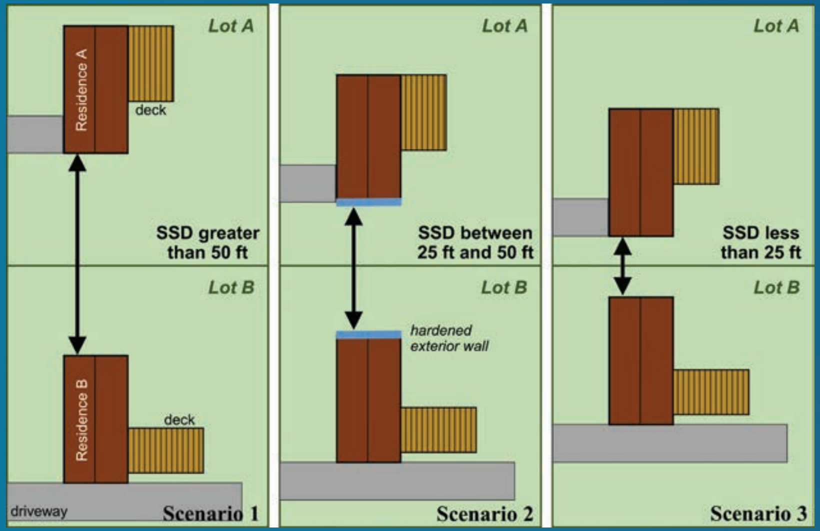
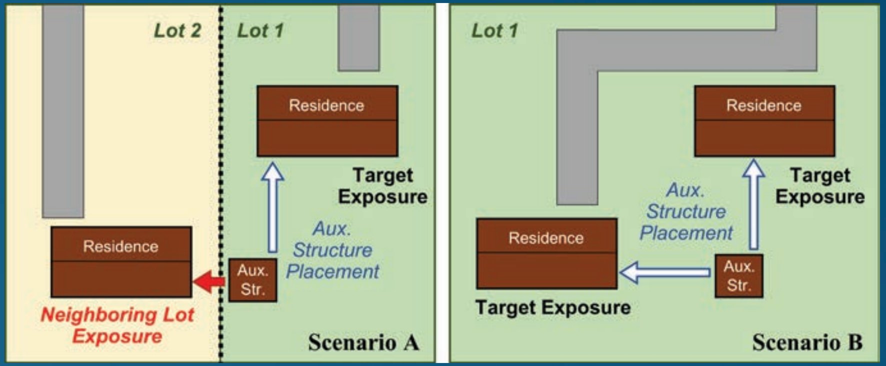
WUI Structure / Parcel / Community Fire Hazard Mitigation Methodology (HMM)

NIST WUI DAYS 2022





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Introduction

WUI Definitions

WUI Fire Exposures

Fire Spread Pathways

Structure Hardening

Multi-Parcel Layout Examples

Structure Survivability

Summary

Listing of Key Technical Principles

Presentation Outline

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- Primary Drivers influencing fire losses
- Traditional WUI definitions
- Adding Structure Separation Distance (SSD) in redefined WUI categories
- Relationship between exposure and hardening
- Fire Spread pathways
- Effects of parcel centric approach of fire losses
- Effects of fuels agglomeration on fire losses
- Fuel Loading in actual WUI settings
- Technical foundation for the HMM
- HMM ember hardening
- HMM fire hardening including the principles of Fuels Reduction, Relocation, Removal and Structure Hardening options.
- Fuel Spacing, Parcel layouts and Fuels Placement
- HMM Tables A, B and C
- Factors Influencing structure survivability
- Defensive actions
- Partial structure hardening
- Partial community hardening
- Housing density (i.e., SSD)
- Effects of Housing Density on Resident Participation and Complete Structure and Parcel Hardening
- HMM comparison to WUI Codes

HMM

- WUI Structure / Parcel / Community Fire Hazard Mitigation Methodology
- A performance-based approach to structure/parcel and community hazard mitigation
- Designed specifically to address hazard mitigation of existing communities
- HMM can also be used for new construction

Presentation Themes

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- SSD refines the WUI Definitions in Context of Hazard and Hazard Mitigation
- Fire and Embers are different hazards with impacts over different spatial dimensions
- Ember hardening is "required", fire hardening is spatially dependent – HMM provides an effective and *cost-efficient* pathway to address both hardening needs for existing communities
- Protection provided by partial hardening of the structure and parcel is not linearly related to hazard mitigation
- Community implications of partial structure and parcel hardening are related to community housing density

WUI Fire Hazard Mitigation Components

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

Exposures and Structure Hardening

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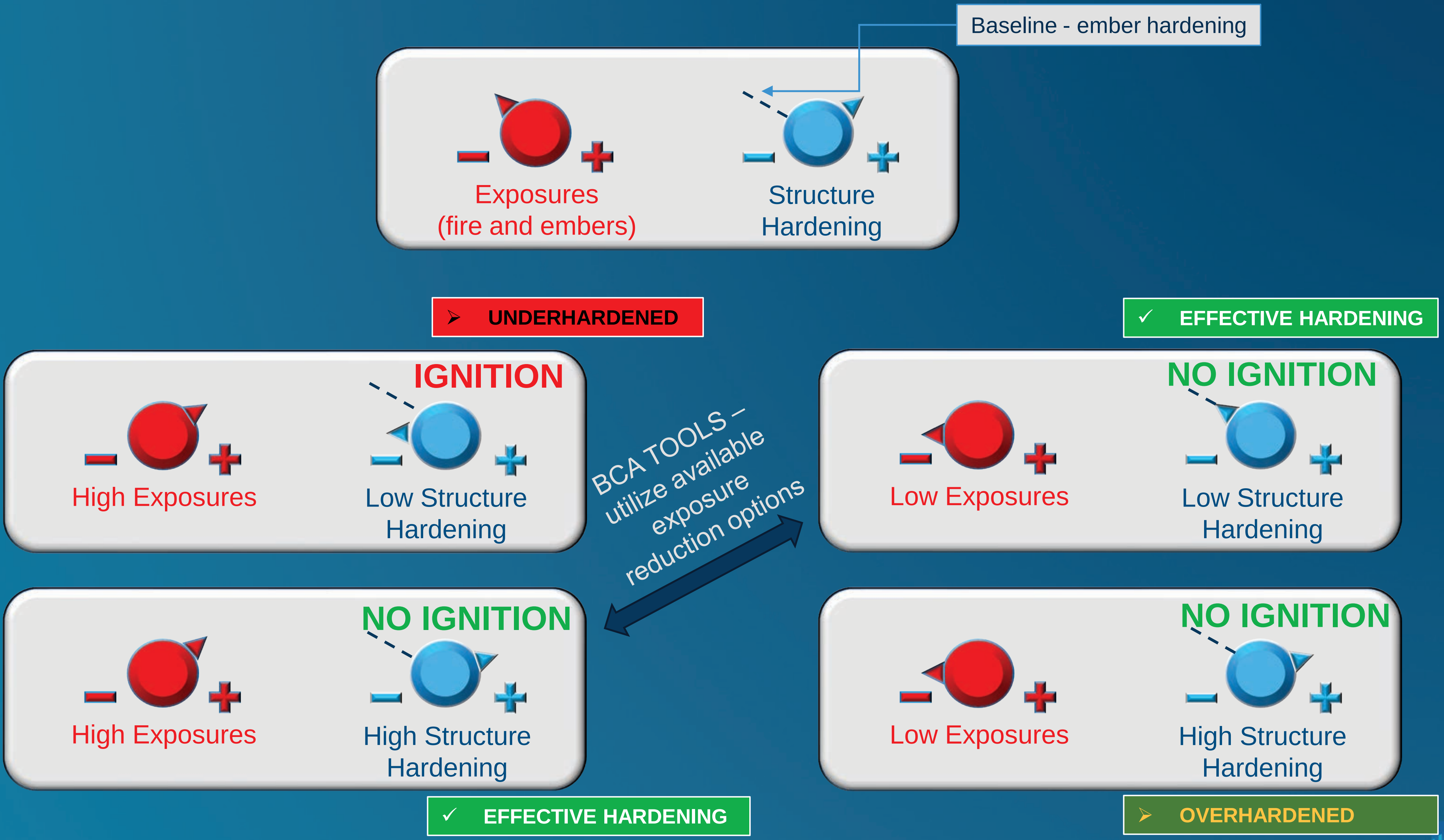

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WUI Fires – Structure Ignition Hazard Mitigation

Existing Buildings/Communities

- – Limitations to exposure reduction - existing Structure Separation Distance (SSDs)
- – Limited ignition resistance

- Transition from parcel to multiparcel hazard assessment and mitigation needed
- Lifestyle - paradigm shift needed
- Large building stock – cost effective hardening/funds needed

New Buildings/Communities

- Greater exposure reduction options:
  - Community design
  - Structure spacing
- Cost effective construction/hardening
- Lifestyle/paradigm shift easier to implement

Primary Drivers of WUI Fire Losses

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1. Fuel ignition potential
2. ***Density of vegetative and structural fuels***
3. Wind and terrain
4. Extent/size of fire front reaching the communities

Communities and residents can **only** control the density of vegetative and structural fuels

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WUI Definitions

Traditional WUI Definition

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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

NIST TN 2205 (HMM), Table 1.

WUI by SSD and Parcel Size

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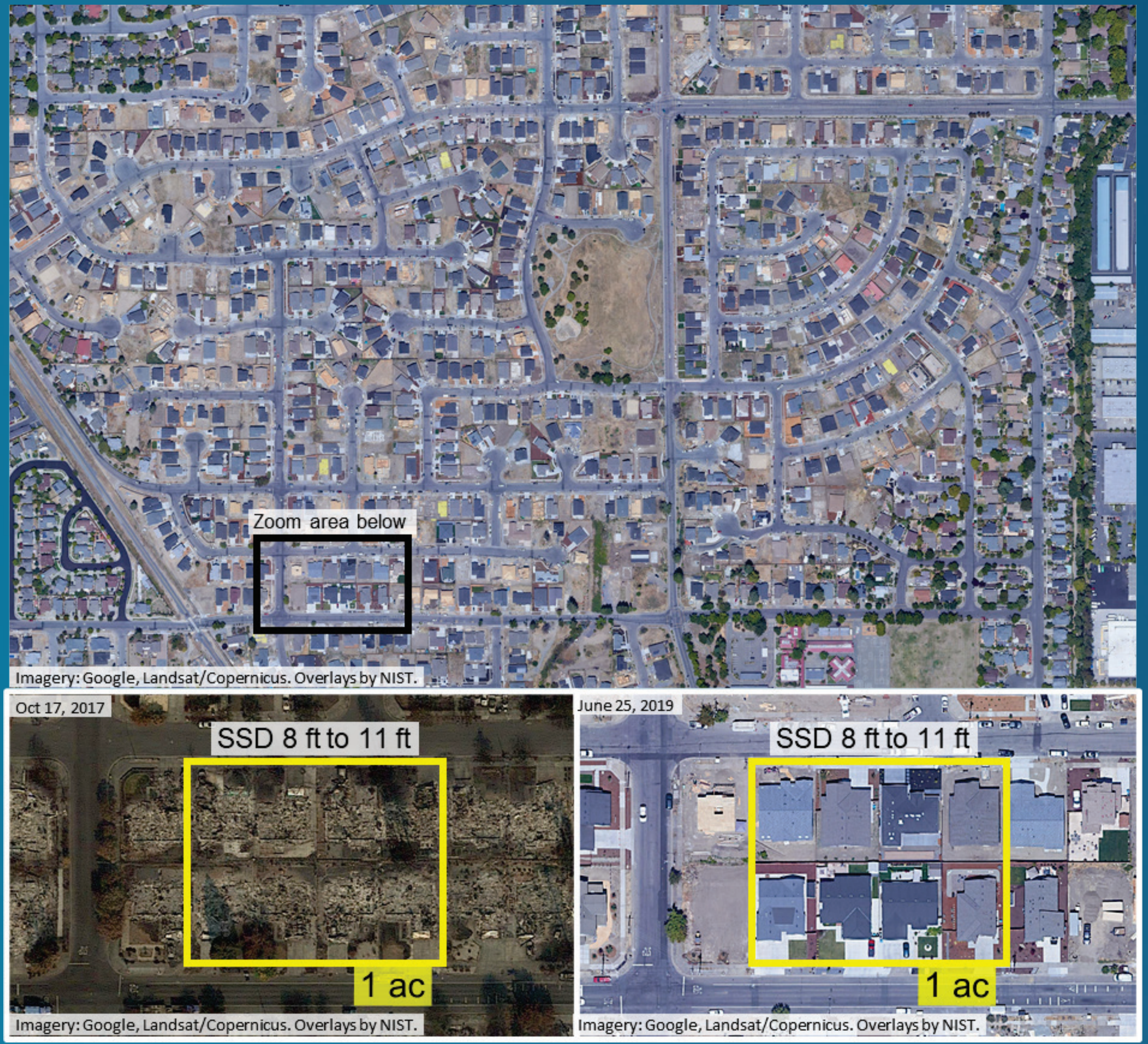
Table 2. WUI Types classified by structure separation distance (SSD) and typical parcel size.

