are present through a community of hundreds of homes (extending beyond the illustrated parcels). Residential structures, with nominal SSD of 8 ft, and the parcel-level fuels including combustible fences, decks, sheds, and vehicles, can allow a single ignition to destroy significant portions of the community.

Spacing requirements to prevent direct high fire exposure to residences, together with the need to reduce overall high fire exposure conditions to enhance life safety, require a detailed spatial parcel-level fuel loading assessment. The methodology described in this report provides the tools to address this issue. The fuel/spatial relationships mentioned here are detailed in **Table B** and **Table C** in Appendix A. The impacts of non-compliance with spacing requirements on structure ignitions and community resilience will be addressed in Section 5.4.3.

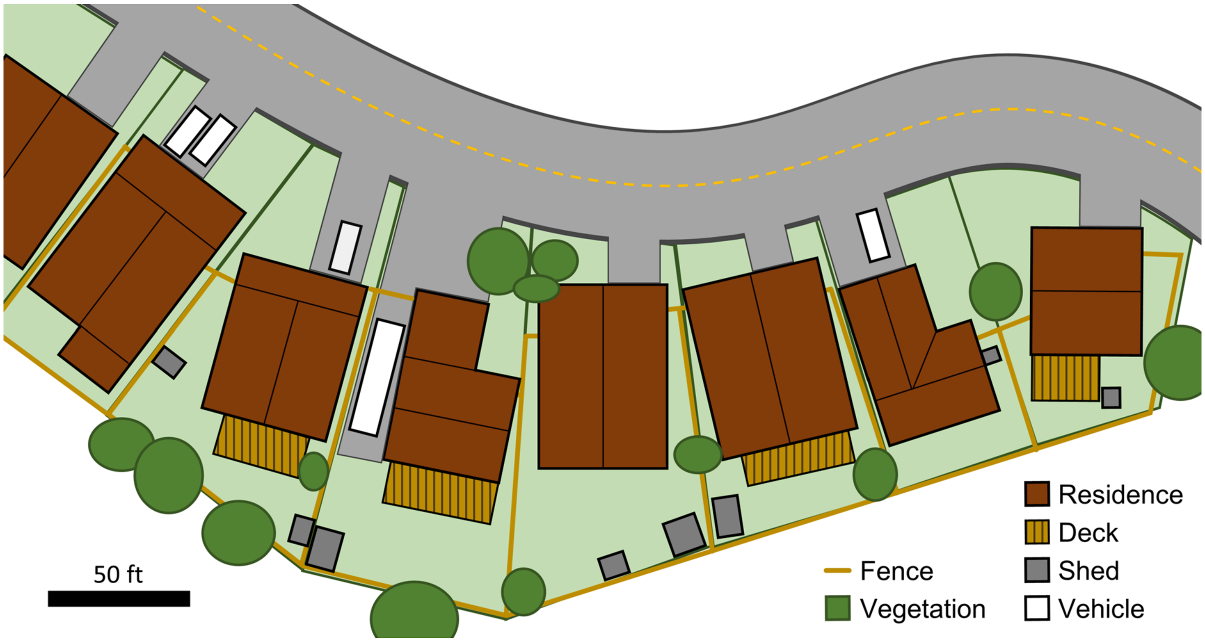

Figure 14. Illustration, based on an actual WUI community, showing real world fuel agglomeration and nominal 8 ft SSD on high-density parcels. Illustrated conditions extend across the street and throughout the community (not pictured). Fuel continuity is present across the community of hundreds of homes.

5. Hazard Mitigation at the WUI

The primary goal of the proposed structure and parcel hardening methodology is to minimize the chance of structure ignitions. The technical information presented here can be used for new construction; however, the methodology is focused on the retrofit of existing structures. In order to reduce overall retrofit costs, removal or displacement of fuels should be addressed first to reduce or eliminate the need for any structure hardening for fire. Factors influencing the effectiveness of the mitigation strategy are discussed in the following subsections.

A significant increase in structure ignition prevention is achieved by hardening structures against the complete range of expected exposures. This necessitates that all structures are hardened for high ember exposures. Ember showers are uncontrollable and often unpredictable because of airflow circulation patterns, unknown variability of primary wind direction, and ember characteristics. Hardening to prevent structure ignition from embers is achieved by addressing the multitude of known structure-level vulnerabilities. A total of 40 separate vulnerabilities have been identified along with associated mitigation actions. These vulnerabilities include the roof, gutters, windows, doors, vents, and attached combustibles. The full list of structure hardening requirements to prevent ignition from embers can be found in **Table A** in Appendix A.

A spatial analysis is necessary to identify potential exposures to the structure of interest. This consists of characterizing the extent of the potential exposure of the source and assessing its location with respect to the residential structure and other combustibles. If the placement has the potential to generate hazardous exposures, action must be taken to mitigate the exposure. This is accomplished by the approaches listed below:

a. Remove the fuel—this approach removes the exposure all together and is essential when there is limited space for fuel relocation/displacement.

b. Reduce the fuels—this approach reduces the number of combustibles and therefore the expected exposures.

c. Relocate the source—this approach allows the fuel to remain on the parcel but moves it away from the primary residence to reduce fire exposures.

d. Harden structures for fire exposure—if the above three approaches cannot be implemented, hardening the structure for fire will likely be necessary. The hardening option increases the likelihood of structure survivability but may not be as effective as hazard removal, and therefore, is the least desirable option. Additionally, hardening is typically the most expensive option.

The first approach of fuels removal (item a. above) is the most effective at hazard reduction and is the only implementable fuel reduction option on very small lots. Fuel removal works particularly well by replacing hazardous features with noncombustible alternatives, particularly when the combustibility of the feature does not add any functional component to its use.[10] This approach is the most effective and can be used even on larger lots.

Reducing the quantity of fuels will directly reduce the exposures generated. The extent of exposure reduction will depend on the fuel type, fuel geometry, and local conditions. An example of fuel reduction would be keeping less firewood on the property.

Fuel relocation has been a key anchor of many hazard mitigation strategies. As discussed in Section 5.4.4, this is a valid approach for medium and large lots (medium and low housing density WUI). However, this approach can cause unanticipated problems when neighboring parcels are not considered in the hazard risk assessment, particularly on small lots.

Hardening for fire exposures may be necessary in certain spatial situations where fuel removal or displacement is not possible (e.g., primary residential structure spacing 25 ft to 50 ft, see **Table B** Item #1). The various components of structure hardening are presented in Appendix A (**Table B** and **Table C**) and must be evaluated for each structure. The potential effectiveness of structure hardening is dependent on the potential fire exposure from neighboring structures, wildlands, and other sources. **Table 3** shows the effectiveness of hardening for fire in the various WUI Types.

The table illustrates that the effectiveness of hardening for fire is directly related to structure density. The coloring used in **Table 3** is summarized for the following three structure density scenarios:

a. Low Density (SSD on the order of >50 ft) – lower potential losses from individual structure ignitions, low potential for urban conflagration,
b. Moderate Density (SSD on the order of 25 ft to 50 ft) – greatest impact on structure ignition resistance by hardening for fire exposures from neighboring structures, and
c. High Density (SSD on the order of < 25 ft) – must not have any structures ignite as risk of entire community loss is very high due to structure-to-structure fire spread.

The above strategy is based on field fire behavior observations as well as controlled laboratory and field fire experiments [4, 31]. Fire behavior at the parcel level is very dynamic and, in a sense, very opportunistic, leveraging ignition vulnerabilities of different fuels and exposures between fuels. The above exposure/distance hardening strategy offers a path forward that creates discontinuities for fire exposures and selectively hardens structures where clear benefits can be achieved in ignition resistance.

The best available knowledge was utilized to determine the spacing distances to make the methodology implementable. As is the case with other guidance documents, ongoing research will continue refining the spacing guidance included here.

[10] Note: noncombustible features may not always provide identical aesthetics

Table 3. Structure and parcel hardening effectiveness.

#	WUI Type	Probability of Structure Survivability if Neighboring Structure Ignites	Potential Fire[a] Exposure from Burning Neighboring Structure	Exposure from Other Parcel Fuels	Exposure[b] from Wildlands	Impact of Structure Ignition on Fire spread in Community	Likely Effectiveness of Partial Structure/ Parcel Hardening	Community/ Neighborhood Participation
1	HD Interface – Perimeter	Low	High	*f* (fuels, dist.)[c]	Variable	High	Low	Necessary
2	HD Interface – Interior	Low	High	*f* (fuels, dist.)[c]	Low	High	Low	Necessary
3	MD Interface – Perimeter	*f* (hardening)	Moderate	*f* (fuels, dist.)[e]	Variable	Moderate	*f* (wildland fuels, parcel fuels)	Desired
4	MD Interface – Interior	*f* (hardening)	Moderate	*f* (fuels, dist.)[e]	Low	Moderate	*f* (parcel fuels)[d]	Desired
5	MD Intermix	*f* (hardening)	Moderate	*f* (fuels, dist.)[e]	Variable	Moderate	*f* (wildland fuels, parcel fuels)	Desired
6	LD Interface	*f* (hardening)	Low	*f* (fuels, dist.)[e]	Variable	Low[f]	*f* (parcel fuels)	Desired
7	LD Intermix	*f* (hardening)	Low	*f* (fuels, dist.)[e]	Variable	Low[f]	*f* (parcel fuels)	Desired

HD = high density, MD = medium density, LD = low density

f (*X*) indicates "a function of *X*" (e.g., the level of exposure from other parcel fuels is a function of the fuels and distance from the target structure)

[a] flames and radiation

[b] based on fire history, fuel loading, wind, and topography/aspect; wildland fuel treatments may not be at the control of the community

[c] parcel-level mitigation will have limited impact if nearby upwind structures catch on fire

[d] would be a function of wildland fuel treatment AND hardening of most/all perimeter structures and parcels

[e] parcel-level mitigation, including wildland fuel treatment, together with home hardening, will enhance structure ignition resistance

[f] ignitions due to embers from burning residential structures have been observed as far as 200 ft to 300 ft downwind

5.1. Using the HMM

The Hazard Mitigation Methodology (HMM) described in this report is summarized in four tables that can be found in Appendix A. The tables include all identified vulnerabilities; however, not all vulnerabilities may be present on every structure and/or parcel. Communities and homeowners need to address all vulnerabilities present on each individual structure to enhance ignition resistance significantly.

Table A, in Appendix A, describes all 40 structure hardening actions that have been identified to date and that are needed to significantly reduce the ignition of structures from varying ember exposures. **Table A** contains information on the structure component, assembly, or attached combustible, the hardening action, the goal, and the applicable conditions (when that hardening action is needed). The table also contains notes and a relative cost column. Structural features with large surface area (e.g., other than Class A roof coverings) or interior corners can contribute disproportionately to ember accumulation and ignition, especially in low-ember exposure situations. Because of the variability in actual experienced ember exposures, all 40 actions must be addressed if a significant reduction in structure ignition probability is to be achieved. More details on partial use of the HMM are provided in Sections 5.4.2 and 5.4.3.

Fire exposures and reduction in structure ignitions from radiation and convection are addressed by three interconnected tables in Appendix A. **Table B** and **Table C** evaluate the spatial relationships of fuels on surrounding parcels and on the parcel where the structure of interest is being protected. Here the concept of Fuel Separation Range is used. This notion is described next in Section 5.2 and **Figure 15** and **Figure 16**. **Table B** and **Table C** contain columns describing the fuel (hazard), minimum required fuel separation distance, the fuel separation range, the hardening action, notes, and whether the structure will need to be hardened against flames. Additional consideration may be needed when complex topography can result in higher exposures. The intent is to displace or remove the fuels to reduce or eliminate any structure hardening for fire in order to reduce overall retrofit costs. It should be noted that structure hardening is directional based on the expected exposures, and an all-around (full 360-degree) hardening is not required by default.

If any hardening is required by **Table B** or **Table C**, the user is directed to **Table D** where structure hardening is explicitly addressed. **Table D** contains a list of 10 specific vulnerable structural components that need to be addressed to significantly reduce the ignition potential of the structure from radiative and/or convective exposures.

5.2. Fuels Spacing

Specific hardening needs for structure protection against fire are addressed through the relationship of the exposure intensity and distance between the exposure source and the residence. The rapid decrease in radiation and convection with distance is leveraged here to optimize the required level of structure hardening. To illustrate different structure hardening needs, three scenarios of a residential structure with different structure separation distance

(SSD) to an auxiliary structure >120 ft^2, and therefore different fire exposure levels, are shown in **Figure 15** and described below. The term SSD is used in **Figure 15** because both the source and the target are structures. The same concept applies for non-structure fuels, and in those cases the term fuel separation range (FSR) is used (**Table B**). Note that in all three scenarios the residence must also be fully hardened against ember exposures, regardless of the required fire hardening.

