WUI HANDBOOK FOR

FIRE RISK ASSESSMENT & MITIGATION, 2ND EDITION

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SFPE Foundation®

About The Handbook

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Welcome to the Second Edition of the *Wildland-Urban Interface (WUI) Virtual Handbook for Fire Risk Assessment & Mitigation*.

The WUI Virtual Handbook is the product of two U.S. Department of Homeland Security Federal Emergency Management Agency Fire Prevention & Safety Grants. The initial grant facilitated the creation of the First Edition of the *WUI Virtual Handbook* to address individual property fire risk assessment and mitigation, published in 2023. The second grant expands the content for property fire risk assessment and mitigation, but more importantly, adds a section about community and neighborhood fire risk assessments and mitigation.

This second edition of the *WUI Virtual Handbook* is a flexible tool that can be utilized for a wider range of needs, including (1) training property inspectors, (2) conducting WUI property assessments, (3) engaging with homeowners regarding WUI risks and mitigation activities, and (4) engaging community leaders and stakeholders in understanding WUI fire risks and potential mitigation activities. It has been designed to meet the needs of both more- and less-experienced fire departments and to empower fire service personnel to reduce community risk. Notably, it is not intended to replace any existing tools or programs that departments or communities may already have in place. Instead, we hope that it will be adopted as an open-access companion tool or supplementary guidance wherever needed.

In addition to expanding parcel-level and community-level content and images, this updated edition includes a website with four videos explaining how to use and share the Handbook, educational flyers, and a basic Parcel-Scale Wildfire Risk Assessment Checklist that fire departments (and other stakeholders) can use as a starting point for property fire risk assessment and mitigation in the absence of other similar tools.

It is our intent that use of the *WUI Virtual Handbook* will result in communities being better prepared to assess and address the fire risks associated with living in the wildland-urban interface.

To learn more about the SFPE Foundation and our efforts to engage fire engineers and other stakeholders in better understanding and addressing WUI fire risks, please visit our website at: https://www.sfpe.org/foundation/wildland-urban-interface/wui-initiatives

Sincerely,

Leslie Marshall, Ph.D.

Director, SFPE Foundation

Project Team

Project Personnel

SFPE and the SFPE Foundation led the implementation of this project by leveraging the expertise of the Society of Fire Protection Engineers' membership - including the fire service, engineering, and insurance industries - alongside the expertise of fire departments with WUI fire risk assessment and mitigation experience.

This project was made possible with support from Fiscal Year 2020 and 2022 U.S. Department of Homeland Security Federal Emergency Management Agency Fire Prevention & Safety Grants held by SFPE and the SFPE Foundation. The first edition of the handbook was released in 2023. This is the Second Edition, released in 2025.

SFPE and SFPE Foundation staff and a Project Advisory Panel provided oversight throughout the two projects. The First Edition of the WUI Virtual Handbook was developed by an Engineering Technical Consulting team from Jensen Hughes and adapted for a web-based platform by AS Creative Services. The Second Edition of the handbook was developed by an Engineering Technical Consulting team from Jensen Hughes, an Engineering Risk Consulting Team from Code Red Consultants, and a Web Developer & Creative Consultant Team from Engineered Fire Systems and Bareknuckle Branding.

SFPE, the SFPE Foundation, the Project Teams, and the Advisory Panel would like to thank the many volunteers from fire engineering companies, fire safety organizations, universities and fire departments from across the United States and around the globe whose input and expertise were invaluable to this project.