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 2



High Density Interface – Interior

Coffey Park in Santa Rosa, CA

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NIST TN 2205 (HMM), Figure 1.

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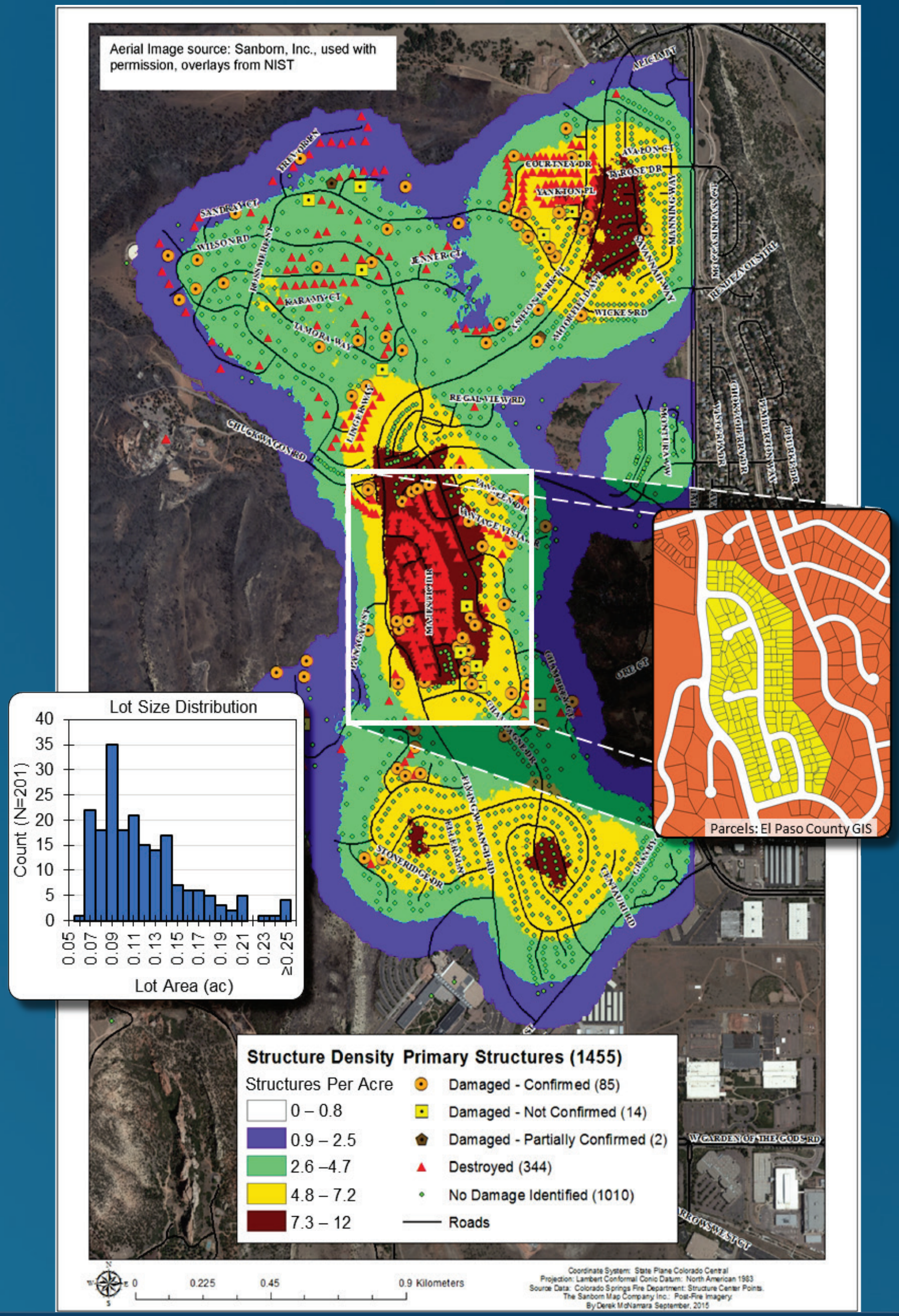
WUI Type 2

- An example of structure density of the Mountain Shadows neighborhood in Colorado Springs, CO
- Insets show the highest density area (yellow) and associated lot size distribution, most <0.2 ac.



NIST TN 2205 (HMM), Figure 2.

WUI Type 2 – SSD

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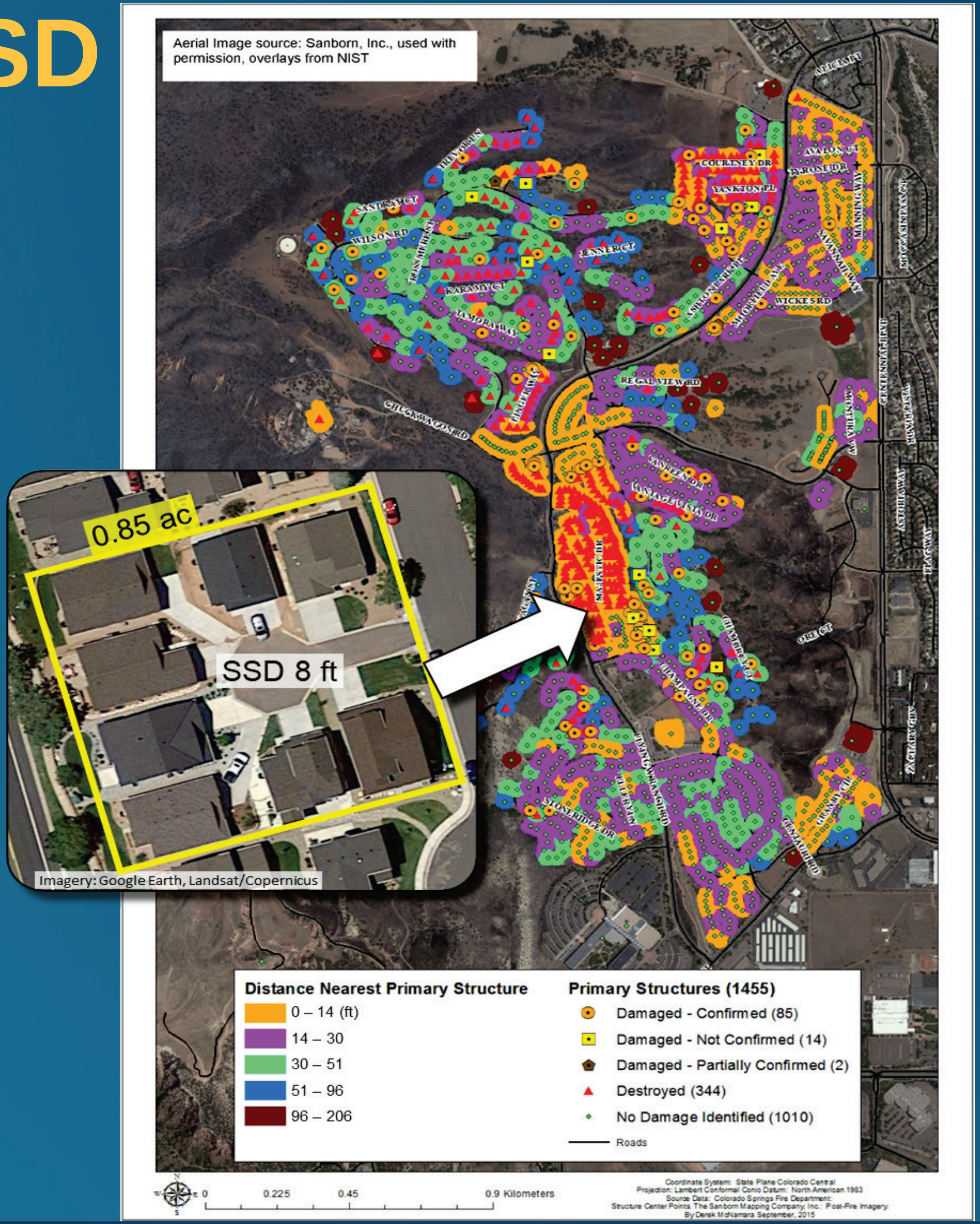
- Varying structure separation distances in the Mountain Shadows neighborhood of Colorado Springs, CO



WUI Type 6

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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

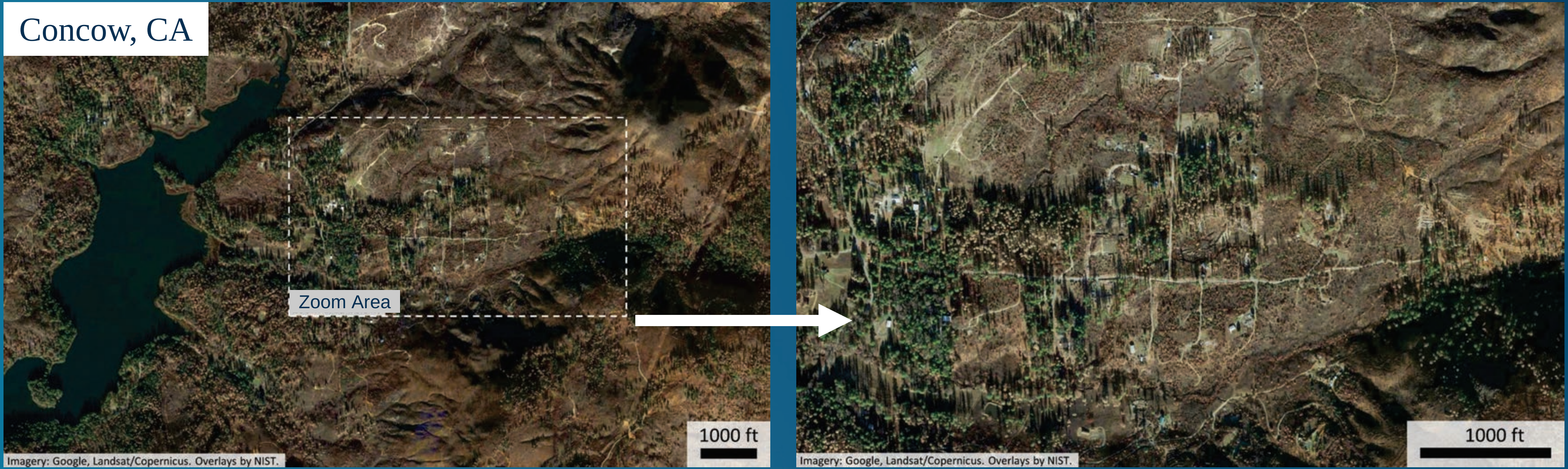
Low Density Intermix Rancho Santa Fe, CA.