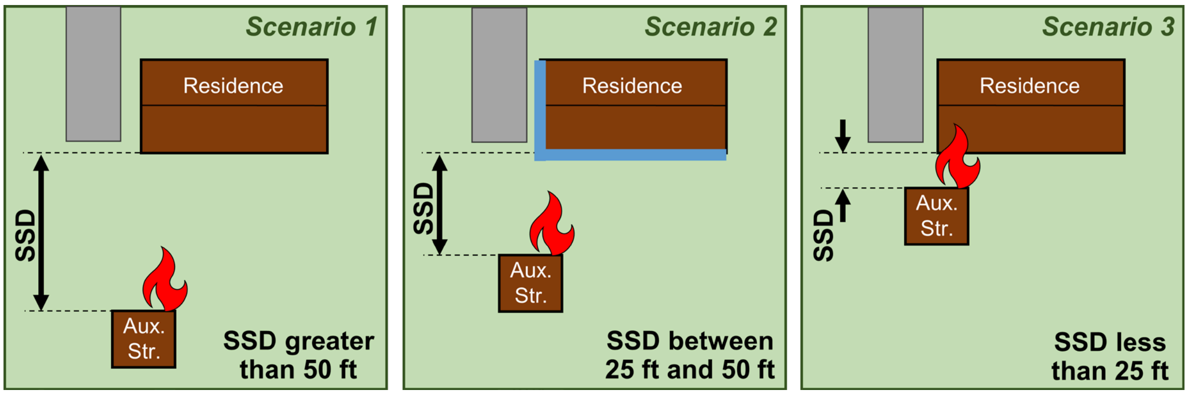

Figure 15. Three scenarios with a range of SSDs between the primary residence and auxiliary structure >120 ft^2: *1)* greater than 50 ft, *2)* between 25 ft and 50 ft, and *3)* under 25 ft. Structure hardening to increase ignition resistance is illustrated in blue (Scenario 2). Note that hardening is directional and is not necessarily required around the entire structure. Hardening for embers is required in all scenarios.

Scenario 1

This scenario represents exposure/distance combinations where the fire exposures do not reach the structure to be protected. A distance of 50 ft or greater is used in this example of auxiliary structures with floor area greater than 120 ft^2 (**Table C** Item #3). Based on field observations, the residence will not experience significant fire exposures at this distance (radiation and convection) and no hardening for fire is required.

Scenario 2

This scenario represents exposure/distance combinations where the fire exposures can ignite a structure. Hardening the residence can significantly mitigate the likelihood of structure ignition. Another way to say this is that there is a “sweet spot” in the spacing between the source and the target (residential structure or other asset to be protected) where hardening will add value. To follow the example of the auxiliary structure in Scenario 1, this range in spacing is when the auxiliary structure is between 25 ft and 50 ft from the target. This distance range is a function of the source’s energy content and spatial configuration. In this case, hardening the auxiliary structure (the source) would also reduce its ignition potential, and consequently, exposure to the primary structure.

Scenario 3
In many ways this is the most challenging scenario. This spacing range represents exposure/distance combinations where the very high fire exposures (e.g., direct flame contact from a fully involved residence) will ignite a structure and mitigation in the form of hardening will have limited or no effect in reducing the ignition potential of the structure. This represents scenarios with very high fuel densities. In the case of the auxiliary structure greater than 120 ft^2, this occurs when the auxiliary structure to target (residence or other asset to be protected) separation is less than 25 ft.

In this scenario, the path forward to increase the survivability (i.e., ignition resistance) of the target is to prevent the ignition of the source. For auxiliary structures this can be achieved by also applying the hazard mitigation methodology to the auxiliary structure. The best practice is to displace or remove the shed. Relying on ignition prevention of auxiliary structures enhances primary structure survivability under certain conditions, however, does not provide the same protection provided by displacement or removal.

The same approach applies to fire spread between residential structures and is illustrated in **Figure 16**. Unlike small auxiliary structures that can be removed or relocated in many cases, the spacing between existing residential structures is fixed and the applicable scenario will depend on the SSD.

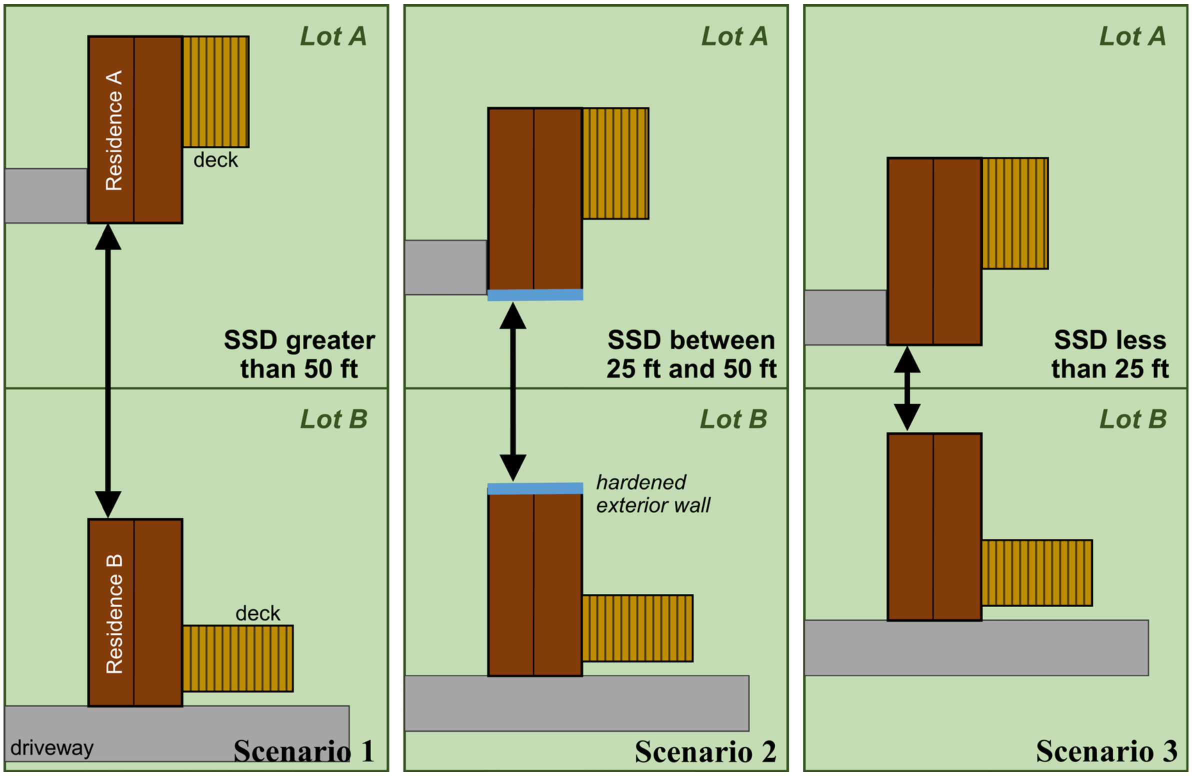

Figure 16. Three scenarios with a range of SSDs: *1)* greater than 50 ft, *2)* between 25 ft and 50 ft, and *3)* under 25 ft. Structure hardening to increase ignition resistance illustrated in blue (Scenario 2). Note that hardening is directional and is not required completely around both structures. Hardening for embers is required in all scenarios.

5.3. Fuel Density in Different WUI Types

In Section 5.2 the fuel spacing concept was introduced. This section explores the implications of fuel spacing/density across multiple parcels and different WUI Types. WUI Types can be viewed macroscopically; however, assessments need to be conducted at the parcel level. There may be considerable variability between two parcels with the same WUI Type. Lot size alone is not sufficient to determine availability of space for combustible features. Residence placement, lot geometry, and structures on surrounding parcels will impact space availability for combustible features. This is illustrated in the following example scenarios listed in **Table 4**.

Table 4. Parcel layout and fuel placement in different WUI Types visualized in Figures 17 through 20.

Scenario	WUI Type	SSD (ft)	Lot Size (ac)	Lot Dimensions (ft × ft)	Backyard Size (ac)	Backyard Dimensions (ft × ft)
A	2	10	0.14	110 × 55	0.06	55 × 25
B	4	41 to 55	0.45	150 × 150	0.14	150 × 35
C	6/4	31 to 34	1	330 × 130	0.6	200 × 130
D	6	> 50	1 to 1.2	variable	variable	variable

For SI: 1 ft = 0.305 m, 1 ac = 0.4 ha

Compare SSDs for Scenario B (WUI Type 4) and Scenario C (Type 4 or Type 6). While SSDs for Scenario B are larger, the lots are smaller which is the exact opposite of Scenario C. **Figure 17** through **Figure 20** illustrate how much space may be available on individual parcels or between parcels from select locations in the WUI. The blue shapes in these figures represent general locations where high hazard combustibles such as sheds, RVs, gazebos, and other parcel-level auxiliary fuels may be placed without directly compromising the surrounding structures from radiative and convective fire exposures. The shapes are approximate and used for illustration purposes only; exact dimensions would be a function of the combustibles present. The actual placement of the combustibles to prevent structure ignition from fire can be determined using the tables in Appendix A.

Scenario A, in **Figure 17**, shows a high-density interface community with SSD of 10 ft between residences. The area highlighted in red depicts the limited space available for auxiliary fuels in the backyard. In this scenario, the shed located in the highlighted area is closer to the neighboring residence (20 ft) than the owner's residence (27 ft). Additional hazards include the tight spacing of fences between residences, the shed placed against the fence, and interconnected fences joining multiple parcels. Conditions like this negatively impact defensible space, safe operation of first responders, and structure survivability.

An example from a medium-density interface community (Type 4) is illustrated in Scenario B, **Figure 18**. However, within this community, locations may be classified as Type 5 due to increased wildland vegetation. This scenario illustrates the effect of structure placement (on residential lots) on the available space for auxiliary fuels. The red highlighted area between the two residences contains fuels that can result in high exposures to both parcels. The area contained by the blue outline is selected here to illustrate portions of the parcel where combustibles might be safely placed away from both residences. The connectivity of the two areas outlined in red increase the number of available fire spread pathways to both primary residences. The lower two figures depict the actual fire progression pathway (*shed→fence→shed→house*) between parcels which resulted in the destruction of the structure on the left even while defensive actions were taking place.

Larger lots, in Scenario C for example, are often found in lower density communities (Type 6) and typically have space to accommodate additional combustible fuels. However, structure positioning on the parcels can result in locally high structure densities with reduced SSD, reclassifying to WUI Type 4 or 5 (medium-density interface or intermix). An example is shown in **Figure 19**, where parcels have large backyards (0.6 ac) and the structures are placed well away from the wildland boundary. However, SSD is a key driver to fire propagation between residences and will require targeted hardening in the illustrated case. While the SSD in this scenario is greater than in high density communities, fuel placement between structures can still impact fire spread and defensive actions (fuel agglomeration effectively reducing SSD).

Scenario D (**Figure 20**) shows another case with large lots similar in size to Scenario C. However, structure placement towards the center of the lot increases the average SSD and creates auxiliary fuel zones, or areas within the community that are well away from all surrounding residential structures, highlighted by the blue outlines. Avoiding agglomeration of fuels within the outlined areas would influence the total number of auxiliary fuels allowed in these spaces.

Figure 17. Scenario A, WUI Type 2. Small parcel with small SSD provides minimal space for auxiliary fuels. The shed is located closer to the neighboring residence than the owner's residence.