Second Edition - Project Team

Project Advisory Panel:

- **Brad Cronin**, CFPS - Assistant Fire Chief Avon (MA) Fire Department and Chair, SFPE Fire Service Subcommittee
- **Kris Cooper** - Fire Marshal, Colorado Springs Fire Department
- **Daniel Gorham**, PE - Research Engineer, Fire Safety Research Institute, UL Research Institute
- **Jerry McAdams** - CWMS - Owner/Consultant, MC Fire, LLC
- **Brian Meurer** - Asst. Chief & Fire Marshal, Louisville (KY) Fire Department, and Member, SFPE Fire Service Subcommittee
- **Steve Quarles**, PhD - Retired, University of California Cooperative Extension Advisor Emeritus and Insurance Institute for Business & Home Safety (IBHS)
- **Peter Senez**, PhD - Principal & President, Senez Consulting, and Chair, SFPE Foundation Board
- **Ashley Whitworth** - Program Administrator, Wildfire Mitigation Section, Colorado Springs Fire Department

SFPE & SFPE Foundation:

- Leslie Marshall, PhD
- Amanda Tarbet, MSLS
- Lisa VanBuskirk, PE
- Austin Guerrazzi

Engineering Risk Consultants:

- Code Red Consultants, LLC
    - Hubert Biteau PhD, PE
    - Jen Hoyt, PE
    - Jeremy Souza, PE, CFPS

Web Developer & Creative Consultant:

- Engineered Fire Systems
    - Daniel Price, PE
    - Santiago Correa
- Bareknuckle Branding
    - Bill West
    - Courtney O'Neill

Engineering Technical Consultants:

- Jensen Hughes
    - Darlene Rini, PE
    - Amelia Pludow, PhD
    - Julia Cuendet
    - Kristina Fauss
    - Walker Donuji, PE
- Wildfire Planning International
    - Molly Mowery, AICP

First Edition - Project Team

Project Advisory Panel:

- **Brad Cronin**, CFPS - VP, Fire Protection, Strategic Code Solutions LLC, and Chair, SFPE Fire Service Subcommittee
- **Daniel Gorham**, PE - Research Engineer, Insurance Institute for Business & Home Safety (IBHS)
- **Brett Lacey**, PE - Fire Marshal, Colorado Springs Fire Department
- **Jerry McAdams** - Sr. Captain and Wildfire Mitigation Specialist, Boise (ID) Fire Department
- **Brian Meurer** - Asst. Chief & Fire Marshal, Louisville (KY) Fire Department, and Member, SFPE Fire Service Subcommittee
- **Steve Quarles**, PhD - Retired, University of California Cooperative Extension Advisor Emeritus and Insurance Institute for Business & Home Safety (IBHS)
- **Ashley Whitworth** - Program Administrator, Wildfire Mitigation Section, Colorado Springs Fire Department

SFPE & SFPE Foundation:

- Leslie Marshall, PhD
- Amanda Tarbet, MSLS
- Steffen Blings, PhD
- Austin Guerrazzi

AS Creative Services:

- Chris Hoover
- Justin Watson

Jensen Hughes:

- Darlene Rini, PE
- Alex Cooper
- Julia Cuendet
- Walker Donuji, PE
- Hannah Govaert
- Meghan Joy
- Amelia Pludow
- Christine Pongratz, PE
- Michael Wojcik, PE

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PARTS I AND II - PARCEL-SCALE WILDFIRE RISK MITIGATION

Overview

Part I and Part II of the WUI handbook provide fire engineering guidance to increase wildfire resiliency of an individual structure through a variety of design, construction, and maintenance considerations for building components, assemblies, and systems throughout the exterior envelope of a building, as well as selection, spatial layout, and maintenance of vegetative and non-vegetative fuels in the surrounding yard space or landscaping at building-/ parcel-scale. The intent is to limit the likelihood of damage or loss of an individual property to wildfires and/or structure-to-structure fire spread. Functionally, the handbook is primarily designed to support Fire Departments in assessing parcel-level WUI risk and providing mitigation guidance to homeowners The handbook centralizes the latest WUI fire research, science and engineering knowledge, and practice into one tool, while also supporting ongoing cooperation and collaboration between fire engineering/fire science and firefighting/fire service entities.

- **Part I - Structural Hardening**. This chapter provides a range of building construction features that can be implemented into the design of a new building or introduced as retrofits to existing buildings/homes to help limit structure ignition and total loss due to wildfires. These measures include various active and passive building features, elements, and systems from the top of structure down to the foundation (e.g., roof covering fire-rating, joint or interface detailing [See Figure A], vent protection).