WUI Type 6/5

Irrigated lawns, long paved driveways, pools

Some structure-to-structure distances are representative of Moderate Density Intermix (lower part of image). Also note limited high density non irrigated vegetative loading.

WUI Type 7



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Concow, CA. Note the overall large SSD and structures located within the wildland vegetation. Note the imagery is taken post-fire.

WUI Fire Exposures

embers + fire

WUI Fire Hazard Mitigation and Structure Survivability

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

Why Do Structures Survive?

1. Construction that can withstand exposures
2. Defensive Actions – effectively lowering exposures

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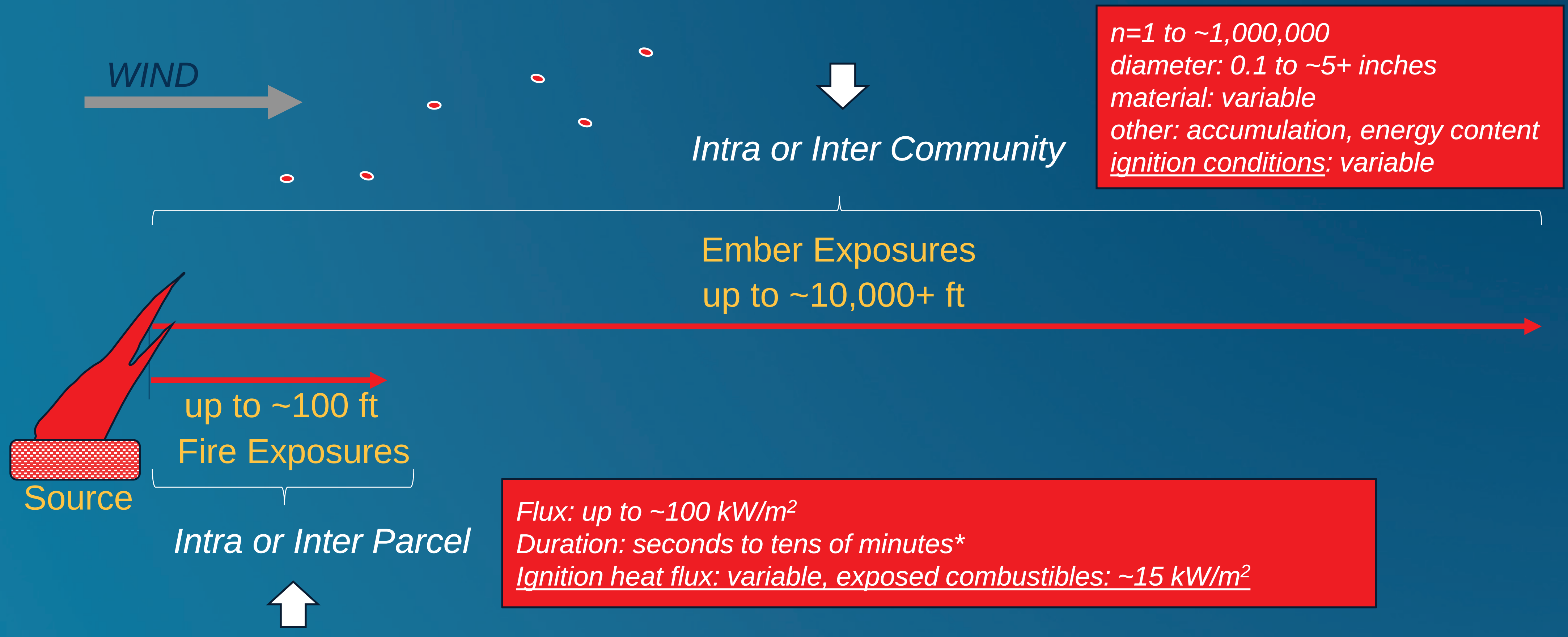
Fire and Ember Exposures

Two Different Problems with Different Spatial Scales



* Ignition is driven by the combination of duration and flux intensity

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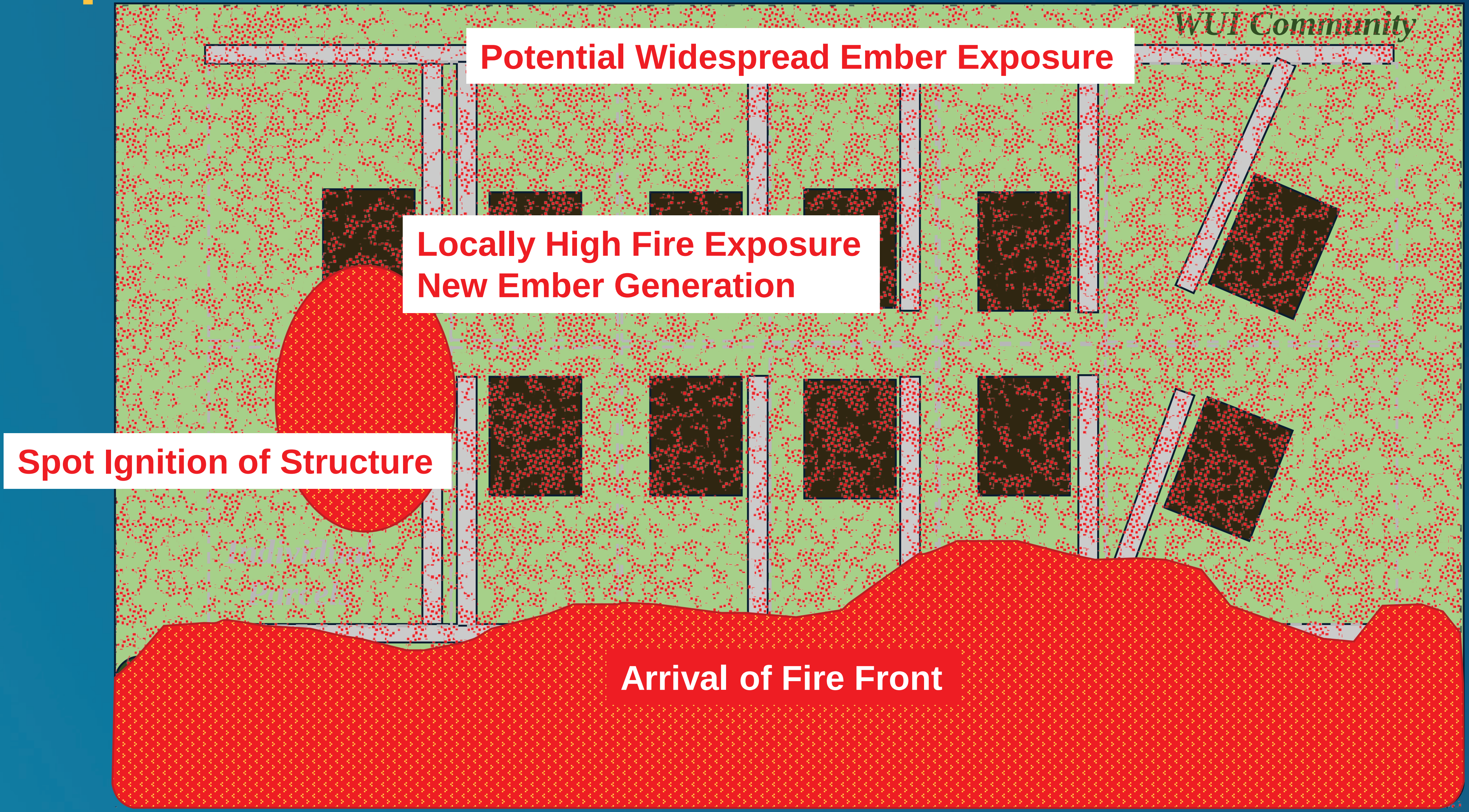
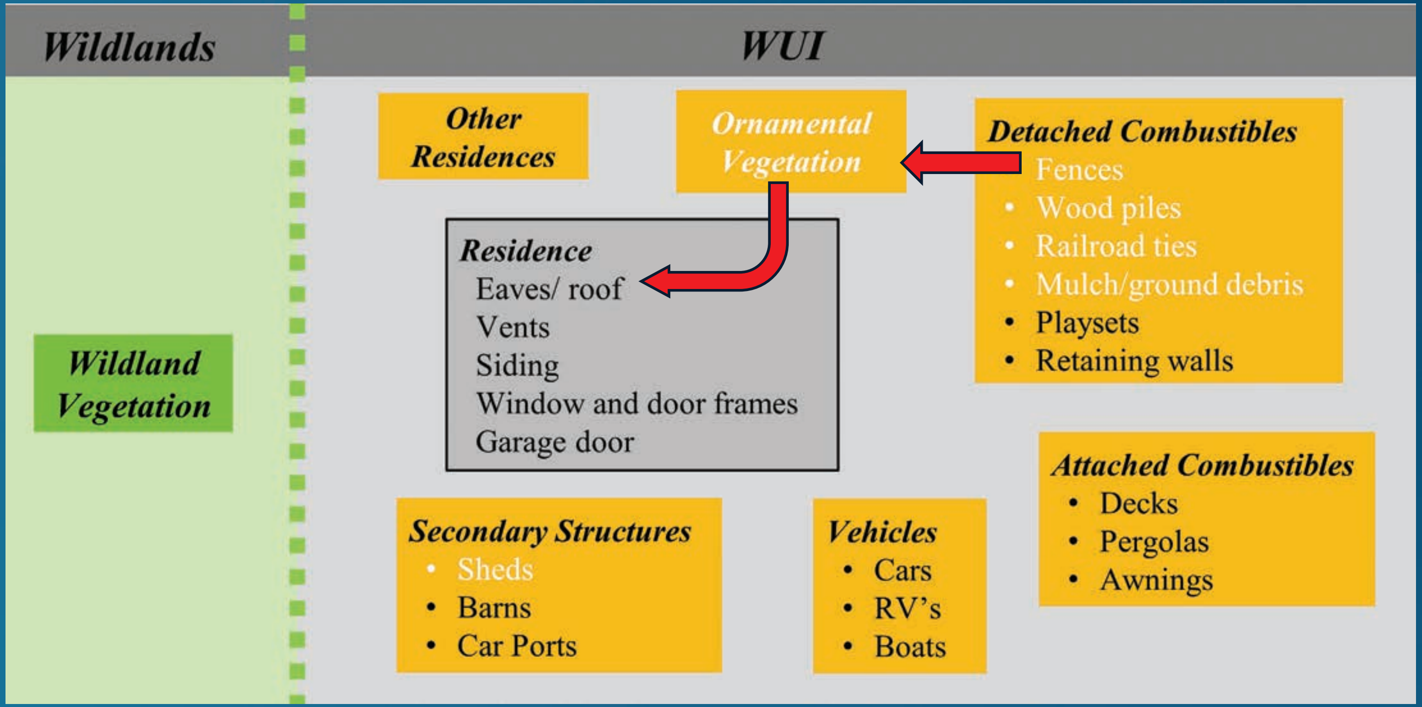
Fire and Ember – Different Spatial Exposure Hazards



Structure Ignition Pathways and Parcel Level Combustible Attributes

All burning hazards (sources) generate embers and fire exposures



Highlighted in white are hazards that NIST has performed extensive study.