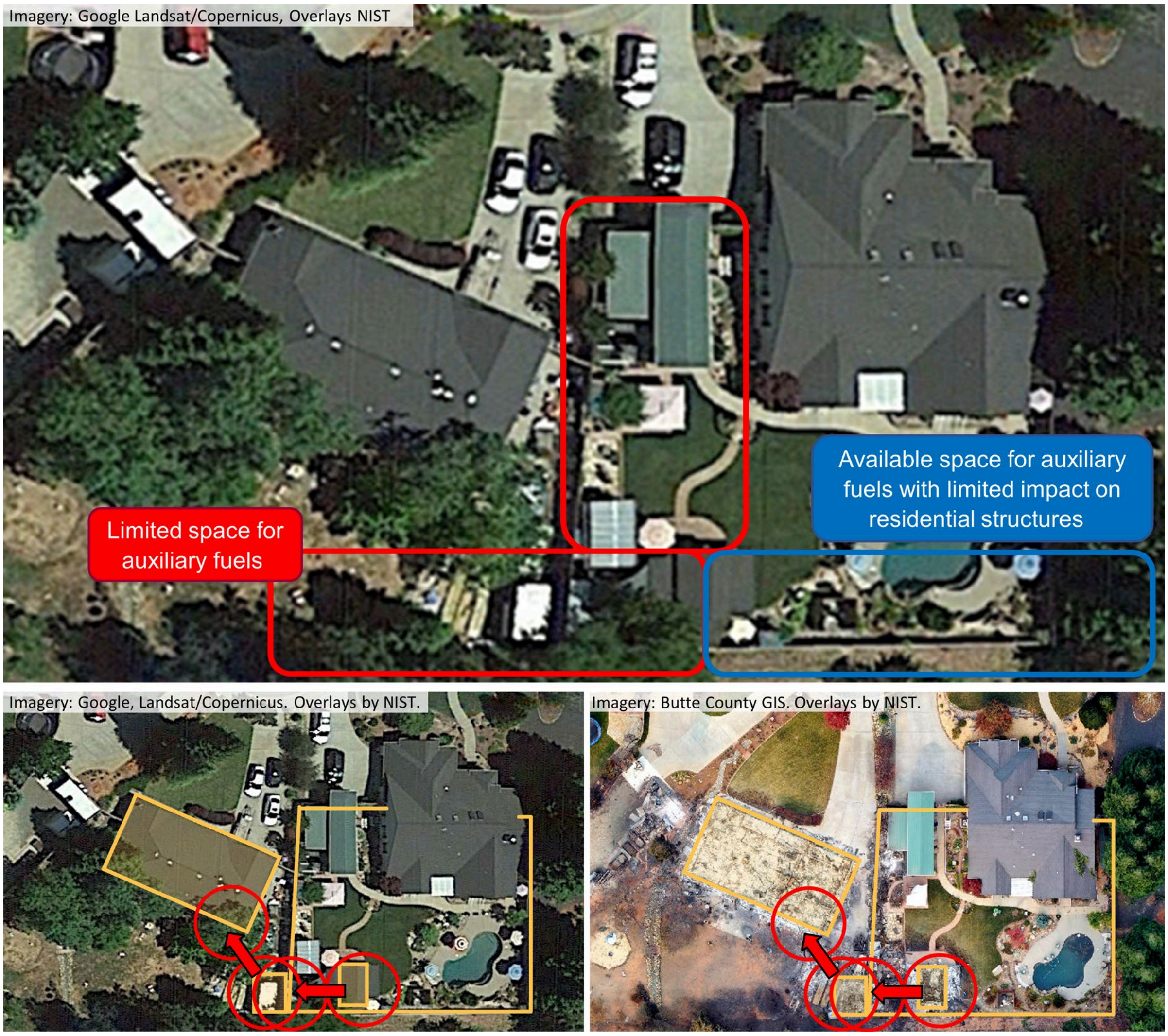

Figure 18. Scenario B, WUI Type 4. Moderate density interface. In some areas there is limited space for auxiliary fuels, shown by the agglomeration on the property boundaries (red highlights). The area highlighted in blue presents reduced impact on residential structures. The lower figures show before and after fire imagery with the actual fire spread pathway highlighted.

Figure 19. Scenario C, WUI Type 4 or Type 6. While the structures are placed on large parcels with extensive backyards, the primary structures are very large with considerably smaller SSD. Selective hardening may be required in this scenario despite the large parcels.

Figure 20. Scenario D, WUI Type 6. This community is characterized by large parcels with more extensive space available for auxiliary fuels. Avoidance of agglomeration of fuels within the outlined areas would influence the total number of auxiliary fuels allowed in these spaces.

5.4. Factors Influencing Structure Survivability

Four primary factors influence the impact of structure hardening/mitigation on structure survivability in WUI fires:

- defensive actions,
- partial structure hardening,
- partial community hardening (i.e., fraction of structures/parcels within the community that are fully hardened), and
- housing density (i.e., SSD).

5.4.1. Effects of Defensive Actions on Structure Survivability

NIST post-fire WUI case studies, conducted together with state and local stakeholders, have identified that defensive actions by first responders have a significant impact on structure survivability. NIST WUI fire reconstructions have determined that most (> 90 %) damaged structures were defended and saved by explicit first responder actions. **Table 5** summarizes the defensive action/damaged structure relationship for the Witch/Guejito, Tanglewood Complex, and Waldo Canyon Fire case studies. Remote sensing has also identified the extensive contributions of defensive actions and their impact on fire containment [42, 43].

Table 5. Defensive actions identified in NIST post-fire case studies.

Case Study	Structures in Case Study	Damaged Structures	Damaged Structures Identified as Defended	% of Damaged Structures Identified as Defended
Witch/Guejito	245	16	15	94 %
Tanglewood Complex	179	13	11	85 %
Waldo Canyon	1455	101	94	93 %

The second important finding between defensive actions and structure survivability is that many structures are often defended that are not damaged or destroyed. This was observed during both the Witch/Guejito and the Waldo Canyon Fire case studies. During the Waldo Canyon case study 154 of the 397 undamaged structures within the fire perimeter were identified as being defended (39 %). This number does not include additional actions that were taken at the parcel level which might have indirectly saved structures by reducing exposures and stopping fire spread further from the structure.

These two findings have significant implications on assessing the WUI built environment. The percentages of identified first responders that extinguished and saved the ignited structures suggests that if a home in a WUI event is damaged it was more than likely defended and that an ignited structure will not survive unless actively defended. Both the Witch/Guejito and the Waldo Canyon Fire case studies confirmed that not only were a large fraction of the undamaged homes defended but also that, in many cases, these defensive actions were not always readily identifiable in the field (during or after WUI fires). The NIST WUI data collection methodology has enabled the identification of such actions through detailed technical discussions with large fractions of the first responders involved in each incident.

Exposures have been demonstrated to vary at a sub-parcel level in all NIST case studies [4-8, 32]. Additionally, information from field data collection does not indicate that the varying exposures and defensive actions "average out" throughout an incident. All these findings suggest that post-fire analysis of damage and survivability should not be conducted in the absence of defensive action data. Any assessments not accounting for defensive actions will likely be incomplete and possibly inaccurate.

The occurrence of large WUI fires, like the Tubbs and Camp Fires, together with the numerous fire storms that have occurred in California since 2000, suggest that structures must be designed to stand alone as the number of exposed structures can quickly outnumber statewide resources. Defensible space contributes to making structures defensible by first responders; however, this is not a substitute for homes standing completely alone throughout a WUI fire event.

5.4.2. Impacts of Structure Mitigation Compliance on Structure Resilience

The impact of partial hardening on structure survivability is not directly proportional to the fraction of hardening actions implemented. As an example, doing half of the ember hardening specified in **Table A** (see Appendix A) does not automatically translate to a 50 % increase in ignition resistance. The relationship between effectiveness of partial hardening and local exposures can be represented by the following statement:

$$\begin{matrix}\textit{Effectiveness of}\\ \textit{partial hardening}\end{matrix} \propto \frac{1}{\left(\begin{matrix}\textit{local fire and}\\ \textit{ember exposures}\end{matrix}\right)\left(\textit{incident size}\right)\left(\begin{matrix}\textit{number of}\\ \textit{simultaneous}\\ \textit{incidents}\end{matrix}\right)}$$

If the structure of interest receives very limited exposures, then the effectiveness of partial hardening is increased. Considering the 50 % ember hardening scenario discussed previously—if a structure is in a location where only very few embers land on it, there is a better chance of survival. However, the high exposure scenario is quite different. If very high ember exposures impact the structure, it is improbable that the structure will survive unless all the ember hardening identified in **Table A** had been implemented. That is because in high ember exposures, where thousands and thousands of embers hit the structure, it is likely that embers will "find" one or more of these vulnerabilities and cause the structure to ignite. The same concept applies to hardening structures for fire exposures. If a structure is only partially hardened and the weak spot ignites, the otherwise hardened components will have limited to no effect on structure survivability once the structure has ignited. In this situation only timely defensive actions will result in a damaged, rather than destroyed, structure.

The increase in incident size has a negative effect on partial structure hardening. As the incident gets larger (in terms of area and number of structures ignited), the number of available first responders per residence or parcel decreases. This also holds true in the event of a fire storm where the finite number of first responders will have to respond to multiple WUI fires, further reducing the number of responders per residence or parcel.

It should be noted that among local fire and ember exposures, incident size, and number of simultaneous incidents, the only potential control that can be exercised is the reduction of fire exposures at the parcel level. Fuel reduction, displacement, and removal will all impact local exposures. However, the ember exposures will only be partially impacted as embers can travel from far beyond residential parcel boundaries; therefore, hardening is required.

The above can be summarized by saying partial ember hardening only adds some value in low exposure conditions, and almost no value in high exposure conditions. The localized variability of fire behavior results in unpredictable ember exposures. Full ember hardening is necessary to enable structures to stand alone during high ember exposures. The same holds true for fire exposures. Suppose a combustible, and readily ignitable, auxiliary structure or RV is located too close to a home, and there is significant fire or ember activity on the parcel. In that case, there is a likelihood that the auxiliary structure or RV will ignite and proceed to ignite the structure. Therefore, to stand alone, the structure must be evaluated and fully hardened for embers, and the structure and parcel hardened for fire where necessary.

5.4.3. Impacts of Community Mitigation Compliance on Community Resilience

The impact of a partially hardened structure on the community is inversely related to SSD; partially hardened structures need to be further apart.

In low density communities, a structure ignition will increase local ember exposures; observations have shown these ember exposures to be significant in the first 300 ft downwind [4].[11] Locally there will also be increased exposures from fire (radiation and/or convection). These exposures may impact parcel-level combustible features; however, there should not be any direct fire exposures to adjacent properties due to larger SSD. The impact to the adjacent properties and community will be indirect in terms of fire, and possibly low for ember exposures (because of the large SSDs). Therefore, in low density communities with large SSDs the impact of structure ignition on the surrounding structures is low.

[11] Data collected from the Waldo Canyon Fire case study showed embers from burning structures resulted in structure ignitions 200 ft to 300 ft downwind.

In moderate density communities, a structure ignition can ignite an adjacent property under a "favorable" wind direction and other local conditions. The embers generated from a burning structure will generate significantly higher exposures to the downwind structures relative to the low-density case due to separation distance. Compared to low density, the relative impact of a structure ignition to the surrounding structures can be seen as medium.

However, high density communities are in a very different exposure category. Here the ignition of a structure will almost invariably result in the ignition of one or more adjacent properties and will likely result in the loss of a significant fraction of the community, as evidenced by several large loss WUI fires in the U.S. This is not only because fire spread occurs very easily between tightly spaced structures, but also because it is very difficult to contain a fully involved structure fire, even when only moderate winds of 10 mi/h to 15 mi/h are present. Fire spread is difficult to stop as it is very challenging to remove/block the heat between residential buildings when they are constructed 6 ft to 10 ft apart.[12] In high-density construction, a single ignition can have a disproportionate impact on the overall community losses.

5.4.4. Effects of Housing Density on Mitigation Strategies

The fire spread information provided in this report can be used to develop an overall community WUI mitigation strategy. The community response specifically in terms of community participation is summarized in **Table 3**. The primary technical messages for the different structure density and WUI types are listed below.

1. *High Density Communities*
   Community participation is necessary in high-density communities. This is due to the disproportionate impact of a single structure ignition on the community. There are many ways to accomplish this via voluntary or mandatory community hazard mitigation programs. Different programs can be implemented using HOA, county, or state rules and regulations. The design and implementation of such programs are beyond the scope of this report. What is important in these communities is to harden the structures and parcels for ember exposures, as these can originate from outside the community, and also ensure that there are no fire spread pathways that can generate fire exposures to residences. In certain scenarios, additional protection may be provided by structure cladding (siding and roofing) hardening requirements (such as included in CA Chapter 7A). While these requirements add significant value for protecting against low and moderate exposures, they will frequently not be able to cope with the full exposure assault of a residence burning 6 ft to 10 ft away because of limitations of one of the components in the wall or roof assemblies. Parcel-level hardening is a critical requirement in these high-density communities, and auxiliary fuel removal (instead of displacement) will likely be necessary on very small lots. A key issue that will need to be addressed is the presence of vehicles in the community, as they can generate locally high fire exposures resulting in structure ignitions.