- **Part II - Defensible Space**. This chapter provides guidance on the location, selection, and maintenance of vegetation and other combustible materials immediately surrounding a home or structure and the various means and methods to help slow or stop fire from spreading to the structure, causing ignition.

Note: *While the focus of this handbook is primarily on residential construction, many of the wildfire safety requirements, guidance, and principles are conceptually relevant to commercial buildings and other structures in the built environment.*

Note: *The information and guidance in Part I and II are interrelated with key concepts and provisions at the neighborhood and community-scales. Thus, it is critical of users to be familiar with any practical constraints, existing conditions, limitations of community-scale services, and other underlying factors that may influence wildfire resiliency at the building/parcel-scale (e.g., limited access/egress, unreliable firefighting water supplies). There may be a need to enhance wildfire resiliency at the parcel-/building-scales to offset vulnerabilities of community-scale characteristics.*

Note: *This handbook is not intended to act as a code or standard, but a guidance document and reference tool. Codes referenced herein are the most recent editions at the time of development. Refer to the relevant jurisdiction(s) for adopted codes, standards, and local ordinances for statutory requirements.*

Chapter Organization

Key Considerations

- **Systems Concept**

  While Parts I and II of this Handbook provide guidance on individual components and features of the exterior envelope of a building and its immediate surroundings, an important concept to understand is that wildfire resiliency of a property relies on the system of interconnected and interrelated components. While each element, component, and assembly are critical, equally important is how each feature interacts with one another and must work together to reduce the chance of structure ignition. For the exterior envelope of the building, this may include paying special attention to how fire resistant the construction details are at joints (e.g., expansion joints, window-to-wall joints, wall-to-wall joints), interfaces of different building elements (wall-to-roof interfaces), edges, ridgelines, ventilation openings, etc. Protection of joints and interfaces is vital, as embers, flames and hot gases can enter a building via gaps between different building elements. For a building to be well protected, mitigation strategies must be applied holistically to ensure that the fire resistance, integrity, and continuity of the system of parts is maintained.

- **Critical Items (for Retrofits)**

  While structural hardening and defensible space guidance in the Handbook are important for reducing wildfire risk and should be provided for all new construction in high fire prone areas, most property owners with existing buildings or homes that pre-date WUI fire safety regulations will likely need to prioritize critical features on their property as retrofits. The following retrofits are considered critical for increasing wildfire resiliency of existing construction:

1. **Roof Construction & Covering** - Upgrade roof covering to Class A. Refer to Section 1.1.1 *Roof Construction & Covering* Section for more details.
2. **Exterior Wall Construction & Cladding** - Upgrade exterior cladding materials to noncombustible (e.g., stucco, masonry). For added fire resistance, provide a single layer of 5/8" Type X exterior rated gypsum below the cladding and weather seal. Refer to Section 1.3.1 *Exterior Wall Construction & Cladding Section* for details.
3. **Vent Protection** (e.g., roof vents, soffit or under-eave vents, crawl space/basement vents) - Upgrade vents to those that are fire-rated/approved. Where infeasible, install corrosion-resistant metal mesh of maximum 1/8" (preferably 1/16") to protect the vent. Refer to Sections 1.1.2 *Roof Vents & Chimneys*, 1.2.2 *Soffit or Under-Eave Vents*, and 1.2.1 *Crawl Space/Basement Vents* for more details.
4. **Window Protection** - Upgrade windows to dual-paned with outer layer tempered glass and inner layer laminated. Ensure window framing is ignition-resistant, noncombustible or metal clad wood framing materials. Refer to Section 1.3.4 Windows for more details.
5. **Zones, Spacing, and Landscape Design (particularly Zones 0-1)** - Pay special attention to keeping Zone 0 (0-5 ft) as a noncombustible zone, where plants and other man-made fuels are removed or minimized. Zone 0 should be provided around the entire home/building, including all combustible extensions (e.g., decks, balconies). Reduce vegetation density and move or remove combustible materials in accordance with guidelines and state/local requirements beyond 5 ft. Refer to Part II of the Handbook for more details.
6. **Roof Joints (e.g., roof panel-to-panel, around through-penetrations, roof-to-wall joint) and Wall Joints (e.g., head-of-wall to Roof, Bottom-of-Wall to Roof, around windows, doors, bottom-of-wall to foundation, wall-to-wall intersections)** - Seal gaps within joints with fire-resistant caulk/sealant and protect gaps at interfaces with metal flashing. Refer to Sections 1.1.5 *Roof Joints* and 1.3.5 *Joints* for more details.