- Local conditions will drive ember exposures to specific structure elements. Extreme variability influence actual exposures.
- *Source placement* (and local wind) will drive fire exposures to specific structure elements.

NIST TN 2205 (HMM), Figure 8.

Structure Ignition Pathways and Parcel Level Combustible Attributes

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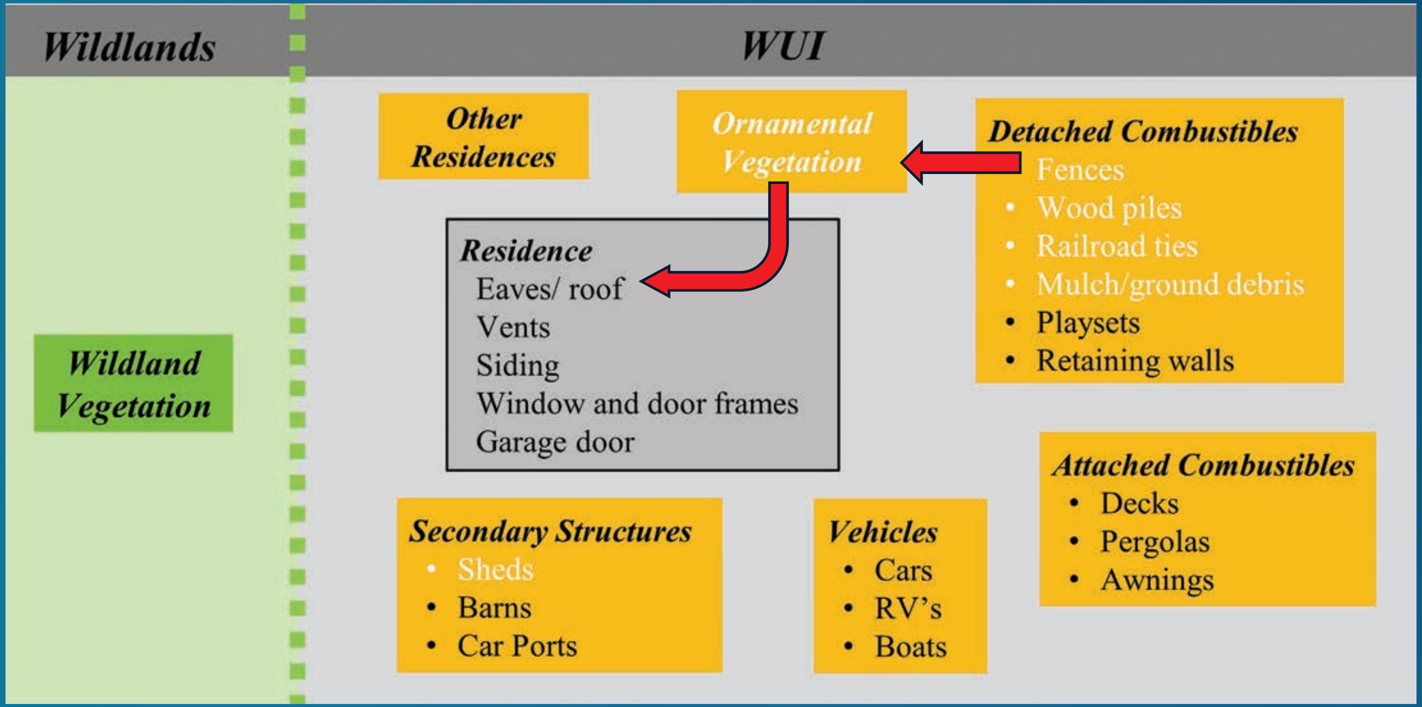

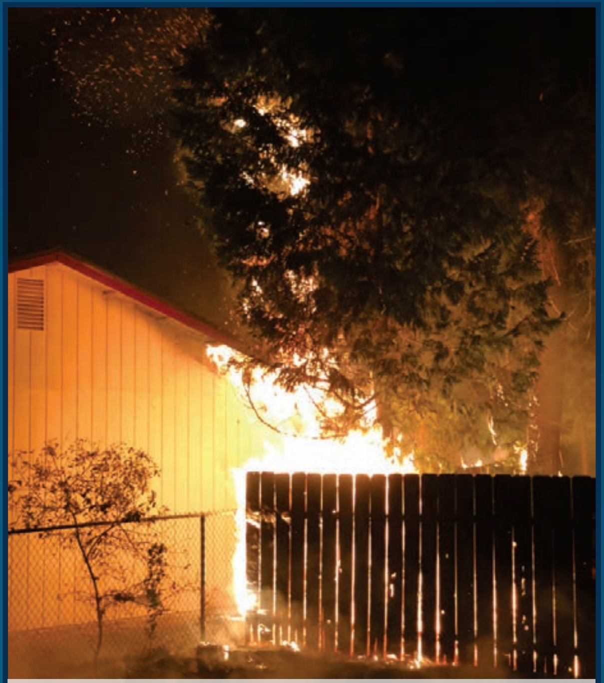
Photo courtesy of CAL FIRE, used with permission

- Local conditions will drive ember exposures to specific structure elements. Extreme variability influence actual exposures.
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NIST TN 2205 (HMM), Figure 8.

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Fire Spread Pathways

structures and parcels

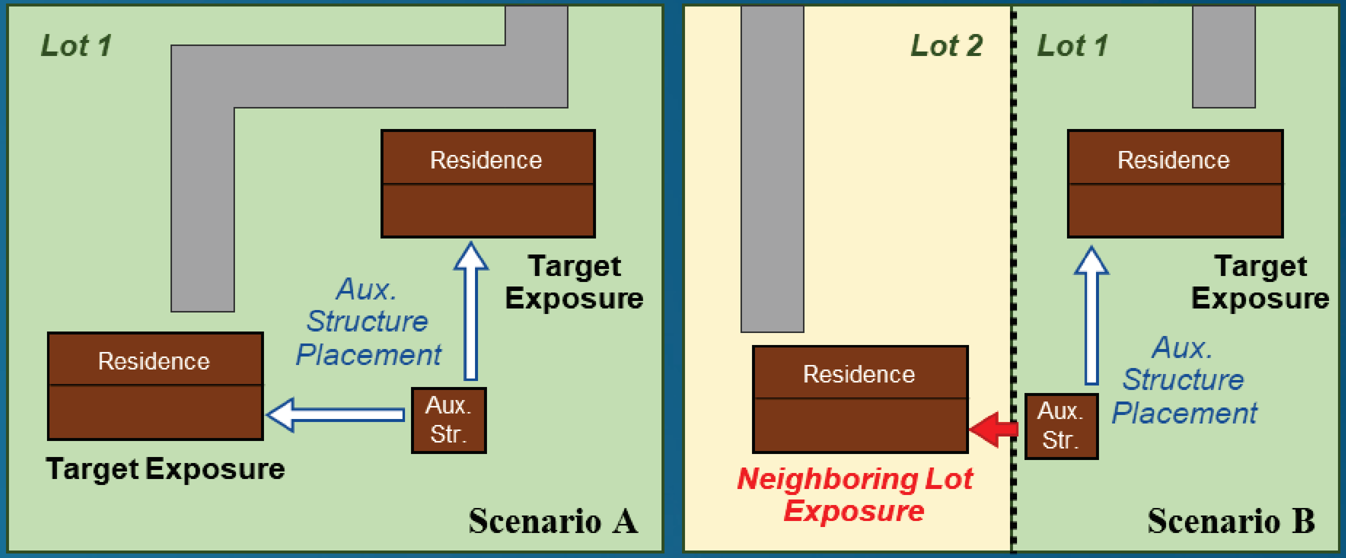
Fire Spread within and Across Parcels

1. Parcel boundaries typically limit the continuity of protection between parcels

2. Linear features can carry fire very efficiently within and in between parcels

3. Fuel agglomeration has significant impact on energy release and fire spread

Parcel boundaries typically limit the continuity of protection between parcels



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

Existing codes are parcel centric and can offer limited protection between parcels

NIST TN 2205 (HMM), Figure 9.

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Impact of Linear Features on Fire Spread

A single ignition B 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.

Embers can bring fire into communities. Once fire has started, fire spreads along multiple pathways:

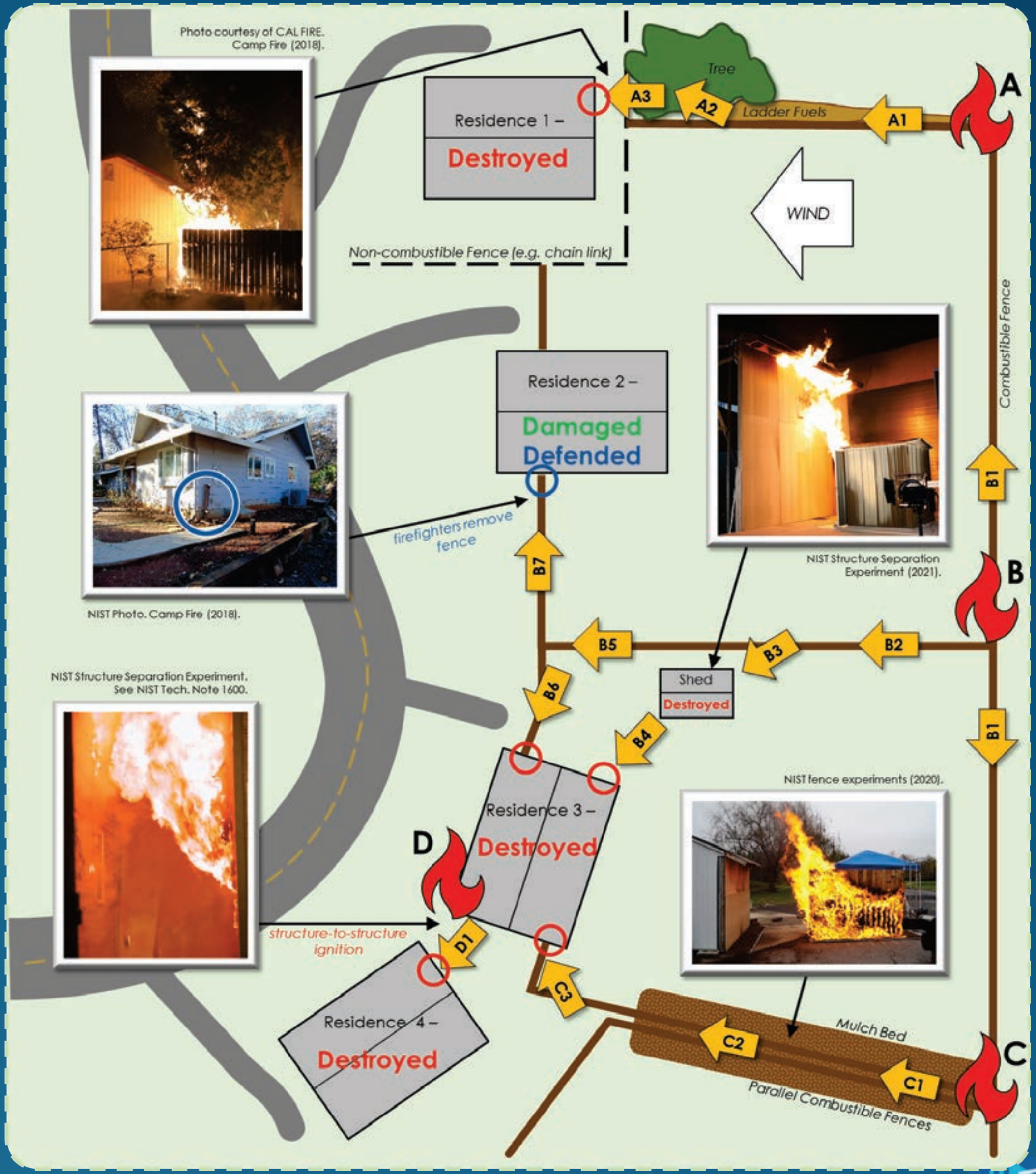
A: Spot fire ignites fence, burning along ladder fuels (*A1*) to larger vegetation (*A2*), and ignites Residence 1 on adjacent parcel (*A3*).