[12] Common building setback requirements are often 3 ft to 5 ft from the property line.

Ongoing research by NIST, CAL FIRE, and IBHS aims to provide guidance on minimum spacing between vehicles and residences in the future.

2. *Moderate Density Communities*
Moderate density communities offer more options to residents for community participation in hazard mitigation. In moderate density construction, the ignition of a single residence may directly impact one or more adjacent residences. However, direct fire (via radiation and convection) progression across the community will depend on local construction, spacing, and fuels more than in high density. Here there is an opportunity to slow down that fire spread and reduce the structure ignition pathways by selectively hardening structure sides that may see increased exposures. This selective structure hardening reduces overall community hardening program costs while increasing community resilience. Hardening of all structures for embers is still necessary in these communities. Fuel displacement, reduction, and removal may also need to be implemented to reduce fire exposures.

3. *Low Density Communities*
These community types, by the nature of their structure density, do not present a direct structure to structure fire spread pathway as can be expected in high density and certain moderate density configurations. These larger parcels also offer a significantly large number of fuel displacement options to residents, as auxiliary parcel level fuels can be placed where they will not impact other fuels, the primary residence, or neighboring structures. The notion of sacrificial auxiliary structures/features can be introduced in this setting; a resident with a large lot may be willing to accept the loss of an auxiliary structure that is located far from their residence or other features to be protected. In a low-density community this may be a readily acceptable hazard if the residence is hardened for ember exposures and all other potential fire propagation pathways near the residence have been disrupted (using the provided methodology).

6. Frequently Asked Questions

A few common scenarios are presented in a question-and-answer format to provide examples of the thought process behind applying the HMM to each case. Questions are posed as if they are from homeowners with an interest in personal and community mitigation.

Q: I live in a high-density community. What can I do to prevent my structure from burning during a WUI fire?

A: There are three steps that you can take to increase the likelihood of your home surviving a WUI fire:

1. Apply the methodology in this report to your home and parcel. You will need to harden your home against embers and evaluate and address any potential fire exposures within your parcel. This may require you to reduce, relocate, replace, and possibly remove some auxiliary parcel-level fuels.
2. Work with your neighbors and get them to engage and follow the same practices.
3. In your high-density community you will want to get as many residents as possible to follow the hazard mitigation methodology. To accomplish this, you could engage your community (via a homeowner's association (HOA), if present) as well as your local and county representatives (e.g., FireSafe Councils, Firewise USA, and local town/city/county jurisdictions) about implementing community-wide tools for hazard reduction. Whether the tools are mandatory or voluntary, complete community participation is essential.

Q: I have a shed on my 2-acre lot that is far from any other fuels on my property. Can I keep that shed where it is?

A: There are two parts to this answer:

1. Consider clearing the zone within 5 ft of your shed to minimize the chance of a surface fire or embers directly igniting the shed. You can always work on hardening the exterior building materials of the shed to make it more ignition resistant; however, these actions may not be necessary if the shed itself is an acceptable loss.
2. You should also consider how your shed may impact neighboring properties. What you want to avoid is your shed posing a significant exposure to your neighbor's residence. If your shed is close to a neighboring residence, consider moving your shed elsewhere on your property. If that is not possible, consider hardening the exterior building materials of the shed to make it more ignition resistant. You can apply the methodology to harden your shed against embers and increase the likelihood that your shed will not ignite. By preventing the ignition of your shed, you are contributing to preventing the ignition of your neighbor's residence. Fire does not care about property lines, and WUI fire mitigation is a community-level effort. You want to work with your neighbors to protect their home, as you may need their help to protect your own home.

Q: I have a half-acre lot and my neighbors are 60 feet away. My home is older and does not have a hardened wall cladding (siding). Do I need to replace my wall cladding (siding)?

A: There are three parts to this answer:

1. First make sure that your residence is hardened for ember exposures. You should address all 40 vulnerabilities identified in this methodology.
2. Look at your parcel and make sure you do not have any parcel-level pathways that can bring fire to your residence. Address any potential fire spread pathways (e.g., fence to house, fence to vehicle to house) by reducing, relocating, replacing, and possibly removing, auxiliary parcel-level fuels.
3. The exposure from your neighboring structure is beyond the special limit outlined in the Hazard Mitigation Methodology. However, if your cladding is old and you are concerned that local conditions may cause significant fire exposures, you can consider replacing the cladding only in the direction (side) that is facing your neighbor's residence. This will reduce the overall mitigation expense.

7. Comparison of this Hazard Mitigation Methodology with National and International WUI Codes

None of the current codes/best practices implement the breadth of mitigation components considered in the HMM, and none of them harden as extensively as the HMM requires.

Table A includes 40 items with a total of 57 options to specifically address structure hardening for ember exposures. The list encompasses all currently identified vulnerabilities; however, some structures may not have all of the vulnerabilities identified, and vulnerabilities to embers not currently identified in the HMM may also exist. All of the ember ignition vulnerabilities present on each individual structure need to be addressed to significantly enhance ignition resistance. An additional 10 structure ignition vulnerabilities are identified in **Table D** to harden for fire exposures identified in **Table B** and **Table C**.

Table 6 below summarizes the number of options completely included in each of the selected WUI building codes for both fire and ember vulnerabilities. While a lot of ember and fire hardening information is included in the compared codes, the exact requirements outlined in HMM are only identified in the existing codes in limited numbers. Fire progression and structure hardening at the component and assembly level requires very detailed and exact guidance. The detailed information presented in this document is based on the latest science and field observation data. Appendix B contains a tabulated list of detailed comparisons of primary solutions listed in the analyzed building codes, in **Table E**.

The differences between the compared codes and best practices and HMM may be due to different goals and objectives. Some codes may emphasize defensible space and explicitly rely on first responders to save structures, while other best practices may focus on engaging residents, providing education, and/or starting community participation. The purpose of the HMM is to present implementable guidance to significantly increase the likelihood of structure survival without external intervention in the form of defensive actions. This was set as the structure protection criteria because the predominance of large WUI events and fire storms in the last twenty years point to that need.

Table 6. HMM items completely included in selected existing WUI building codes.

WUI Code	Number of ember items from **Table A** (out of 57)	% of ember items	Number of fire items from **Table D** (out of 10)	% of fire items
7A/1140/IWUIC	5 to 13	9 to 23	0 to 5	0 to 50
All 3 codes	3	5	0	0
None	42	74	5	50

8. Summary

WUI fires have grown in intensity, frequency, and devastation in the past twenty years. NIST, CAL FIRE, and IBHS have developed the Hazard Mitigation Methodology detailed in this report. The goal of HMM is to reduce the vulnerability of structures and parcels in a cost-efficient and implementable way. The HMM was conceived to allow structures in the WUI to "stand alone" and survive fire and ember exposures without contributions from first responders. This was deemed necessary as field data has demonstrated that wildfire progression can quickly outpace the efforts of first responders during large and/or concurrent WUI fires. NIST WUI reconstruction data has also shown the efficient and effective structure protection actions by first responders; very little or no meaningful improvement can be achieved in this area. The emphasis must be shifted to making structures stand alone.

This HMM has outlined a detailed structure hardening strategy to resist ignitions from ember exposures. The 40 identified structure ignition vulnerabilities illustrate how detailed structure hardening must be for a structure to stand alone. Structures in the WUI need to be protected against ember exposures independent of WUI Type and housing density. This list goes significantly beyond what is outlined in many best practice documents currently available to WUI residents. The spatial analysis used in the HMM was developed specifically to address fire (radiation and convection) exposures within and across parcels. The latest science and expert knowledge combining decades of field observations were used to develop the spatial relationships outlined in the HMM. Discussions with the building industry were necessary to clarify and improve different implementation solutions.

Full community participation will be critical to hardening existing high-density communities. This document has outlined a technical path forward to accomplish this. The methodology was also developed specifically to reduce the overall financial burden of mitigation. The preferential/partial use of this methodology is undesirable and provides only very limited actual structure ignition resistance.

HMM was developed based on how fire spreads between and across parcels, as fire behavior does not respect parcel boundaries. HMM was developed utilizing the principles of fuel reduction, relocation, and removal. By implementing the HMM, residents and communities can significantly reduce structural losses from future WUI fires.

NIST and IBHS are non-regulatory entities, while CAL FIRE has regulatory authority in the state of California. This HMM was developed to provide AHJs and homeowners with the latest comprehensive understanding of fire behavior and structure response in the WUI. This report has demonstrated the benefits of using HMM as it is designed and presented here, as well as the limitations of partial implementation. Regulatory agencies and homeowners will choose where to implement any or all of the components presented in the HMM. Future hazard mitigation research (including laboratory and field observations) will be incorporated into the methodology to further enhance its effectiveness.

Summary of Key Technical Principles

This section contains two types of technical principles. The first is a list of specific principles followed by two lists of generalized relationships between exposures, structure hardening, and community survivability.

In the WUI, structures can experience two distinct fire exposure problems/hazards—embers and fire. Following are three sets of technical principles specific to fire, embers, and parcel/community hazard mitigation implementation.

Embers

1. Ember exposures to the residence/parcel to be protected can originate from adjacent and/or far field parcels and are beyond the control of the owner of the parcel being protected.
2. Increased ignition resistance of features and specific combustion considerations can decrease ember generation.
3. Large surface area combustibles (e.g., combustible roof) contribute significantly to the ember ignition hazard.
4. Large ember exposures can be generated and observed in WUI fire incidents. Ember exposures can vary significantly in space and time.
5. The potential for high ember exposures drives the need to harden structures against ember exposures completely.
6. Partial structure hardening for embers does not relate linearly to hazard reduction. 90 % ember hardening does not translate to 90 % risk reduction.
7. In high ember exposures, complete ember hardening (100 % compliance) is necessary to significantly reduce the structure ignition potential from embers.

Fire

8. Fire represents a direct and indirect exposure hazard to residences, commercial structures, and infrastructure in the WUI. Direct exposures occur when a source (item burning) directly impacts a target, in this case a residence or commercial structure. Indirect exposures occur when a source ignites a secondary fuel, impacting the target.
9. Fire exposure increases via fuels agglomeration. Increased fire exposures can then potentially impact the residence/commercial structure. Increased exposure also negatively impacts defensible space, making it more hazardous for first responders to conduct firefighting and rescue operations.
10. A property owner can control and reduce fire exposures to their residence/commercial structure by managing their parcel-level combustibles.
11. A property owner may not be able to control fire exposures from adjacent parcels.

Parcel/Community

12. The parcel size and placement of structure(s) will determine structure-to-structure exposures within the parcel and to adjacent parcels.
13. Structure separation distances have significant impact on fire propagation in the WUI.
14. Fuel relocation, reduction, and/or removal should be considered when addressing parcel hardening independent of WUI housing density.
15. Even if certain parcel-level combustible features are seen as expendable/disposable in the context of parcel hardening, the impact of these features must be considered in the context of fuels agglomeration and exposures to structures and other nearby combustibles.
16. In high-density WUI communities, fuel removal may be necessary to comply with the HMM and reduce structural losses.

The following lists contain information intended to capture the relationships between exposures, parcel and structure hardening, and community structural losses. The relationships illustrated here are intended to provide relative performances and highlight trends and critical thresholds. Actual conditions, including construction, parcel sizes and fuel loading, structure separation distances, parcel and structure hardening, local weather, ignition sequencing, and defensive actions, will impact actual fire spread and community resilience.

General Relationships between Exposure and Hardening

1. Low fire exposures are relatively easy to address by hardening the structure.
2. High fire exposures (direct flame impingement from large sources such as a burning residence) are very difficult to address by hardening the structure. This is because both the cladding (siding and roofing) material and the assembly need to be hardened not only to withstand the exposure but also to withstand it for the entire exposure duration, therefore potentially propagating energy into the assembly past the external cladding component.
3. Fire exposures from a fully involved single family residence will result in fire propagation that will be very difficult to stop in the presence of wind in high density communities.
4. High fire exposures can readily cause direct ignition of exposed combustibles.
5. The ember hardening and structure survivability relationship is not linear. Hardening 80 % of the vulnerabilities will not necessarily result in 80 % decrease in structure ignition potential. While the actual values will vary based on local conditions and specifics of hardening, the relationship will apply to almost all scenarios.
6. In situations where a potential fuel source is located near a residential/commercial structure and when fuel reduction, relocation, or removal cannot alleviate severe fire exposures to that structure, hardening the structure for fire may frequently add limited value. In these situations, ignition prevention of the fuel source will be the critical path to reducing the ignition of the residential/commercial structure.