Note while prioritizing the critical items indicated above should provide increased wildfire resiliency of an existing home or property, there's no guarantee that loss or damage will not occur in a major wildfire incident. Ongoing inspection and maintenance of the exterior of the home or property per the guidance in this Handbook provides the best odds of minimizing risk.

- **Fire Resistance by Assembly - How to Inspect**

  For several building construction components (e.g., walls, roofs, windows, doors), fire resistance is generally achieved by the build-up or assembly of many materials and components as a whole. For example, a Class A roof system may require the assembly of a Class A roof covering (e.g., asphalt single) with an underlying layer of gypsum product. However, in the field, a fire/wildfire safety inspector will likely be unable to verify if a Class A roof system is constructed appropriately to satisfy the "assembly" requirements to achieve fire resistance. This introduces some uncertainties into how a building component is constructed, as what can be seen on the outside may not be consistent with what's behind the surface. For example, some key through depth vulnerabilities includes combustible insulation, weather proofing, and combustible cavity materials. For increased certainty, property owners can refer to construction drawings or have a professional conduct small 'opening-up' works to verify construction.

- **Importance of Flame Spread**

  While fire-resistance of the materials and assemblies in the exterior envelope of a home, building or structure is important in reducing ignition risk, so is the vertical and lateral flame spread characteristics of those materials and systems. Flame spread is defined as "the propagation of flame over a surface" by the International Building Code. So, while a material or assembly may be able to resist fire and smoke from entering the building or home, if the exterior materials do not meet minimum flame spread requirements (e.g., a flame spread index of 25 or less when tested in accordance with *ASTM E84* or *UL 723*), they may be providing a surface for fire to spread along the exterior envelope of the building, potentially igniting other building materials and other debris in more vulnerable parts of the structure, leading to fire spread into the interior of the home or building.

- **Site Constraints**

  Most urban and suburban homes cannot achieve 30 feet of setback to other structures or topographic hazards (e.g., steep slopes, ridge slides, drainages), let alone 100 feet of defensible space on all sides. Current wildfire building codes and referenced standards on structural hardening and defensible space do not provide requirements on how to achieve wildfire resiliency when various site constraints exist. These constraints can oftentimes introduce additional hazards (e.g., adjacent unmanaged vegetation, vacant lots, structure-to-structure fire spread, high intensity fire exposures due to topography) that are mostly outside of the control of the property owner. Some industry guidance does exist that recommends adopting "communal defensible space" concepts, enhancing defensible space requirements and/or structural hardening measures on the aspects of the buildings with limited setbacks and other site constraints [1]. However, this guidance is limited and does not necessarily address all forms of site constraints, construction typologies, vegetation conditions, and other practical limitations. Alternative methods, such as communal defensible space with neighbors and other structural hardening measures, are needed to address these increased risks. Some suggestions are provided in Part II for Defensible Space in the "Zones, Spacing, and Landscape Design" subsection and Part III for Neighborhood and Community-Scale Planning in the "Developing Siting" section.

- **Fire Flow Pathways**

  Fire can move across parcels via connecting "pathways" formed by combustible features such as vegetation, sheds, and fences. This is especially prevalent across linear features (e.g., fences, continuous path of surface fuels), which can carry fire between parcels [2]. While the most straightforward method of removing these pathways is to utilize noncombustible materials, there are a number of features where it is impossible to achieve this (such as vehicles) [2]. Refer to NIST Technical Note 2205 for more information [3].