B: Fence ignition propagates fire on multiple parcels (*B1, B2*). Fence ignites shed (*B3*). Exposures from shed and fence ignite Residence 3 (*B4, B6*).

Fence ignites Residence 2 (*B7*). Defensive actions save Residence 2.

C: Parallel fences on adjacent parcels exponentially intensify fire exposure (*C1, C2*) which ignites Residence 3 (*C3*).

D: The exposure from burning Residence 3 ignites Residence 4 (*D1*).



Inset photographs are from field observations and experiments.

Impact of Linear Features on Fire Spread

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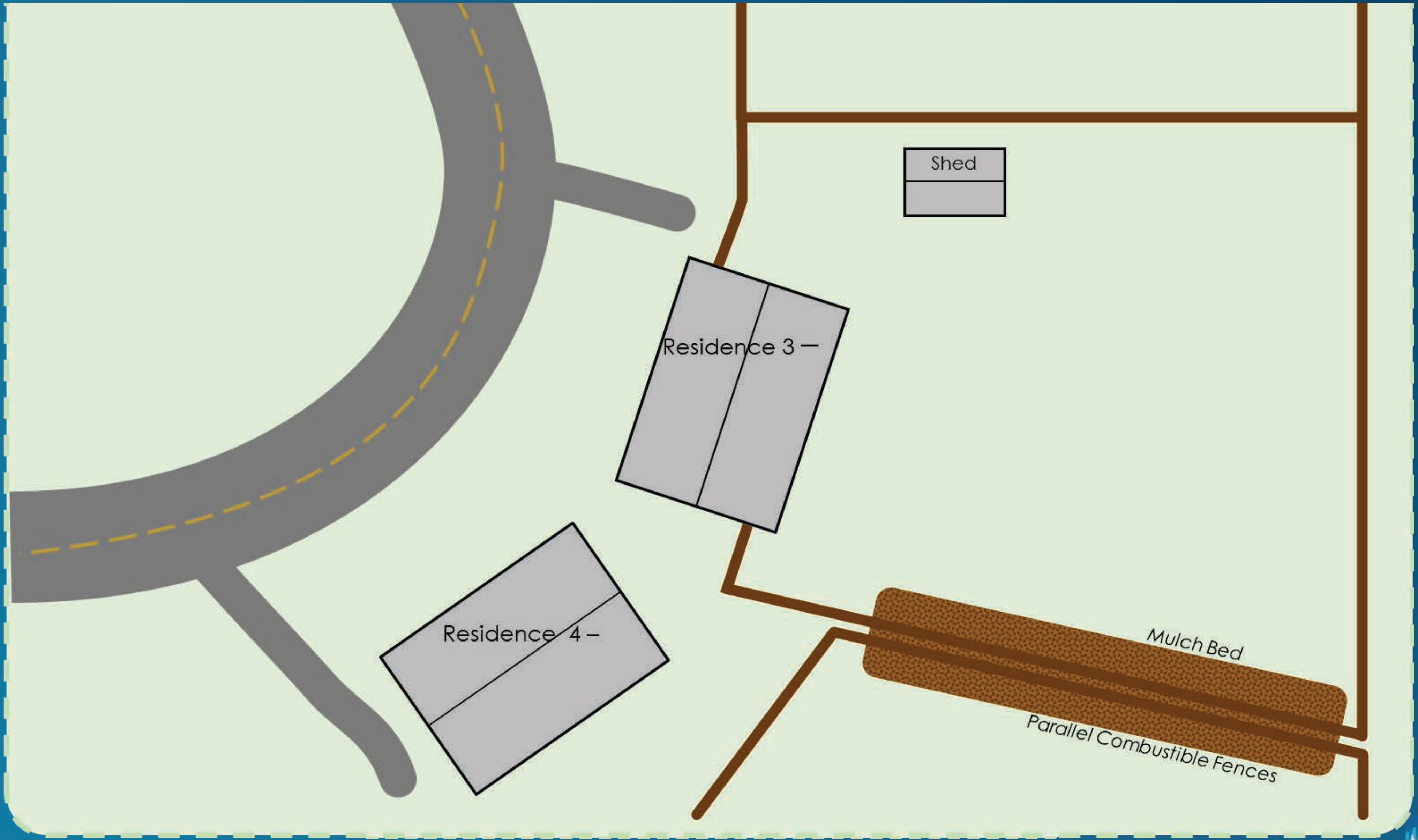

Impact of Linear Features on Fire Spread

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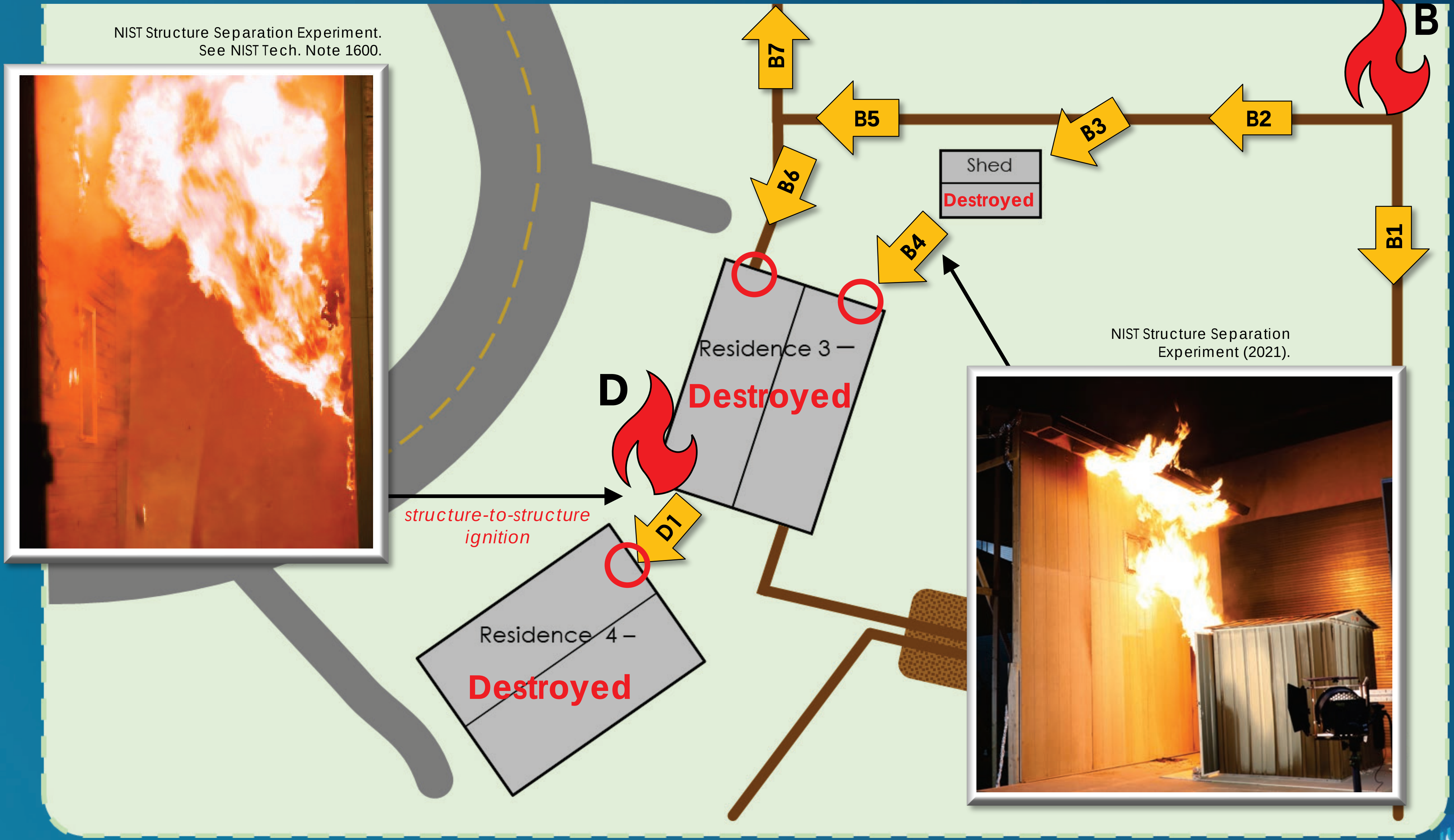

Impact of Fuel Agglomeration on Fire Spread

Parallel western red cedar fences vs. Single burning fence

Fences burning with an applied wind of 13 mi/h (6 m/s)

NIST TN 2205 (HMM), Figure 11.