General Relationships between Structure/Parcel Hardening Compliance and Community Survivability

1. Partial community compliance, in the form of incomplete structure and parcel hardening, has limited impact beyond the partially hardened properties in a low-density community.
2. Partial community compliance, in the form of incomplete structure and parcel hardening, has moderate impacts beyond the partially hardened properties in a moderate-density community.
3. Partial community compliance, in the form of incomplete structure and parcel hardening, has *very significant* impacts across the *entire community* in high- density communities. Just a few partially hardened properties can jeopardize an entire high-density community.

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References

[1] Weber K.T. , Yadav R. (2020) Spatiotemporal Trends in Wildfires across the Western United States (1950–2019). *Remote Sensing* 12:2959. https://doi.org/10.3390/rs12182959

[2] Buechi H., *et al.* (2020) Long-term trends in wildfire damages in California. emLab at UC Santa Barbara. https://emlab.ucsb.edu/sites/default/files/documents/wildfire-brief.pdf. Accessed: January 2022.

[3] CAL FIRE (2021) *Top 20 Most Destructive California Wildfires*. (Updated October 25, 2021) Available at https://www.fire.ca.gov/media/t1rdhizr/top20_destruction.pdf. Accessed: January 2022.

[4] Maranghides A., *et al.* (2015) A Case Study of a Community Affected by the Waldo Fire – Event Timeline and Defensive Actions. *NIST Technical Note 1910*. National Institute of Standards and Technology, Gaithersburg, MD. https://doi.org/10.6028/NIST.TN.1910

[5] Maranghides A. , McNamara D. (2016) 2011 Wildland Urban Interface Amarillo Fires Report #2 – Assessment of Fire Behavior and WUI Measurement Science. *NIST Technical Note 1909*. National Institute of Standards and Technology, Gaithersburg, MD. https://doi.org/10.6028/NIST.TN.1909

[6] Maranghides A., *et al.* (2011) Initial Reconnaissance of the 2011 Wildland-Urban Interface Fires in Amarillo, Texas. *NIST Technical Note 1708*. National Institute of Standards and Technology, Gaithersburg, MD. https://doi.org/10.6028/NIST.TN.1708

[7] Maranghides A., *et al.* (2021) A Case Study of the Camp Fire — Fire Progression Timeline. *NIST Technical Note 2135*. National Institute of Standards and Technology, Gaithersburg, MD. https://doi.org/10.6028/NIST.TN.2135

[8] Maranghides A. , Mell W. (2009) A Case Study of a Community Affected by the Witch and Guejito Fires. *NIST Technical Note 1635*. National Institute of Standards and Technology, Gaithersburg, MD. https://doi.org/10.6028/NIST.TN.1635

[9] Maranghides A. , Mell W. (2013) Framework for Addressing the National Wildland Urban Interface Fire Problem – Determining Fire and Ember Exposure Zones using a WUI Hazard Scale. *NIST Technical Note 1748*. National Institute of Standards and Technology, Gaithersburg, MD. https://doi.org/10.6028/NIST.TN.1748

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

[11] US Department of Agriculture , US Department of Interior (2001) Urban Wildland Interface Communities Within the Vicinity of Federal Lands That Are at High Risk From Wildfire. *Federal Register* 66(3):751-777. https://www.federalregister.gov/d/01-52

[12] Davis J.B. (1989) Demography: A Tool for Understanding the Wildland-Urban Interface Fire Problems. *Proceedings of the Symposium on Fire and Watershed Management (Oct. 26–28, 1988, Sacramento, CA),* General Technical Report PSW-109, ed Berg N.H. (USDA Forest Service, Pacific Southwest Forest and Range Experiment Station, Berkeley, CA), pp 38–42.

[13] GAO (2003) Wildland Fire Management: Additional Actions Required to Better Identify and Prioritize Lands Needing Fuels Reduction. *GAO-03-805*. U.S. General Accounting Office, Washington, D.C. https://www.gao.gov/assets/gao-03-805.pdf. Accessed: December 2021.

[14] Stewart S.I., *et al.* (2007) Defining the Wildland-Urban Interface. *Journal of Forestry* 105(4):201–207.

[15] Mell W.E., *et al.* (2010) The wildland-urban interface fire problem–current approaches and research needs. *International Journal of Wildland Fire* 19:238-251. https://doi.org/10.1071/WF07131

[16] Healthy Forests Restoration Act of 2003, 16 U.S.C. § 6511, (2003) (https://www.govinfo.gov/content/pkg/USCODE-2003-title16/pdf/USCODE-2003-title16.pdf)

[17] Radeloff V.C., *et al.* (2005) The Wildland-Urban Interface in the United States. *Ecological Applications* 15(3):799–805.

[18] Martinuzzi S., *et al.* (2015) The 2010 wildland-urban interface of the conterminous United States (NRS-RMAP-8). U.S. Department of Agriculture, Forest Service, Newtown Square, PA. https://doi.org/10.2737/NRS-RMAP-8

[19] Wilmer B.G. , Aplet G. (2005) Targeting the Community Fire Planning Zone: Mapping Matters. The Wilderness Society, Washington, D.C.

[20] Theobald D.M. , Romme W.H. (2007) Expansion of the US wildlan-urban interface. *Landscape and Urban Planning* 83:340–354. https://doi.org/10.1016/j.landurbplan.2007.06.002

[21] Platt R.V. (2010) The Wildland-Urban Interface: Evaluating the Definition Effect. *Journal of Forestry* 108(1):9–15.

[22] Stewart S.I., *et al.* (2009) Wildland-Urban Interface Maps Vary with Purpose and Context. *Journal of Forestry* 107(2):78–83. https://www.fs.fed.us/rm/pubs_other/rmrs_2009_stewart_s001.pdf

[23] Greetan J.D. (2016) The Wildland-Urban Interface in Lassen County, California: A Change Analysis 2000–2015 [Masters Thesis]. (University of Southern California, Los Angeles, CA). Retrieved from https://spatial.usc.edu/wp-content/uploads/formidable/12/Josh-Greetan.pdf. Accessed: December 2021.

[24] Kramer H.A., *et al.* (2019) High wildfire damage in interface communities in California. *International Journal of Wildland Fire* 28(9). https://doi.org/10.1071/wf18108

[25] Cal. Pub. Res. Code § 4201–4204, (Fire Hazard Severity Zones)

[26] CAL FIRE (n.d.) *Fire Hazard Severity Zones*. Available at https://osfm.fire.ca.gov/divisions/wildfire-planning-engineering/wildfire-prevention-engineering/fire-hazard-severity-zones/. Accessed: December 2021.

[27] California Building Standards Commission (2019) Chapter 7A: Materials and Construction Methods for Exterior Wildfire Exposure. *2019 California Building Code (Cal. Code Regs., Title 24, Part 2)*, (International Code Council, Inc.).

[28] California Building Standards Commission (2019) Chapter 49: Requirements for Wildland-Urban Interface Fire Areas. *2019 California Fire Code (Cal. Code Regs., Title 24, Part 9)*, (International Code Council, Inc.).

[29] Cal. Gov. Code § 51175–51189, (2020) (Very High Fire Hazard Severity Zones)

[30] LANDFIRE (n.d.) Available at https://www.landfire.gov/. Accessed: January 2022.

[31] Maranghides A. , Johnsson E.L. (2008) Residential Structure Separation Fire Experiments. *NIST Technical Note 1600*. National Institute of Standards and Technology, Gaithersburg, MD. https://doi.org/10.6028/NIST.TN.1600

[32] Maranghides A.*, et al.* (2013) A Case Study of a Community Affected by the Witch and Guejito Fires Report: #2 – Evaluating the Effects of Hazard Mitigation Actions on Structure Ignitions. *NIST Technical Note 1796*. National Institute of Standards and Technology, Gaithersburg, MD. https://doi.org/10.6028/NIST.TN.1796

[33] CAL FIRE (n.d.) *Defensible Space*. Available at https://www.readyforwildfire.org/prepare-for-wildfire/get-ready/defensible-space/. Accessed: January 2022.

[34] Caton S.E.*, et al.* (2016) Review of Pathways for Building Fire Spread in the Wildland Urban Interface Part I: Exposure Conditions. *Fire Technology* 53(2):429–473. https://doi.org/10.1007/s10694-016-0589-z

[35] El Houssami M.*, et al.* (2016) Experimental Procedures Characterising Firebrand Generation in Wildland Fires. *Fire Technology* 52(3):731-751. https://doi.org/10.1007/s10694-015-0492-z

[36] Suzuki S. , Manzello S.L. (2018) Characteristics of Firebrands Collected from Actual Urban Fires. *Fire Technology*. https://doi.org/10.1007/s10694-018-0751-x

[37] Thomas J.C.*, et al.* (2017) Investigation of firebrand generation from an experimental fire: Development of a reliable data collection methodology. *Fire Saf J* 91:864-871. https://doi.org/10.1016/j.firesaf.2017.04.002

[38] Bouvet N., Link E.D., Fink S.A. (2020) Development of a New Approach to Characterize Firebrand Showers During Wildland-Urban Interface (WUI) Fires: a Step Towards High-Fidelity Measurements in Three Dimensions. *NIST Technical Note 2093*. National Institute of Standards and Technology, Gaithersburg, MD. https://doi.org/10.6028/NIST.TN.2093

[39] Bouvet N., Link E.D., Fink S.A. (2021) A new approach to characterize firebrand showers using advanced 3D imaging techniques. *Experiments in Fluids* 62:181. https://doi.org/10.1007/s00348-021-03277-6

[40] Hakes R.S.P., *et al.* (2016) A Review of Pathways for Building Fire Spread in the Wildland Urban Interface Part II: Response of Components and Systems and Mitigation Strategies in the United States. *Fire Technology* 53(2):475–515. https://doi.org/10.1007/s10694-016-0601-7

[41] Butler K. , *et al.* (2022) Wind-driven Fire Spread to a Structure from Fences and Mulch. *NIST Technical Note (in progress)*. National Institute of Standards and Technology, Gaithersburg, MD.

[42] McNamara D., Mell W., Maranghides A. (2020) Object-based post-fire aerial image classification for building damage, destruction and defensive actions at the 2012 Colorado Waldo Canyon Fire. *International Journal of Wildland Fire* 29:174–189. https://doi.org/10.1071/WF19041

[43] McNamara D. , Mell W. (2022) Towards the use of Remote Sensing for Identification of Building Damage, Destruction, and Defensive Actions at Wildland-Urban Interface Fires. *Fire Technology* 58:641–672. https://doi.org/10.1007/s10694-021-01170-6

Appendix A. Home Hardening Requirements

The following tables identify the various potential structure and parcel ignition vulnerabilities and their associated mitigation options.

Table A specifically addresses hardening against ember exposures. **Table B** and **Table C** list hazards from adjacent parcels and hazards from within the parcel containing the residence being protected. These tables are linked spatially to **Table D**, which contains structure hardening requirements for exposures from fire (flames and radiation).

Table A is divided into 8 major categories (e.g., roof, walls, vents, etc.) listing specific structural components or assemblies. The table contains columns listing the hardening action, the performance goal of the action, and the applicable conditions associated with each component. Also included are any brief notes, and a column estimating relative cost of each action. The final column indicates which of the selected existing WUI building codes (CA Building Code Chapter 7A, NFPA 1140, and ICC IWUIC) address the specific hazard to the necessary detail.

Table B addresses parcel fire exposures to the primary residence from far-field fuels included in adjacent parcels. For each fire-emanating source (e.g., neighboring structure, wildland fuels) a minimum required fuel separation distance (MFSD) or fuel separation range (FSR) is provided. If the hazard is located closer than the listed MFSD, or within the listed FSR, structure hardening must be addressed via **Table D**. If the fuel is further than the listed distances, no hardening action is required for fire exposures. If the fuel is closer to the structure being protected than the listed FSR, hardening for fire will have limited impact due to the expected severity of the exposure, and is therefore not required in the HMM for cost savings. AHJs or homeowners may choose to add an additional level of protection by hardening in these situations.

Table C addresses parcel hazard mitigation and lists 9 separate types of vulnerabilities. The table contains columns on hardening actions, goals, and the applicable conditions. Similar to **Table A**, notes and expected relative cost are included. As in **Table B**, MFSDs are provided, and links to **Table D** when spatial conditions require mitigating action.

Table D lists 10 separate structure components requiring hardening for fire exposures. The use of **Table D** is driven by the spatial requirements identified in **Table B** and **Table C**. Similar to the other tables, columns are included for hardening action, the performance goal, and the applicable conditions of the component/assembly. Columns for notes and expected relative cost are also provided. As in **Table A**, comparison to selected existing codes is also included.