- **Multi-Hazard Considerations**

  In locations where wildfire is a concern, there are typically other hazards which pose a risk as well. Residents and property owners need to make decisions about structures, vegetation, and other aspects of their parcel, while balancing consideration of multiple hazards and other objectives such as cost, aesthetics, and durability. Depending on the combination of relevant hazards, specific actions at the parcel-level may reduce the potential impacts of more than one hazard or the most effective action for one hazard may increase vulnerability to a different hazard. For example, ignition-resistant roofs can be designed to also help mitigate wind damage. On the other hand, some methods of fuels reduction (e.g., total removal of vegetation) may increase the likelihood or rate of slope erosion during flooding. The user of this handbook should be aware of how fire safety provisions, features, and assemblies might impact the effectiveness of mitigation for other hazards and performance criteria. Mitigations undertaken for one hazard should not exacerbate risk from another hazard.

Overview of Key Gaps in Knowledge

Current, nationally recognized wildfire-specific building codes are generally nascent. Some key gaps in knowledge are detailed in the table below.

Table 1. Key gaps in knowledge (regarding wildfires) for codes, standards, and products.

Topic	Gap in Knowledge
Nationally Recognized Wildfire-Specific Building Codes	• Limited fire safety requirements for variable construction practices, all types of components in the exterior envelope of the building at construction-level detail, joint systems, through penetration detailing, etc. • Lack of mitigations for new technologies such as residential solar panel installations and associated battery storage systems. • Because building codes typically only apply to new construction, there are limited requirements or guidance for retrofits of existing buildings. • Lack of requirements on fire separation distances for single family homes, duplexes, and 1-3 story townhomes. • Limited fire safety requirements designed to allow a home or structure to survive a fire without fire service intervention. Fire safety performance for residential construction relies heavily on local firefighting response capacities. • Many states and local jurisdictions have limited requirements for defensible space measures, particularly when site constraints limit property owners from achieving 30 ft of setback and/or 100' of yard space. • Lack of exterior sprinkler system design, activation, installation, and maintenance procedures. • Lack of design criteria for exterior suppression systems (e.g., design criteria for layout, water supplies, water pump and associated power supplies, detection and activation systems). • Lack of requirements or guidance on wildfire detection and alarm systems. • Limited requirements on access/egress requirements for new developments and neighborhoods. • Most building and fire codes assume a single, small-scale fire incident in determining fire safety requirements. This assumption is no longer valid during large-scale wildfire incidents.
Wildfire-Specific Test Standards	• There is a limited number of existing wildfire-specific fire test standards compared to interior building fire-specific test standards. While some wildfire-specific fire tests standards exist in California codes, other nationally recognized wildfire codes do not explicitly reference all available wildfire test standards. • Existing wildfire test standards are focused on primary forms of heat transfer (e.g., radiation, convection, and direct flaming), as opposed to ember exposure. • Wildfire test standards may not incorporate pre-weather conditioning as part of the fire test protocols, which may limit our understanding of long-term performance and reliability of exterior elements, components, and assemblies to wildfire exposures over time. • While wildfire-specific test standards for elements such as under-deck flame impingement exposure and performance of gutter cover devices are in development, there are still gaps. These include wildfire exposure to exterior roof and wall surfaces to flame spread, in addition to fire resistance.
Wildfire Listed Products	• While many catalogs of listed products exist for interior building components, there are no equivalent catalogs at the national level for exterior building components exposed to wildfires in combination with weathering pre-tests. (Note: California has state approved WUI products. However, there are a limited number of listed assemblies for joint and other interface detailing products specific to WUI).