Spatial Relationships Between Fuels on Two Adjacent Parcels

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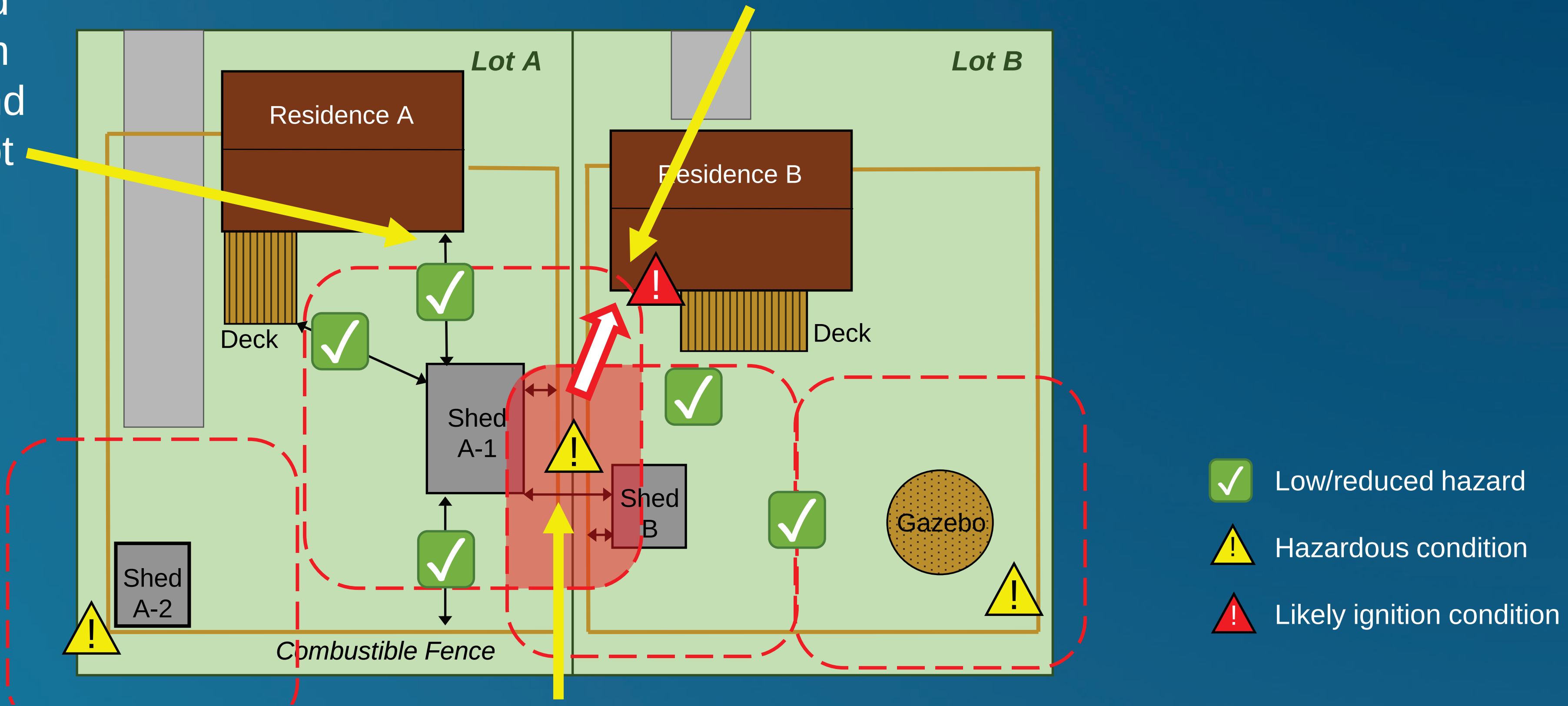
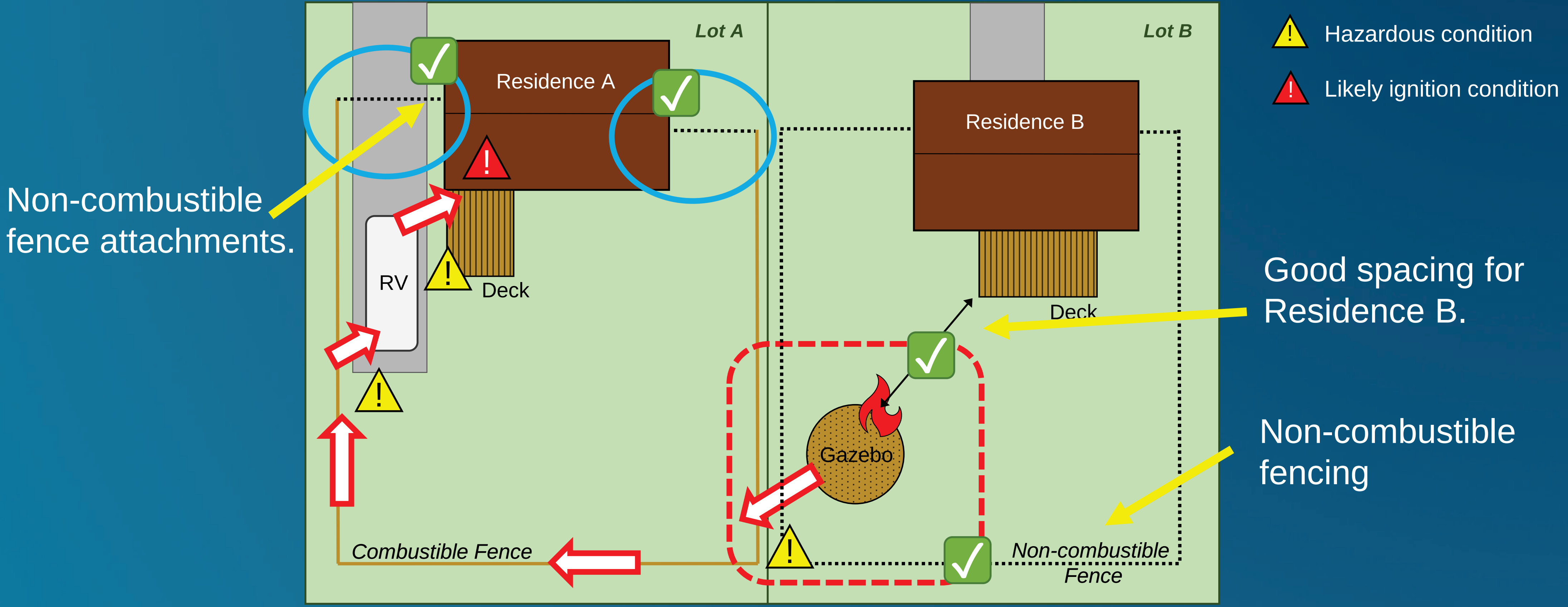
Shed A is too close to *Residence B*, and both sheds are agglomerated along the property border.

Sheds are spaced appropriately from the residences and other fuels, except fences, on their respective lots.



The sheds and fences will substantially increase the exposures from the red highlighted area, igniting the structures.

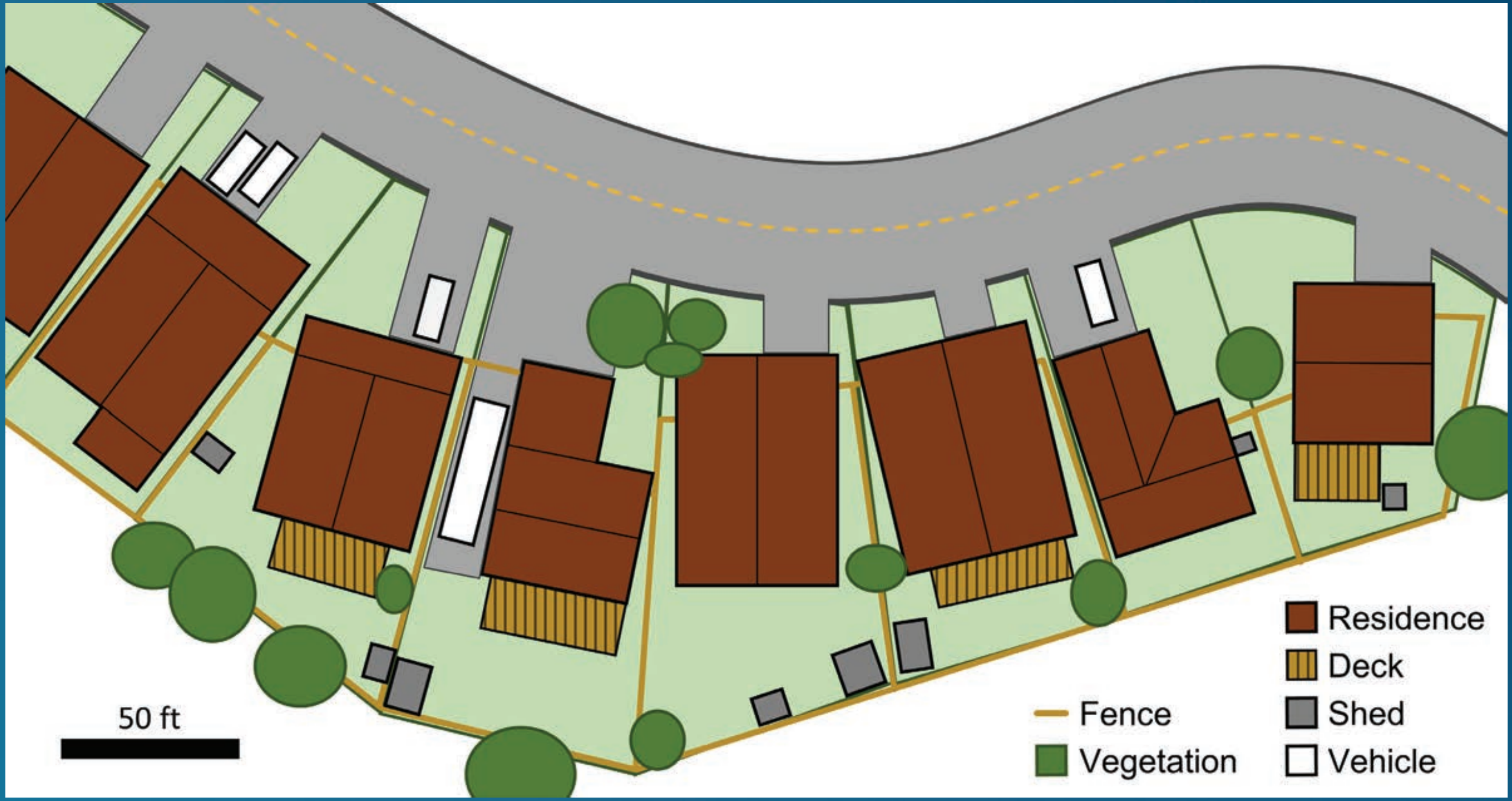
Fuel Agglomeration Combined with Linear Features



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.

NIST TN 2205 (HMM), Figure 13.

Fuel Loading and Spacing of Actual WUI Community



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.

NIST TN 2205 (HMM), Figure 14.

Structure Hardening

Hardening for Embers

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- Ember exposures are uncontrollable and unpredictable.
- A total of 40 separate vulnerabilities have been identified along with associated mitigation actions.

All structures must be hardened for high ember exposures

Hardening for Fire

a. **Reduce** the fuels

This approach reduces the number of combustibles and therefore the expected exposures.

b. **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.

c. **Remove** the fuel

This approach removes the exposure all together and is essential when there is limited space for fuel displacement.

d. **Harden** structures for fire exposure

If the above three approaches cannot be implemented, hardening the structure for fire may be necessary. The hardening option increases 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.

Effectiveness of Hardening for Fire directly related to Structure Density

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

NIST TN 2205 (HMM), Table 3.

HMM Implementation

A. Harden for embers — Always

B. Surrounding parcel hazard mitigation
C. Primary parcel hazard mitigation
D. Harden for identified fire exposures

f (fuels, spacing)

Table A. Hardening Against Ignition from Embers

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

Table A. Hardening Against Ignition from Embers

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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

- 40 identified vulnerabilities
- 57 options to implement

- 8 major categories
  - Roof
  - Cladding
  - Vents
  - Windows
  - Doors
  - Attachments
  - Mobile home skirting/crawl spaces
  - Optional

Table B. Surrounding Parcel – Hazard Mitigation

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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 ft² 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 ft² to 120 ft² (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 ft² 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.