Table A. Structure and attached combustible hardening against ignition from embers.

Item #	Structure Component, Assembly, or Attached Combustible	Hardening Action	Performance Goal	Applicable Condition(s)	Notes	Expected Cost Range ($, $$, $$$)	Matched in Existing Code
Roof							
1	Skylights	Replace plastic skylight with multipaned glass with tempered glass outer pane. If skylight opens, install metal screen on the inside. If screen is non-metal replace with metal.	Minimize embers with enough energy to cause ignitions	Plastic skylight pane, nonmetal screen, no screen	Screen is needed only on openable skylights	$	Chapter 7A NFPA 1140 ICC IWUIC
2	Roof to skylight flashing	Check for standard metal flashing and that no exposed wood is present, repair as necessary.	Prevent ignition of combustible skylight framing	Lack of metal flashing around skylight	n/a	$	None
3	Roof assembly details (i.e., dormer and other roof-to-wall intersections)	Metal flashing at roof-to-wall	Prevent ignition of roof from burning debris accumulation	Combustible siding at roof-to-wall intersection	Alternative option: Add the 6 inch "tall" flashing over the existing siding or remove the siding and put flashing on.	$	None
		Replace with noncombustible siding in that area only (e.g., dormer or split-level residence)			Preferred option: remove combustible siding and replace with noncombustible siding.	$$	None
4	Solar panels	Minimize debris accumulation under and next to solar panels	Prevent ignition of debris, solar panels, and roof	Solar panels on roof	No additional baffles or screening should be installed as they may impact PV cooling	$	None
5	Roof covering – old wood shake	Replace with Class A (with noncombustible birdstopping, if needed)	Prevent ignition of roof material	Non-fire retardant treated wood shake roof	n/a	$$$	Chapter 7A NFPA 1140 ICC IWUIC
6	Roof covering – Class B	Replace with Class A when needed	Prevent ignition of roof material	Degraded or end of life Class B roof and needs replacement	n/a	$$$	Chapter 7A
	Roof covering – Class C			Degraded or end of life Class C roof and needs replacement			
7	Roof covering with openings between roof covering and edge or ridge	Close/plug with noncombustible material	Prevent accumulation of debris between roof covering and roof deck	Style of roof (tile or metal) that creates openings	n/a	$-$$	Chapter 7A NFPA 1140 ICC IWUIC
8	Gutters	Noncombustible gutter cover [a]	Limit accumulation of ignitable debris in gutters	Combustible gutter cover or no gutter cover	If metal cover cannot be installed on plastic gutter, then replace gutter with metal gutter and noncombustible cover	$-$$	ICC IWUIC NFPA 1140
		Metal drip edge	Prevent ignition from embers, protect facia and sheathing from flames		Certain gutters already have drip edge as part of the gutter	$	None
		No-gutter	Prevent ignition from embers		Very expensive solution, less expensive options are available	$$$	None
9	No gutter	Add metal flashing if fascia does not cover roof sheathing	Prevent accumulation of embers at fascia-sheathing intersection	Exposed sheathing (i.e., not covered by fascia)	May require subsurface-surface drainage such as ICC 11.01.6	$	None
Cladding (Siding)							
10	Height of wall assembly from the ground	Replace exterior wall covering with noncombustible material for the bottom 2 ft (from ground); add metal flashing to protect bottom edge of sheathing	Prevent windblown debris and local fuels from igniting the wall	All siding within 2 ft of ground	Metal flashing is required for all claddings, including noncombustible	$$	None
Vents[b]							
11	Ridge vent	Add metal baffle	Minimize embers with enough energy to cause ignitions	Plastic ridge vent AND installable metal baffle	Metal flashing	$	None
		Replace ridge vent w/ metal ridge vent		Plastic ridge vent AND non-installable metal baffle	n/a	$$	None

Item #	Structure Component, Assembly, or Attached Combustible	Hardening Action	Performance Goal	Applicable Condition(s)	Notes	Expected Cost Range ($, $$, $$$)	Matched in Existing Code
12	Off -ridge vent	Replace with ember and flame-resistant vent	Minimize embers with enough energy to cause ignitions	Non-ember/flame resistant vent	n/a	$$	Chapter 7A
13	Gable vent	Remove gable vent	Minimize embers with enough energy to cause ignitions	Combustible screen and/or mesh greater than 1/8 inch	n/a	$$	None
		Replace with ember and flame-resistant vent				$	Chapter 7A
14	Under eave and any vents in the under-eave area on the rake (gable) end of the building	Replace with ember and flame-resistant vent, add fire caulking around all blocking	Minimize embers with enough energy to cause ignitions	Non-ember/flame resistant vent and/or uncaulked eaves blocking	n/a	$-$$	Chapter 7A
		Create a soffited eave (horizontal) or enclose eave (angled) using noncombustible material		Non-ember/flame resistant vent and/or open eave	1. All sides of the residence 2. Angled implies following the roof line	$-$$	None
15	Crawl space vents	Replace with ember and flame-resistant vent	Minimize embers with enough energy to cause ignitions	Non-ember/flame resistant vent	n/a	$-$$	Chapter 7A
		Replace with ember and flame-resistant vent and add moisture barrier			Can use plastic ground cover to reduce venting requirement; addition of moisture barrier reduces required vent area by 10x	$-$$	CA Building Code
		Convert to unvented crawl space			Energy benefit, very expensive solution, less expensive options are available	$$$	None
16	Dryer vents	Metal flapper (closed unless in use)	Limit ignition of lint and ducting	No metal flapper in place	n/a	$	None
17	Makeup air intake	Replace with ember and flame-resistant vent	Minimize embers with enough energy to cause ignitions	Combustible screen and/or mesh greater than 1/8 inch	Needed in rooms within occupied portion of residence where gas appliances are located	$	None
18	Other penetrations (electrical, water) to roof and walls	Close with fire caulking and inspect during routine maintenance and close gaps as needed	Minimize embers with enough energy to cause ignitions	Gaps around siding penetrations greater than 1/8 inch	n/a	$	None
	Close up open space under residence	Install noncombustible skirting on all sides. Add vents as required. Vents must be ember and flame resistant.	Limit ignitions under structure	Open space under residence (e.g., pier and post foundation)	n/a	$$	None
19	Other attachments to mobile homes (portico/car port)	6 inches of metal flashing at the wall intersection	Limit mobile home ignition	Mobile home with attachment(s)	n/a	$$	Chapter 7A NFPA 1140
20	Other penetrations	Seal around penetrations with fire caulking	Limit ember intrusion and accumulation	Penetrations	n/a	$	None
Windows							
21	Window screens	Add metal screen	Minimize embers with enough energy to cause ignitions	Opening window	n/a	$	None
22	Exposed wooden frame single pane	Replace with noncombustible frame and double pane tempered glass window	Prevent ignition of combustible frame	Exposed wooden frame single pane	Moisture removal benefits, energy benefit - seek cost sharing	$$	None
23	Exposed wooden frame double pane	Replace with noncombustible frame and double pane tempered glass window	Prevent ignition of combustible frame	Exposed wooden frame double pane	n/a	$$	None
Doors							
24	Exterior door (non-sliding)	Install metal door jamb kit and metal threshold; add metal kick plate, and metal door bottom	Limit ember ignition of door and frame	Wood door frame and/or wooden door and/or wooden threshold	n/a	$-$$	None
		Replace with metal door with metal frame and threshold				$$	None

Item #	Structure Component, Assembly, or Attached Combustible	Hardening Action	Performance Goal	Applicable Condition(s)	Notes	Expected Cost Range ($, $$, $$$)	Matched in Existing Code
	Exterior Door (sliding)	Replace with non-wood containing slider with dual pane tempered glass and with a metal screen	Limit ember ignition of door and frame	Wood sliding door	n/a	$$	None
25	Wood-frame screen door	Replace wooden screen door with metal door and frame	Limit ember ignition of screen door and frame	Wooden screen door	Primary door hardening option that does not require primary door replacement	$$	None
26	Plastic screen in screen door	Replace with metal screen (1/16 inch)	Prevent ignition from embers	If screen door and frame are metal, replace screen or entire system (whichever is more cost effective). If screen door or frame is wood, replace entire screen door (see line above)	n/a	$-$$	None
27	Garage door	If garage door is not metal, go over with metal flashing around the bottom of the door (both inside and outside for first 6 inches (using a metal "C" channel)	Prevent ignition from embers	Wooden garage door	n/a	$-$$	None
		Add metal flashing at base of framing for first 6 inches [go as close to the ground as possible (< 1/4 inch desired), raise wood and extend flushing to lower than bottom of wood]	Prevent ignition from embers	Wood garage door frame	n/a	$-$$	None
		Add gasketing	Prevent ember intrusion and ignition from embers	No gasketing	n/a	$	Chapter 7A
Attachments to Residence							
28	Decks, stairs, and landings attached to residence	Replace walking surface deck boards with noncombustible deck board for first 1 ft away from residence	Prevent ignition of deck and limit spread of fire to residence	Combustible deck, stairs and landings attached to residence	1. Area under the deck footprint must be maintained with no combustibles, addressed through defensible space requirement 2. Replacing boards that are not parallel to the residence may require additional deck framing	$-$$	None
		Replace entire deck with noncombustible option (metal or other option)			n/a	$$$	NFPA 1140 ICC IWUIC
29	Deck-to-wall intersection	Replace bottom 2 ft of combustible siding with noncombustible (e.g., fiber cement) and add metal flashing to protect exposed sheathing	Limit ignition of wall on residence	Combustible siding	n/a	$$	None
30	Combustible decks with combustibles present in 0 ft to 5 ft zone around deck	Remove combustibles in 0 ft to 5 ft zone around deck [c]	Prevent flames from adjacent fuels from igniting the deck	Combustibles in 0 ft to 5 ft zone around deck	n/a	$	None
31	Fence to residence	Replace with noncombustible option (metal or other option), minimum 8 ft	Prevent ignition of combustible fence	Combustible fence	This applies only to single fences; see **Table B** Item #10 for double fences	$-$$	None
32	Steps connected to residence	Introduce noncombustible barrier/section between steps and house, minimum 1 ft	Limit spread of fire to house	Combustible steps	This addressed top of deck ember ignited scenario (not fire under steps/deck)	$	None
		Introduce noncombustible barrier/section between handrails and residence or replace with noncombustible handrail, minimum 1 ft		Combustible handrails	n/a	$-$$	None

Item #	Structure Component, Assembly, or Attached Combustible	Hardening Action	Performance Goal	Applicable Condition(s)	Notes	Expected Cost Range ($, $$, $$$)	Matched in Existing Code
33	Other attachments	Introduce noncombustible barrier/section between combustible attachment and residence or replace with noncombustible, minimum 1 ft	Limit spread of fire to house	Combustible attachment	n/a	$-$$	None
34	Attached retaining walls	Replace retaining wall length equal to two times retaining wall height with noncombustible components	Prevent flames from retaining wall from igniting residence	Combustible retaining wall within two times the retaining wall height from the residence	Structural requirements of the retaining wall must be maintained (must meet code)	$$	None
35	Combustible furniture	Replace furniture with noncombustible framing materials or move away 5 ft (place cushions inside residence before egress)	Prevent flames from combustible furniture from igniting residence	Combustible furniture on deck	Homeowner action item, required action	$	None
36	Pergola/trellis	Remove vegetation, detached from residence, and have a 2 ft open space/separation from residence	Prevent ignition of pergola/trellis from igniting residence	Attached combustible pergola/trellis	Structural integrity of pergola/trellis must be maintained	$$	None
Mobile Home Skirting/Crawl Spaces							
37	Skirting	Install mobile home noncombustible skirting on all sides	Prevent embers from igniting underside of mobile home and prevent accumulation of flammable (windblown) debris	Mobile home without skirting or without noncombustible skirting	n/a	$$	None
38	Crawl space access hinged door with clasp (door construction consistent with cladding)	Install crawl space access ember intrusion protection	Prevent embers from igniting materials in crawl space and prevent accumulation of flammable (windblown) debris	Access to crawl space	n/a	$-$$	None
39	Crawl space vents	Install ember and flame-resistant vents if venting is required	Minimize embers with enough energy to cause ignitions	New skirting with vents if needed	n/a	$-$$	Chapter 7A
				Non-ember- and flame-resistant vents installed	n/a		
Optional Work							
40	Between deck boards	Insert metal flashing between deck boards at joists	Limit ignition of deck	Combustible deck and joists	n/a	$-$$	None

[a] If noncombustible gutter cover cannot be installed on combustible gutter, gutter must be replaced with a noncombustible material and fitted with noncombustible cover. (Item # 8)

[b] Vents need to account for reduction in air flow. If a vent is not fire and ember resistant it should be replaced with one that is.