Cost Considerations

Retrofits or enhancements of new construction for wildfire resilience have cost implications. The following resources provide information on potential costs of various wildfire risk mitigations:

- Retrofitting a Home for Wildfire Resistance: https://headwaterseconomics.org/natural-hazards/retrofitting-home-wildfire-resistance/
- Construction Costs for a Wildfire-Resistant Home: California Edition: https://headwaterseconomics.org/natural-hazards/wildfire-resistant-costs-california/
- Building a Wildfire-Resistant Home: Codes and Costs https://headwaterseconomics.org/wildfire/homes-risk/building-costs-codes/

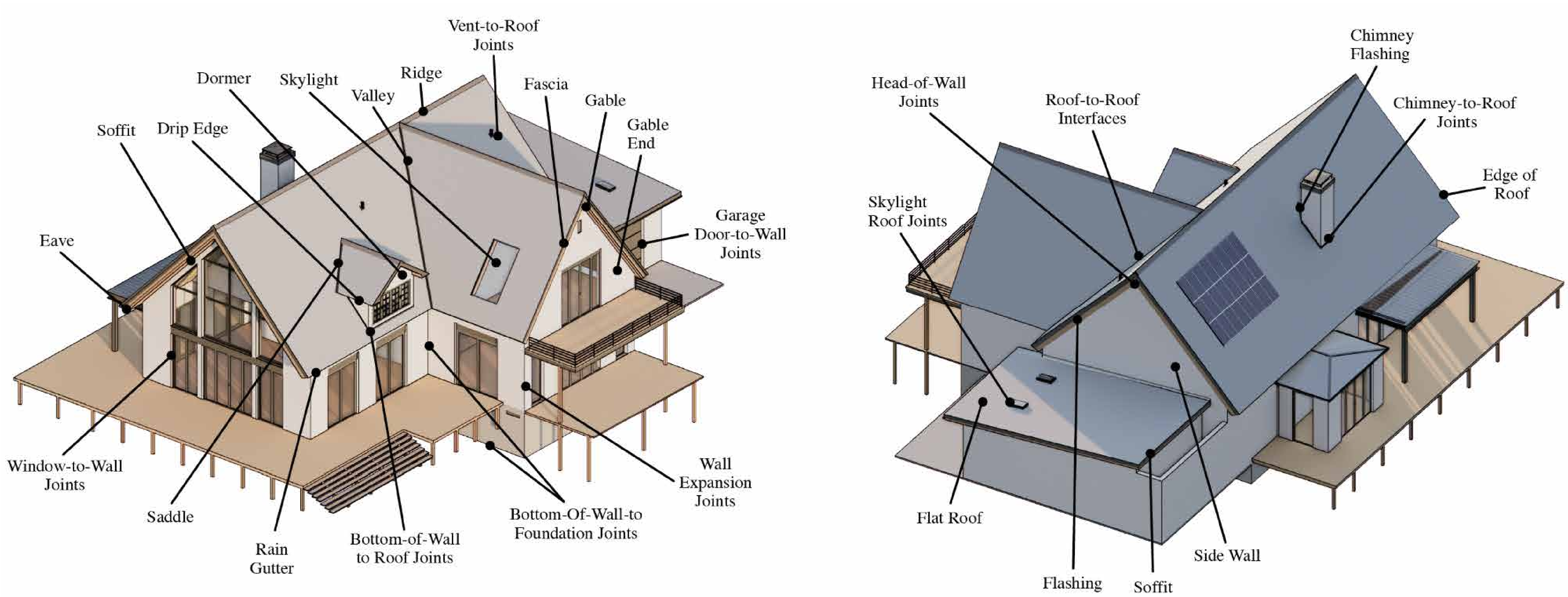
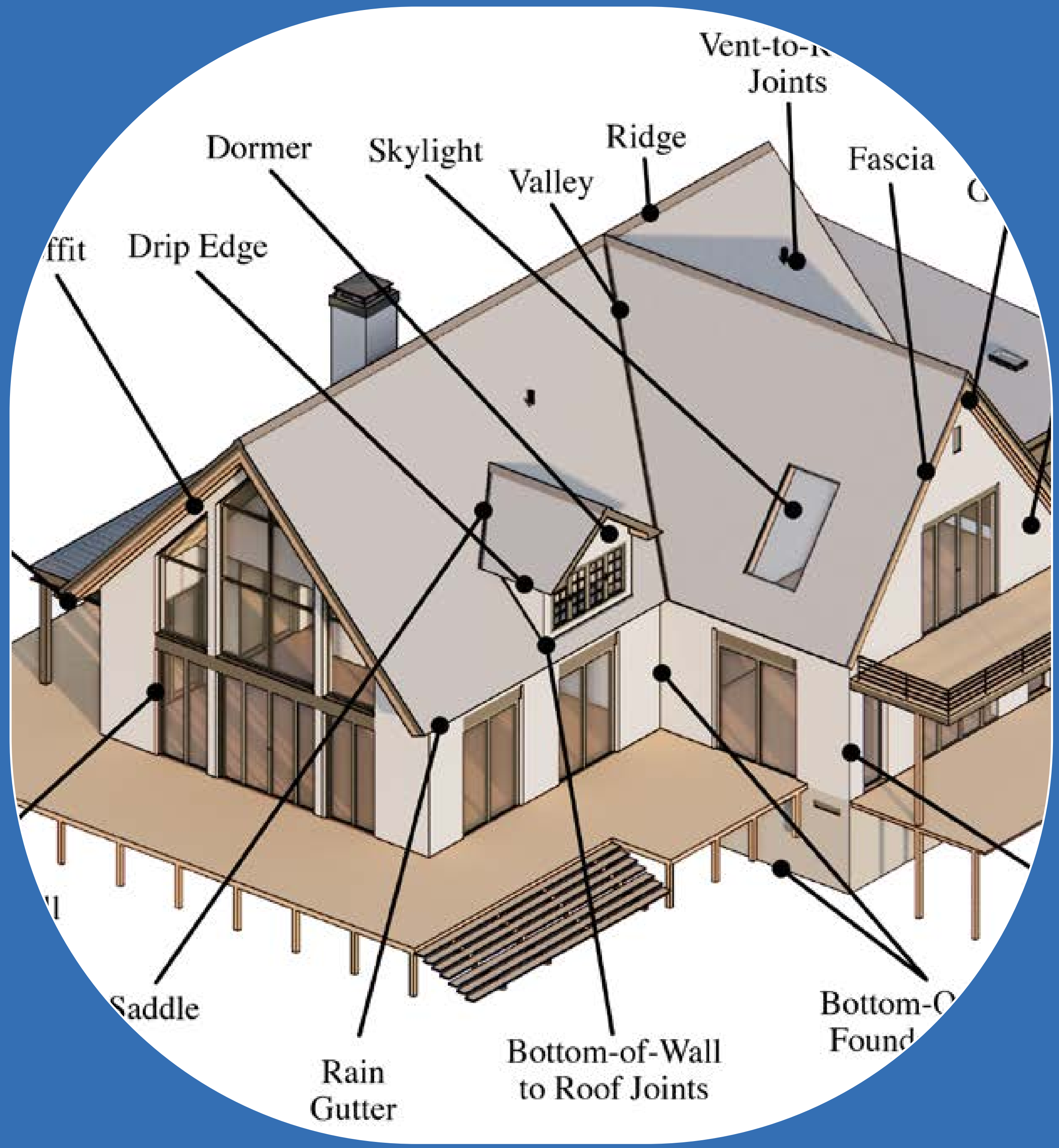