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Table C. Primary Parcel – Hazard Mitigation

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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	$-$$	100 (See Table B)	Required (in Table D) if ED<MFSD
3	Auxiliary buildings (> 120 ft^2) – SSD	Remove or separate 50 ft from main residence and other Table C features or harden the auxiliary building construction in Table C and incorporate a 0 ft to 5 ft ember-resistant zone.	Prevent auxiliary building from directly (flames) igniting residence or other Table C items	If closer than recommended separation distance	If building removal, displacement, or hardening of auxiliary structure is not possible, residence hardening will be required	$$-$$$	50	Required (in Table D) if SSD<MFSD
4	Small (64 ft^2 to 120 ft^2) auxiliary buildings – SSD	Remove, displace 40 ft from main residence, or harden the auxiliary building construction (between 5 ft to 40 ft) from residence and other items in Table C and 0 ft to 5 ft ember-resistant zone	Prevent auxiliary structures from directly (flames) igniting main residence and other Table C items	If closer than recommended separation distance	If building removal, displacement, or hardening of auxiliary structure is not possible, structure hardening will be required	$-$$$	40	Required (in Table D) if ED<MFSD
5	Very small (< 64 ft^2) 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	$-$$$	30	Required (in Table D) if ED<MFSD
6	Other combustible structures (> 120 ft^2) (e.g., gazebo) – SSD	Remove, displace 50 ft from main residence and other Table C features, or harden the auxiliary building construction to noncombustible (If < 50 ft) from other items in Table C and incorporate 0 ft to 5 ft ember-resistant zone	Prevent fuels from directly (flames) igniting other (combustible) items	If closer than recommended separation distance and non-hardened	If building removal, displacement, or hardening of auxiliary structure is not possible; remove or displace the other Table C items or replace with a new structure made of noncombustible material.	$$-$$$	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

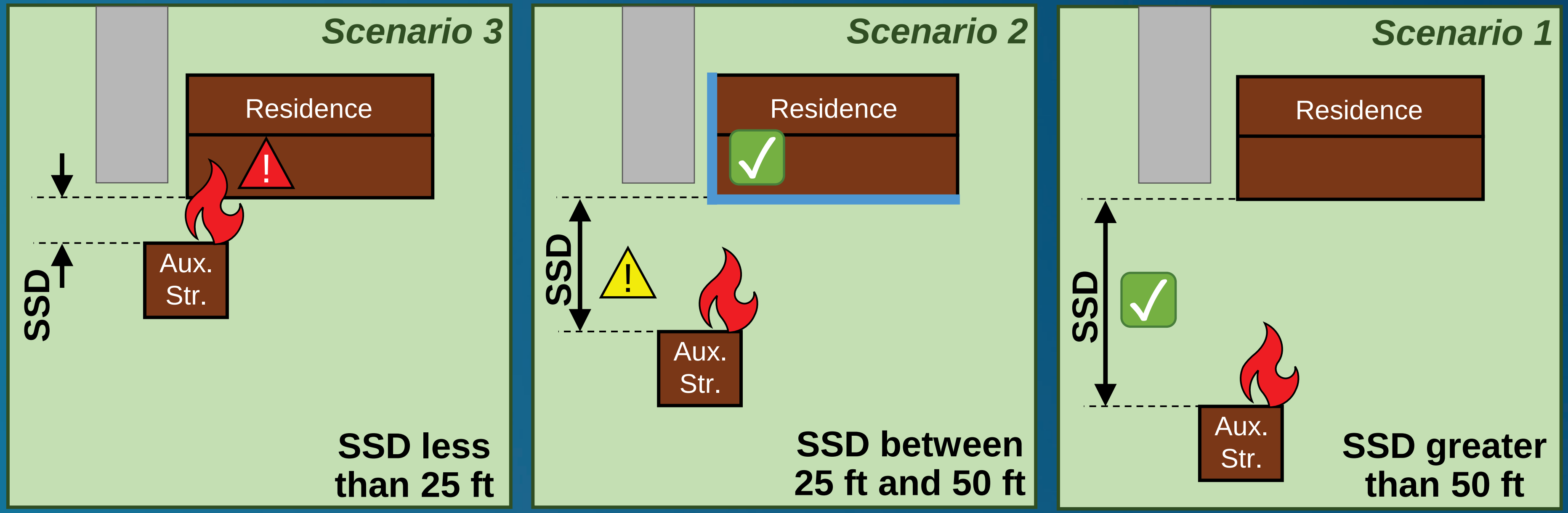
Table D. Structure hazard mitigation – hardening structure and attached combustibles against ignition from fire (radiation, convection).

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.

Using HMM – Fuel Spacing (relocation)



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).

Low/reduced hazard
Hazardous condition
Likely ignition condition

Hardening for fire is directional and is not necessarily required around the entire structure.

Hardening for embers is required in all scenarios.

Using HMM – Fuel Spacing (relocation)

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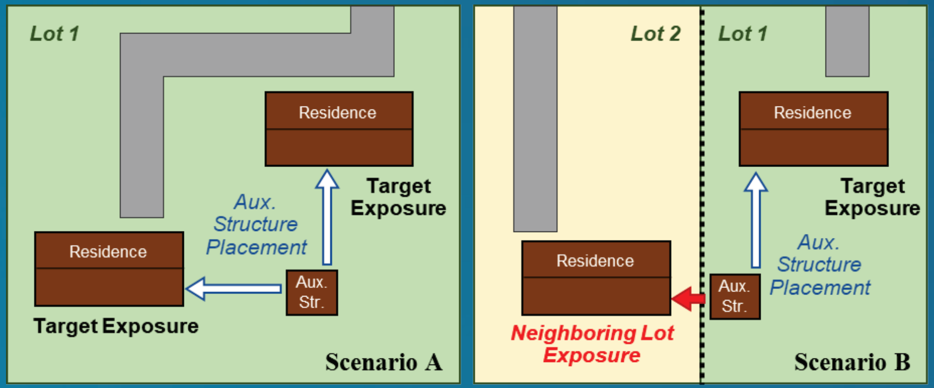
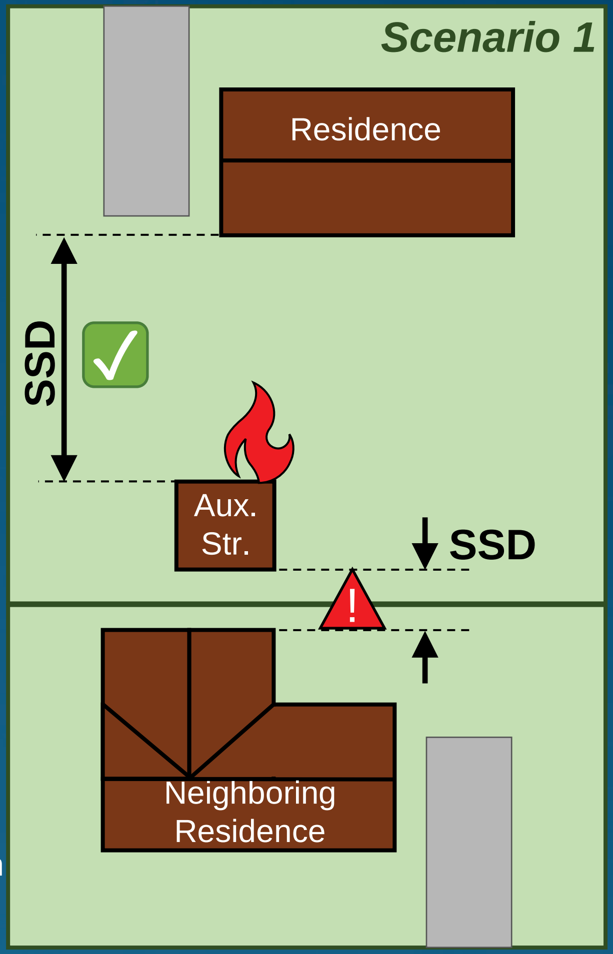
Fuel relocation must consider neighboring parcels

Recall previous parcel-centric discussion…



- Low/reduced hazard
- Hazardous condition
- Likely ignition condition



NIST TN 2205 (HMM), Figure 15.

Using HMM – Fuel Spacing (fixed spacing)

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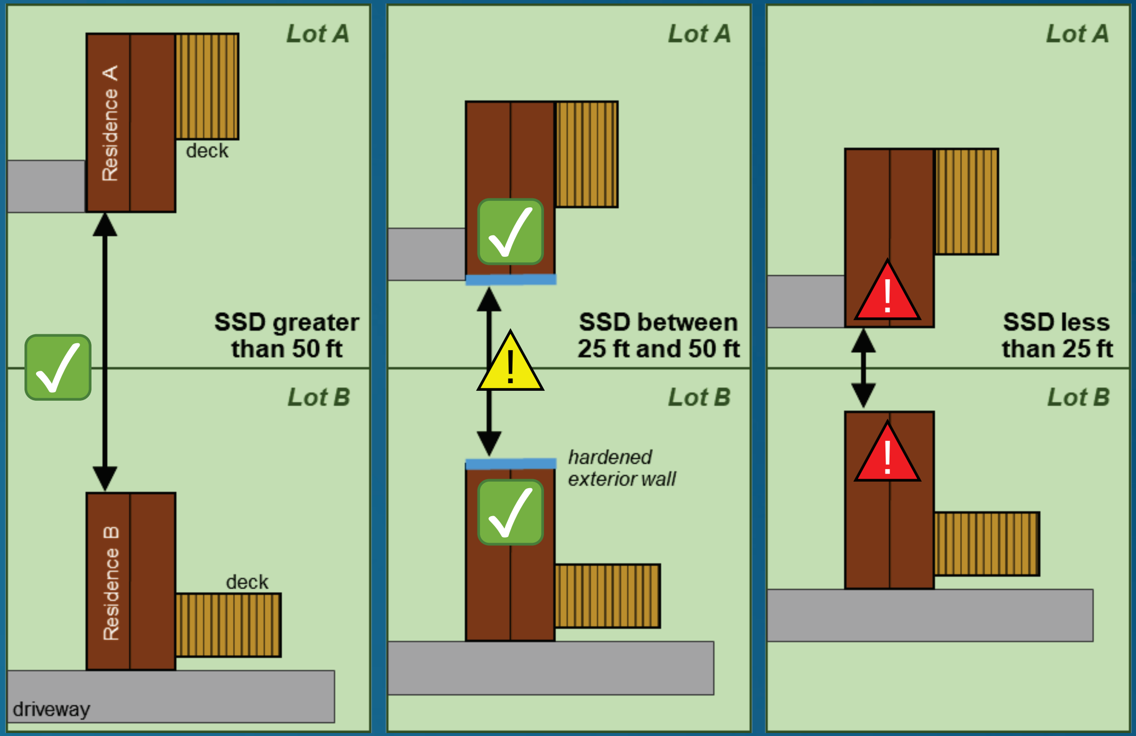

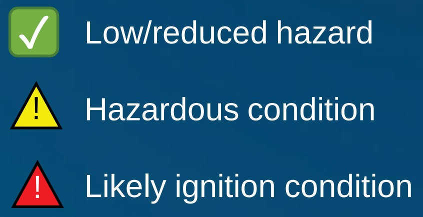

Three scenarios with a range of SSDs: 1) greater than 50 ft, 2) between 25 ft and 50 ft, and 3) under 25 ft. Structure hardening to increase ignition resistance illustrated in blue (Scenario 2).

Hardening for fire is directional and is not necessarily required around the entire structure.

Hardening for embers is required in all scenarios.

NIST TN 2205 (HMM), Figure 16.