[c] Well-irrigated lawn may be allowed in the 0 ft to 5 ft around deck. (Item # 30)

Table B. Surrounding parcel hazard mitigation – hardening structure and attached combustibles against ignition from fire (radiation, convection).

Item #	Structure Separation Distance (SSD) or Neighboring Parcel Exposure Distance (NPED)[a]	Slope and location of structure on the terrain (low, mid, high slope)	Hardening Action (on neighboring parcel)[b]	Notes	Minimum Required Fuel Separation Distance (MFSD) (ft)	Fuel Separation Range (FSR) (ft)	Hardening Structure and Attached Combustibles Against Ignition from Flames (radiation, convection)
1	Proximity of closest neighboring primary residence(s) – SSD			Hardening Structure is required only if neighboring structure falls within Fuel Separation Range		25 to 50	Required (in Table D) if 25<SSD<50
2	Proximity to untreated wildland fuels – NPED	Slope of concern is between wildland fuel and structure (not absolute slope of wildland fuel)		https://www.fire.ca.gov/programs/communications/defensible-space-prc-4291/	100, 150, 200		Required (in Table D) if NPED<MFSD
3	Proximity to treated wildland fuels[c] – NPED	Assumes that slope has been factored in the fuel treatment		https://www.fire.ca.gov/media/umkhhdbs/fuels-reduction-guide-final-2021-print.pdf	100		Required (in Table D) if NPED<MFSD
4	Proximity to auxiliary buildings > 120 ft^2 in size (primary or neighboring parcel) – SSD		Aux. building hardening will need to be treated as primary structure to prevent ignition from fire (radiation) and embers			25 to 50	Required (in Table D) if 25<SSD<50
5	Proximity to auxiliary buildings 64 ft^2 to 120 ft^2 (primary or neighboring parcel) – SSD		Aux. building hardening will need to be treated as primary structure to prevent ignition from fire (radiation) and embers			20 to 40	Required (in Table D) if 20<SSD<40
6	Proximity to auxiliary buildings <64 ft^2 in size (primary or neighboring parcel) – SSD		Aux. building hardening will need to be treated as primary structure to prevent ignition from fire (radiation) and embers			15 to 30	Required (in Table D) if 15<SSD<30
7	Proximity to vegetative fuels not compliant with defensive space[d] – NPED				100		Required (in Table D) if NPED<MFSD
8	Proximity of large auxiliary structures and fuels (e.g., gazebo, RVs, boats) – NPED				50		Required (in Table D) if NPED<MFSD
9	Proximity of small combustible auxiliary structures (e.g., single fence) – NPED				10		Required (in Table D) if NPED<MFSD
10	Proximity of small combustible auxiliary structures (e.g., double combustible fences) – NPED				20		Required (in Table D) if NPED<MFSD
11	Proximity of detached retaining wall – NPED		Retaining wall hardening will need to be treated as primary structure to prevent ignition from fire (radiation) and embers		10		Required (in Table D) if NPED<MFSD

[a] From the edge of the house closest to the exposure.
[b] If neighboring parcel is not part of the program, certain hardening actions may not be implementable and structure hardening may be necessary.
[c] Wildland fuel treatment must have occurred within 3 years; must meet local, state, or federal guidance/standard.
[d] Refers to vegetative fuels on adjacent properties.

Table C. Primary parcel hazard mitigation – hardening structure and attached combustibles against ignition from fire (radiation, convection).

Item #	Parcel Feature – Exposure Distance (ED) or Structure Separation Distance (SSD)	Hardening Action	Performance Goal	Applicable Condition(s)	Notes	Expected Cost Range ($, $$, $$$)	Minimum Required Fuel Separation Distance[a] (MFSD) (ft)	Hardening Structure and Attached Combustibles Against Ignition from Flames (radiation, convection)
1	Firewood – ED	Replace firewood with other heating source, displace firewood 30 ft away from main residence and other Table C features, or store in a noncombustible enclosure 15 ft from Table C features	Prevent firewood from directly (flames) igniting residence or other Table C items	If closer than recommended separation distance	Defensible space expanded to account for all other Table C items	$	30	Required (in Table D) if ED<MFSD
2	Vegetative fuels not compliant with defensible space – ED	Treat vegetation	Defensible space compliance	Not in compliance with defensible space	If vegetative fuels reduction is not possible, and ED is less than distance specified in Table B for untreated wildland fuels, residence hardening will be required	$-$$	100 (See Table B)	Required (in Table D) if ED<MFSD
3	Auxiliary buildings (> 120 ft²) – SSD	Remove or separate 50 ft from main residence and other Table C features or harden the auxiliary building construction in Table C and incorporate a 0 ft to 5 ft ember-resistant zone.	Prevent auxiliary building from directly (flames) igniting residence or other Table C items	If closer than recommended separation distance	If building removal, displacement, or hardening of auxiliary structure is not possible, residence hardening will be required	$$-$$$	50	Required (in Table D) if SSD<MFSD
4	Small (64 ft² to 120 ft²) auxiliary buildings – SSD	Remove, displace 40 ft from main residence, or harden the auxiliary building construction (between 5 ft to 40 ft) from residence and other items in Table C and 0 ft to 5 ft ember-resistant zone	Prevent auxiliary structures from directly (flames) igniting main residence and other Table C items	If closer than recommended separation distance	If building removal, displacement, or hardening of auxiliary structure is not possible, structure hardening will be required	$-$$$	40	Required (in Table D) if ED<MFSD
5	Very small (< 64 ft²) auxiliary buildings – SSD	Remove, displace 30 ft from main residence, or harden the auxiliary building construction (between 5 ft and 30 ft) from residence and other items in Table C and 0 ft to 5 ft ember-resistant zone	Prevent auxiliary structures from directly (flames) igniting main residence and other Table C items	If closer than recommended separation distance	If building removal, displacement, or hardening of auxiliary structure is not possible, structure hardening will be required	$-$$$	30	Required (in Table D) if ED<MFSD
6	Other combustible structures (> 120 ft²) (e.g., gazebo) – SSD	Remove, displace 50 ft from main residence and other Table C features, or harden the auxiliary building construction to noncombustible (If < 50 ft) from other items in Table C and incorporate 0 ft to 5 ft ember-resistant zone	Prevent fuels from directly (flames) igniting other (combustible) items	If closer than recommended separation distance and non-hardened	If building removal, displacement, or hardening of auxiliary structure is not possible; remove or displace the other Table C items or replace with a new structure made of noncombustible material.	$$-$$$	50	Required (in Table D) if SSD<MFSD
7	Large vehicles (e.g., RVs, boats) – ED	Remove, displace 50 ft from main structure and other Table C features, and create a 0 ft to 5 ft ember-resistant zone	Prevent vehicles from directly (flames) igniting main residence and other Table C items	If closer than recommended separation distance	If vehicle removal or displacement (beyond 50 ft) is not possible, structure hardening will be required	$	50	Required (in Table D) if ED<MFSD
8	Fences on property (see Table B for distances) – ED	Replace with noncombustible/ignition-resistant materials (See Table B for distances)	Prevent fuels from directly (flames) igniting main residence and other Table C items	If combustible and closer than recommended separation distance	If replacement with noncombustible/ignition-resistant materials is not possible, structure hardening will be required	$	10 (See Table B)	Required (in Table D) if ED<MFSD
9	Small combustibles within 5 ft of residence (e.g., door mat, planter, garden hose) – ED	Replace with noncombustible/ignition-resistant materials or move away 5 ft	Prevent fuels from directly (flames) igniting main residence and other Table C items	If combustible and closer than recommended separation distance	If replacement with noncombustible/ignition-resistant materials is not possible, structure hardening will be required	$	5	Required (in Table D) if ED<MFSD

[a] MFSD must account for all exposed structure combustible appendages, such as decks. For example, MFSD is measured from the edge of the deck, not the wall of the structure it is attached to.

Table D. Structure hazard mitigation – hardening structure and attached combustibles against ignition from fire (radiation, convection).

Item #	Structure Component – Exposure Distance (ED) or Structure Separation Distance (SSD)	Hardening Action	Performance Goal	Applicable Condition(s)	Notes	Expected Cost Range ($, $$, $$$)	Matched in Existing Code
1	Roof covering and roof design (assembly) including dormer and bump out roofs	Replace non-Class A roofs by assembly or by covering alone	Prevent ignition of roof from flames	Non-Class A roof	n/a	$$$	None
2	Dormer side	Replace all combustible siding with noncombustible options	Prevent ignition of dormer from flames	Combustible dormer siding	n/a	$$	None
3	Dormer under eave	Replace all under eave construction with noncombustible options or cover with noncombustible material	Prevent ignition of dormer from flames	Combustible dormer eave	n/a	$$	NFPA 1140
4	Dormer window	Replace with dual pane window with both being tempered	Prevent complete window failure[a]	Single pane or dual pane non-tempered	n/a	$$	NFPA 1140 ICC IWUIC
5	Exterior wall(s) including bump out(s)	Add on top (of existing cladding) or replace with noncombustible cladding. Trim must be noncombustible	Prevent siding ignition	Combustible cladding facing exposures in Table B and/or Table C	1. Add on top option is available only for residences with cladding that have a flat profile. 2. Add moisture barrier under new cladding.	$$$	None
6	Bump out bottom (underside)	If exposed framing, enclose with noncombustible material. If enclosed with combustible material, replace or cover with noncombustible material. Trim must be noncombustible and extend (vertically) to account for added material	prevent ignition under bump out(s)	Combustible bump out(s) underside material or exposed framing	n/a	$$	None
7	Glazing in doors and glass sliding doors	Double pane windows (both panes tempered)	Prevent complete window failure[a]	Single pane non-tempered, non-tempered double pane, or double pane with one tempered facing exposures in Table B and/or Table C	Vinyl frames must have reinforcement to prevent panes from being dislodged because of frame deformation (due to heating)	$$$	NFPA 1140 ICC IWUIC
8	Under eave(s) - overhanging eave and overhanging rake (gable end)	Create a soffited eave (horizontal) or enclose eave (angled) using noncombustible material	Prevent ignition in under eave area and entry of fire in residence	Under eave(s) combustible construction facing exposures in Table B and/or Table C	n/a	$$	NFPA 1140 ICC IWUIC
9	Screens	Screen over entire window(s) (even if window does not open) and other glazed surfaces. Framing for screens must be of noncombustible material	Reduce radiative exposures to glass and possibly to parts of frame	All glazed surfaces facing exposures in Table B and/or Table C	n/a	$$	None
10	Windows	Replace with dual pane window with both being tempered	Prevent complete window failure[a]	Single pane non-tempered, non-tempered double pane, or double pane with one tempered facing exposures in Table B and/or Table C	Vinyl frames must have reinforcement to prevent panes from being dislodged because of frame deformation (due to heating)	$$$	NFPA 1140 ICC IWUIC

Note: All sides of a structure must be hardened for fire and radiation unless a field inspection identifies more localized exposures that demonstrate directional hazard (with no fire exposure to other side(s)).

[a] Complete glazing failure will open up residence and allow embers and fire to enter.

Appendix B. Comparison of Existing Codes and Standards

This appendix contains a tabulated list (**Table E**) of detailed comparisons of primary solutions listed in three selected WUI building codes commonly used in the United States. The comparison is made with the most recent (2018 or 2019) editions of the International Wildland-Urban Interface Code, NFPA 1140/NFPA 1144,[13] and the California Building Code Chapter 7A. Note that each of these listed codes are regularly revised and improved varying temporal cycles.

There are multiple programs available to the public that can be used to reduce fuels and harden structures in the WUI [40]. Examples include NFPA's Firewise[14] and CAL FIRE's Ready, Set, Go![15] programs which encourage defensible space and structure hardening. Depending on jurisdiction, these types of programs may be voluntary or mandatory and typically complement local, state, and national codes.

[13] NFPA codes are in transition to consolidate related codes. NFPA 1144 is a component of the new consolidated WUI code, NFPA 1140.
[14] https://www.nfpa.org/Public-Education/Fire-causes-and-risks/Wildfire/Firewise-USA
[15] https://www.readyforwildfire.org/prepare-for-wildfire/ready-set-go/

Table E. Comparison of selected existing WUI building codes.

Building Component	2018 IWUIC (Ignition Resistant Construction Class 1)	2018 NFPA 1144	2019 California Building Code Chapter 7A
Roof	Specifies Class A fire rated covering (IR 2 specifies Class B, IR 3 specifies Class C). Requirements for "bird-stopping" / "fire stopping", including 72-pound cap sheet alternate method specified in Chapter 7A, also applies here. Requirements for thickness of metal when used in a valley. Valley using metal flashing also requires use of 72-pound cap sheet underlayment.	Roof covering assemblies tested and rated as Class A in accordance with ASTM E108 (or UL 790). Roof covering tested with all assembly components representing as-built condition (e.g., between panel joints must be present, and joints shall be in alignment with burning brand during test). When a roof profile provides for a gap between the roof covering and a combustible roof deck assembly shall include a 72-pound cap sheet that complies with ASTM D3909 (Asphalt Roll Roofing (Glass Felt) Surfaced with Mineral Granules). The cap sheet shall be rolled out over the entire roof deck. In lieu of the use of such a roll roofing product, fire-retardant treated plywood can be used. Such roof coverings shall also be blocked at eaves, ridges, and hips with a noncombustible material. A metal drip edge shall be installed at all rake and eave edges.	Refers to Chapter 15 of the CBC. Chapter 15 specifies Class A covering in VHFHSZ, Class B in HFHSZ and Class C in MFHSZ. Specifies that any gaps between roof covering and roof deck be fire-stopped (e.g., bird-stopped, fire-stopped). An alternate way to comply would be to install a minimum 72-pound cap sheet material over the decking. Specifies that (metal) valley flashing will be installed over a minimum 36-inch wide cap sheet that runs the full length of the valley.
Under-Eave	Eaves and soffits protected on exposed underside by one of four options, including 1) use of an Ignition Resistant Material or materials approved for a minimum one-hour fire-resistant-rated construction, 2) nominal 2-inch lumber, or 1-inch nominal fire-retardant-treated lumber, or 3/4-inch nominal fire-retardant-treated plywood [fire-retardant materials rated for exterior use]. Open-eave or boxed in "ok", but both must comply with "underside" requirements. Fascia protected on backside by ignition resistant material or materials approved for one-hour fire-resistance-rated construction or nominal 2-inch lumber	Specifies that eaves be enclosed with either 1) exterior FRT wood or ignition resistant material, or 2) a noncombustible material, or 3) a material that, when tested to ASTM E2957 (under eave flame exposure test) complies with provisions provided in Section 5.3.4.1 (absence of flame penetration, absence of structural failure, absence of sustained combustion (flame or smoldering) after 40 minutes).	Provisions are consistent with the provisions of the exterior wall requirements. Soffited eaves must be enclosed with either 1) noncombustible material, 2) ignition-resistant material, 3) use of 5/8-inch Type X gypsum sheathing in the assembly, 4) the exterior portion of a one-hour fire resistive wall assembly, or 5) complies with SFM Standard 12-7A-3. States that traditional open-eave framing using nominal 2x dimension lumber is allowed (prescriptively).
Underfloor Enclosure	Where attached structure projects over a descending slope greater than 10%, the area below the structure shall be enclosed to within 6-inches of the ground with materials that comply with exterior wall requirements.		
Gutters/Downspouts	Specifies gutter made of noncombustible materials (vinyl gutters not allowed). Gutters shall be provided with an approved means to prevent accumulation of debris (i.e., use of gutter cover device is required).	Noncombustible material. Gutters covered by approved noncombustible means to minimize accumulation of debris.	Specifies that gutters be provided with the means to "prevent" the accumulation of leaves and debris. This section has generally been interpreted to mean "install a gutter cover device."
Vents	Attic vent: Cannot be located in soffit, eave overhangs, between rafters, or in other overhang areas. Gable end and dormer located minimum 10-feet from property lines. Foundation vents: located as close to grade as practical. Individual vent openings not to exceed 144 in^2 and covered with corrosion resistant mesh not to exceed 1/4-inch or designed and approved to prevent flame and ember penetration.	Vents screened with corrosion-resistant noncombustible wire mesh, mesh opening not to exceed 1/8-inch, or a vent that, when tested in accordance with ASTM E2886 comply with provisions found in Section 5.3.3 (2). These are the same provisions provided in Chapter 7A. This information applies to all openings / penetrations, with the exception of dryer vents.	General requirement for vents to "resist building ignition from the intrusion of burning embers and flame through ventilation openings." Specific requirements: 1) Tested in accordance with ASTM E2886 and with specified items (no flaming ignition of cotton [ember intrusion], no flaming ignition [flame intrusion], and maximum temperature on unexposed side of vent < 350 °C [662 °F]), *or* mesh openings between 1/16-inch and 1/8-inch, noncombustible and corrosion resistant material. Vents not allowed on underside of eave unless 1) listed tested to ASTM E2886 and complying with stated provisions (above), or 2) AHJ permits vent as being resistant to flames and embers, or 3) attic is fully sprinklered or exterior cladding and underside of eave is noncombustible or approved IRM, and vent is more than 12 feet from ground or walking surface.

Building Component	2018 IWUIC (Ignition Resistant Construction Class 1)	2018 NFPA 1144	2019 California Building Code Chapter 7A
Exterior Walls	Exterior walls with one five methods, including 1) One-hour fire-resistant-rated construction, 2) Approved noncombustible materials, 3) Heavy timber or log wall construction, 4) Fire-retardant-treated wood on exterior side (rated for exterior use), or 5) Ignition-resistant materials on exterior side. Materials must extend from top of foundation to underside of roof sheathing.	An approved ignition resistant material, or exterior fire-retardant- treated wood, or noncombustible material, or be a wall assembly exhibiting a minimum 1-hour fire resistance rating (with tested to ASTM E119) and exhibiting a minimum Class B flame spread index (ASTM E84). Provisions allow for AHJ to require enhanced protection. --- 6-inch vertical noncombustible zone (i.e., foundation)	Objective is to resist building ignition and/or safeguard against intrusion of flames resulting from embers or short-term direct flame contact exposure. Included in "exterior wall" is under-eave and other horizontal projections (with exception of attached deck). Exceptions include trim and fascia. Open eave construction also excepted as long as blocking and rafters have minimum dimension of nominal 2-inches [need to reconcile this statement with Sections 707A.4, 707A.5, 707A.6, 707A.7, 707A.8, 707A.9]. Options for complying include: 1) noncombustible material, or 2) ignition resistant material, or 3) "heavy timber" defined as smallest minimum nominal dimension of 4-inches (glu-lam ok), or 4) log wall construction assembly, or 5) test to ASTM E2707 or SFM Standard 12-7A-1 and complying with specified provisions. Two deemed-to-comply prescriptive options are also available, including 1) incorporation of one-layer 5/8-inch Type X gypsum board behind exterior cladding on exterior side of framing, or 2) exterior portion of 1-hour fire resistive exterior wall assembly. Assemblies listed in *Gypsum Association Fire Resistance Design* Manual are okay.
Windows	Exterior glazing (glass in windows) shall be, 1) tempered glass, multilayered glazed panels or 2) glass block, or 3) have a 20-minute fire-resistance rating. These requirements also apply to skylights.	Applies to exterior windows, windows within exterior doors and skylights. All shall be tempered glass, multilayered glazed panels, glass block or have at a minimum a 20-minute fire-resistance rating. Windows shall be screened using noncombustible material.	Exterior windows and exterior glazed door assemblies and skylights shall comply with one of the following: 1) multipane glazing with a minimum of one tempered pane meeting requirements of Section 2406 Safety Glazing, 2) glass block units, 3) fire resistance rating of not less than 20 minutes (NFPA 257 - using vertical furnace and time-temperature curve also described in ASTM E 119) or 4) meeting performance requirements of SFM 12-7A-2. Skylights also need noncombustible screening with minimum 1/8-inch mesh.
Doors	Doors shall be 1) Noncombustible, 2) solid core wood (thickness of solid core wood not less than 1 3/4-inch), or 3) have at a minimum a 20-minute fire rating. Vehicle access (garage) doors are excluded.	Solid-core wood, > 1 3/4-inch thick, or be construction with noncombustible materials, or a "fire protection" rating of no less than 20 minutes.	Exterior doors shall comply with one of the following: 1 and 2) exterior surface shall be noncombustible or ignition-resistant material, or 3) construction of solid core wood, stiles and rails not less than 1 3/8-inch thick; raised panels not less than 1 ¼-inch thick except exterior perimeter of panel may taper to tongue not less than 3/8-inch thick, or 4) fire resistance rating on 20 minutes when tested in accordance to NFPA 252, or 4 and 5) comply with performance requirements of SFM 12-7A-1 / ASTM E2707. Provision in Section 708 A.4 for minimizing intrusion of embers via inclusion of weather stripping (complying flammability rating V-2 or better via UL 94, Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Appliances.

Building Component	2018 IWUIC (Ignition Resistant Construction Class 1)	2018 NFPA 1144	2019 California Building Code Chapter 7A
Appendages (Decks)	Unenclosed accessory structures attached to buildings with habitable spaces and projections shall have 1) One-hour fire resistant-rated construction, or 2) heavy timber, or either a) noncombustible material, b) exterior rated fire-retardant treated wood, c) ignition resistant building materials. When an attached structure (such as a deck) extends over a descending slope greater than 10%, the area below the structure must be enclosed to within 6-inches of the ground. Enclosing materials complying with "exterior walls" requirements.	Including all projections (exterior balconies, carports, decks, patio covers, unenclosed roofs and floors) shall be constructed of heavy timber, or noncombustible materials, or fire retardant treated wood, ignition resistant materials or be an assembly with a 1-hour fire resistance rating (ASTM E119).	This section only applies to the walking surface of the deck (porch, balcony, stairs, landings, included). Specifies that decking material comply with one of the following: 1) Materials that are tested in accordance with both ASTM E2632 (underdeck flame) and ASTM E2726 (top of deck brand) and comply with provisions found in Section 709.4, or 2) qualifies as Ignition Resistant Material (extended ASTM E84), or 3) complies with provisions of both SFM Standard 12-7A4 and 12-7A-5 (similar to 1 above), or 4) exterior fire retardant treated wood, or 5) noncombustible material, or 6 and 7) complies with provisions in 12-7A-4A (underdeck flame, minimum PHRR only), or tested to ASTM E2632 with acceptance criteria provided in Section 709A.5), with exception that Class B flame spread allows siding that complies with 7A to be used. Allowable PHRR is 25 kW/ft^2 (~276 kW/m^2).
Projections	1) Enclosed to ground ["exterior wall" requirements], or 2) "one-hour construction, or heavy timber, or exterior rated FRT wood.	When projections are attached to an exterior wall, the construction of the projection will be built to maintain the "fire-resistive" integrity of the vertical wall.	Provisions given for general case in Section 707A.2. Specific provisions are included for exterior porch ceilings, floor projections, underfloor projections, and the underside of appendages. Requirement options for these components include 1) noncombustible material, 2) ignition-resistant material, 3) one layer of Type X gypsum sheathing applied behind an exterior covering, 4) the exterior portion of an approved 1-hour fire resistive exterior wall assembly or 5) complying with performance criteria of SFM 12-7A-3. When used in underfloor projections and appendages, heavy timber columns and beams do not require additional protection. When used in porch ceilings and floor projections, architectural trim boards do not need to comply. The minimum size to be considered heavy timber depends on the component.
Detached Accessory Structures	If located less than 50 ft from primary building, exterior wall of building to conform to "exterior walls" section. "Topography" language applies here (i.e., if portion of structure projects over descending slope). Enclosure not required if underside of exposed floors and exposed structural members protected by one-hour fire rating, heavy timber, or exterior rated FRT lumber.	Constructed according to provisions outlined in this standard, or separated from primary building by at least 30 ft.	No requirements for buildings more than 50 ft from applicable building. Specifies that attached accessory structures shall comply with this section (states that structures shall be constructed of noncombustible or ignition-resistant materials); detached accessory structures within 50 ft of the "applicable" building shall comply when required by the AHJ.
Unaddressed Issues that Need Resolution	1) Fence / fencing; 2) Clarification between "projections" "detached accessory structures" and "appendages"; 3) where to include small area out-buildings, such as a tool shed, that is located close to the primary building; 4) make sure the feature of being "attached" is addressed (structural or non-structural not so much an issue - proximity is the issue)"; 5) how much into "defensible space" issues do codes reach (e.g., providing requirements for noncombustible retaining walls in down-slope areas) and other features that can enhance protection of the primary building of interest.		