Multi-Parcel Layout Examples

Parcel layout and fuel placement in different WUI Types

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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

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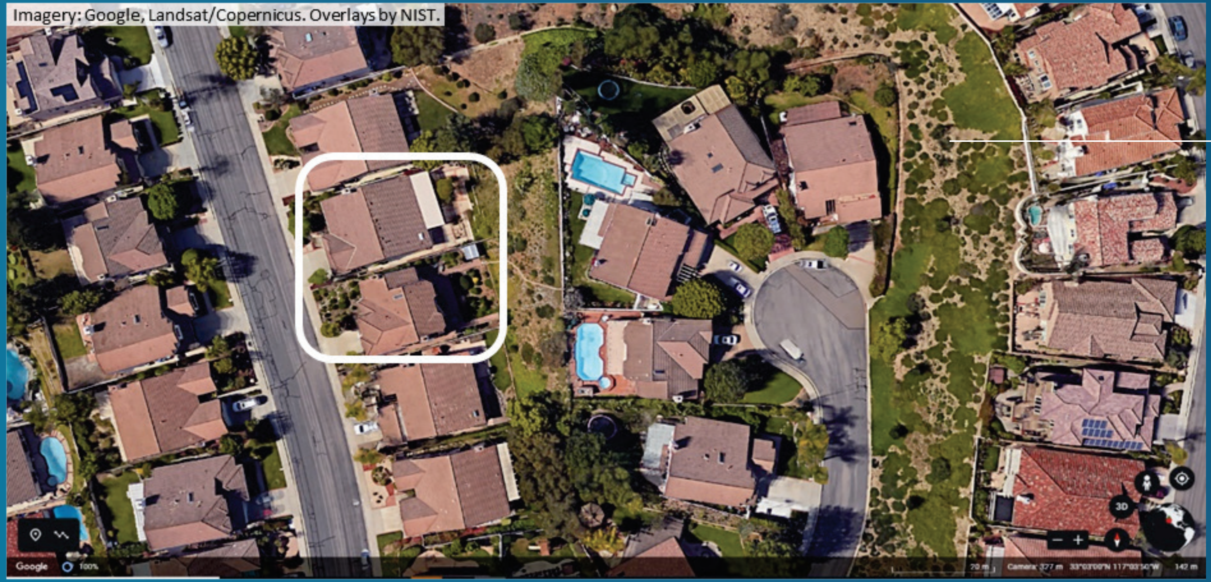
Parcel Layout and Fuel Placement in Different WUI Types –Scenario A



WUI Type 2. Small parcel with small SSD provides very limited space for auxiliary fuels. The shed is located closer to the neighboring residence than the owner's residence.

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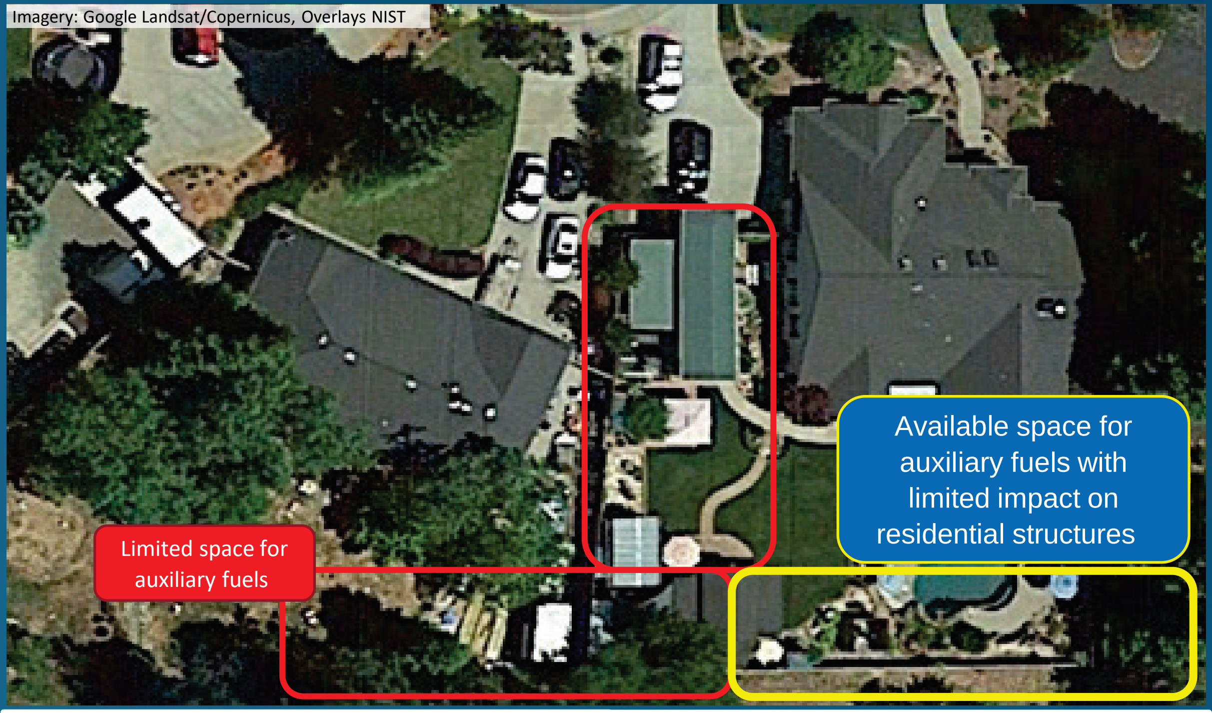
Parcel Layout and Fuel Placement in Different WUI Types – Scenario B

- 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 yellow presents reduced impact on residential structures.
- The lower figures show before and after fire imagery with the actual fire spread pathway highlighted (Camp Fire, NIST TN 2135).



NIST TN 2205 (HMM), Figure 18.

Parcel Layout and Fuel Placement in Different WUI Types – Scenario C

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- 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.

NIST TN 2205 (HMM), Figure 19.

Parcel Layout and Fuel Placement in Different WUI Types – 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.

Structure Survivability

Factors Influencing Structure Survivability

- Defensive actions
- Partial structure hardening
- Partial community hardening
- Housing density (i.e., SSD)

Defensive Actions

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 %

Data from the NIST Waldo Canyon Case Study shows 39% of undamaged structures within the fire perimeter were defended

Defensive Actions, Defensible Space and Structure Response Design Threshold

- Occurrence of large WUI fires, like the Tubbs and Camp Fires
- Numerous fire storms that have occurred in California since 2000
- Number of exposed structures can quickly outnumber statewide resources

Defensive Actions, Defensible Space and Structure Response Design Threshold

- Defensible space contributes to making structures defensible by first responders
- Defensible space is not a substitute for homes standing completely alone throughout a large WUI fire event or a firestorm

Structures must be designed to stand alone

Partial Structure Hardening

Impacts of Structure Mitigation Compliance on Structure Resilience

- The effectiveness of partial hardening represents how much benefit is provided by fractional structure hardening.
- Partial hardening of structures has a reduced impact on structure survivability that is not directly proportional to the fraction of hardening actions implemented.
- Implementing half of the ember hardening specified in Table A does not automatically translate to a 50 % increase in ignition resistance.

Partial Structure Hardening

Impacts of Structure Mitigation Compliance on Structure Resilience

- *Resident has limited control on fire exposures from outside their parcel*
- *Resident has significant control on exposures* ***within*** *their parcel: Fuels Reduction, Relocation, Removal and Structure Hardening options*

Effectiveness of partial hardening is *inversely* proportional to local ***fire*** and *ember exposures*, *incident size*, and *number of simultaneous incidents*.

Availability of Defensive Actions

- *Homeowner has limited control on ember exposures*
- *Must harden to protect against embers*

Partial Community Hardening

Impacts of Community Mitigation Compliance on Community Resilience

The impact of a partially hardened structure on the community is proportional to the inverse of SSD

High Structure Density (Low SSD)
One Structure Ignition ⇨ Large Losses

Moderate Structure Density (Moderate SSD)
One Structure Ignition ⇨ Variable Losses

Low Structure Density (High SSD)
One Structure Ignition ⇨ Limited Additional Losses

Partially hardened structures need to be further apart to prevent cascading losses

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Effect of Housing Density on Mitigation Approach

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Resident Participation and Complete Structure and Parcel Hardening

Structure density		Resident Participation and Complete Structure and Parcel Hardening
High Structure Density (Low SSD) One Structure Ignition ⇨ Large Losses	→	*"Required"*
Moderate Structure Density (Moderate SSD) One Structure Ignition ⇨ Variable Losses	→	*"Desired"*
Low Structure Density (High SSD) One Structure Ignition ⇨ Limited Additional Losses	→	*"Desired"*

Comparison of HMM to WUI Codes

Hazard Reduction Continuum

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Current Codes and Defensible Space

- *Hazard Reduction* achieved for (fire and ember) certain scenarios – losses are scenario specific
- *Structures will not stand alone* in many scenarios
- *Defensive Actions required* in many scenarios

Hazard Reduction Methodology (HMM)

- *Hazard Reduction* achieved for all identified scenarios
- Structures will stand alone if HMM is fully implemented
- *Defensive Actions not required*

No Codes and/or No Defensible Space

- *Very Limited Hazard Reduction in most cases* – large losses expected
- *Defensive Actions* necessary in most scenarios
- *Potentially Hazardous* for first responders
- *Potentially Hazardous* for residents

Comparison of HMM to WUI Codes

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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

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Summary

Summary (1 of 3)

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- Looked at traditional WUI definitions; added Structure Separation Distance in redefined WUI categories
- Outlined the relationship between exposure and hardening
- Fire Spread pathways
  - Effects of parcel centric approach
  - Effects of fuels agglomeration
  - Fuel Loading in actual WUI settings
- Outline the technical foundation for the HMM
- HMM ember hardening (Table A)
- HMM fire hardening including the principles of *Fuels Reduction, Relocation, Removal* and *Structure Hardening* options. (Table B, C, D)
- Fuel Spacing, Parcel layouts and Fuels Placement
- Factors Influencing Structure Survivability
  - Defensive actions
  - Partial structure hardening
  - Partial community hardening
  - Housing density (i.e., SSD)
- Effects of Housing Density on Resident Participation and Complete Structure and Parcel Hardening
- HMM comparison to WUI Codes

Summary (2 of 3)

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- Field Observations, Case Studies and Laboratory and Field Research were used to develop the HMM.
- HMM provides a path forward to reduce structural losses from WUI fires.
- HMM is designed to *leverage the spatial component of exposures* to effectively and *cost efficiently mitigate hazards* at the structure and parcel level.
- While high density communities pose a significant hazard mitigation challenge, HMM demonstrates why it is essential to get full resident buy-in and complete structure and parcel hardening to prevent ignitions that can cascade throughout the community with catastrophic results.

Summary (3 of 3)

- HMM also demonstrates why the strict compliance requirements are not necessary and can be laxed as housing density decreases.
- The comparison to existing codes should be treated with caution as the codes contain many of the components of HMM.
- Where implemented HMM will provide a significant improvement in structure and community resiliency to WUI fires. The effectiveness of partial implementation will be a function of local exposures (driven by SSD and parcel fuels) and defensive actions.

Thank You

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https://www.nist.gov/el/fire-research-division-73300/wildland-urban-interface-fire-73305/hazard-mitigation-methodology

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CAL FIRE SINCE 1885

Insurance Institute for Business & Home Safety®

Summary Of Technical Principles

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 attributes and specific combustion considerations can decrease ember generation.
3. A property owner cannot stop or realistically control ember exposures.
4. Large ember exposures can be generated and observed throughout WUI fire incidents.
5. The potential for high exposures drives the need to completely harden structures against ember exposures.
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.

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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 which then impacts 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 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.

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Parcel/Community

12. The parcel size and placement of structure(s) will determine 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 combustibles attributes are seen as expendable/disposable in the context of parcel hardening, the impact of these attributes 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.

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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 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 in high ember exposures can be conceptualized using the “80/20 Rule”—80 % ember hardening will nominally provide 20 % ember ignition protection. While the actual values will vary based on local conditions and specifics of hardening, the general rule 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 frequently be the critical path to reducing the ignition of the residential/commercial structure.

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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.