Figure A: Parts of a House with Labels for Features Defined and Discussed in This Section. Credit: Image adapted from Marshall Fire Mitigation Assessment Team: Wildfire-Resilient Detailing, Joint Systems, and Interfaces of Residential Building Components, FEMA, 2023. https://www.fema.gov/

ROOF SYSTEMS

STRUCTURAL HARDENING



1.1.1 Roof Construction & Covering

Main Concern(s)

The main concerns associated with roofs, in general, are (1) the large surface area that can accumulate embers (and vegetative debris) and (2) the relative location and slope of the roof to proximate canopy fuels that can increase radiant exposure and direct flaming from crown fires. If the roof covering and overall roof assembly is of combustible materials, not fire rated, not well maintained, or littered with vegetative debris, then it is far more vulnerable to ignition from wildfire. The complexity of the roof shape will also play a key role in the likelihood of ignition [6]. Valleys, roof-to-wall intersections at split levels or dormers, joints, and other architectural embellishments on the roof can also support the collection of embers ("ember accumulation") or vegetative debris that can lead to ignition. Additionally, as shingles age and curl, openings are exposed and may increase the number of places where embers can accumulate [7]. A study by Moore [8] concluded that out of 1,850 homes, 50% of the homes that ignited had wood roofs, while only 24% of homes that ignited had fire-resistant roofs. Within this study, fire-resistant roofs were considered as follows: Class A and B built-up assemblies, Class A and B prepared roofing, and properly installed Class C mineral surfaced asphalt shingles, asbestos cement shingles or sheets, concrete slabs, metal, slate shingles, fiber glass shingles, and clay or concrete tile [8].

Key Terminology

- **Roof Covering:** The exterior roof cover or skin of a roof assembly comprised of a range of materials [6] (e.g., shingles, tiles, slate, metal panels, fiberglass asphalt shingles, bitumen membrane). According to the 2024 IBC, roof coverings are divided into Class A, B, and C, and must be tested in accordance with *ASTM E108* or *UL 790*.

- **Roof Assembly:** An assembly of interacting roof components, including the roof deck, underlayment (comprised of a range of components such as vapor retarder, insulation, insulation cover boards, wood battens), and the roof covering [6].

- **Asphalt Fiberglass Composition Shingles:** Shingles composed of a fiberglass mat with asphalt and mineral overlay.

- **Polyvinyl Chloride (PVC) Roofing:** Thermoplastic roofing membrane typically used for buildings or structures with flat or low profiles and consisting commonly of 60 mil sheets with reinforced membranes. Seams are either hot-air heat welded, or chemical welded, and the membrane is either fully adhered, ballasted, or mechanically fastened.

- **Thermoplastic Polyolefin (TPO) Roofing:** Thermoplastic roofing membrane also used for buildings or structures with flat or low profiles. Sheets range from 40-100 mil, with reinforced or non-reinforced membranes, and installed fully adhered, mechanically fastened, or loose-laid with ballast. Seams are heat welded with hot air.

- **Modified Bitumen (MB) Roofing:** An asphalt-based membrane designed for buildings with low-slope or "flat" roof structures. MB roofing systems typically have five layers of protection (i.e., insulation, piles, MB membranes, adhesive or waterproofing material, surfacing).

- **Fire Retardant Treated Wood (FRTW):** According to the 2024 IBC, Section 2303.2, wood products that, when impregnated with chemicals by a pressure process or other means during manufacture, shall have, when tested in accordance with *ASTM E84, UL 723*, or *ASTM E2768*, a listed flame spread index of 25 or less (the flame front does not progress more than 10.5' (3200 mm) beyond the centerline of the burners at any time during the test which consists of a 30 minute exposure). Where used as roof coverings and evaluated following procedures in *ASTM E108 / UL 790*, FRTW must also be tested per weathering protocols such as *ASTM D2898* [9]. Different test methods are often specified for other materials (e.g., plastic).

Fire Classification and Ratings

The fire resistance of roof assemblies to exterior fire exposures is defined by *ASTM E108 or UL 790 Standard Test Methods for Fire Tests of Roof Coverings*. The test method includes measurements of the surface spread of flame, the ability of the roof assembly to resist fire penetration from the exterior of the building to the inside, and the potential for the roof covering to generate flying brands (i.e., embers) from the burning roof covering [10].

Table 2. Roof assembly fire resistance classifications in *ASTM E108* **and** *UL 790*.

Roof Classification	Technical Description	Examples
Class A	This is the highest rating for roof assemblies. Roof assemblies in this classification are effective against severe fire exposures. Roof coverings on Class A assemblies provide a high degree of fire protection to the roof deck, do not slip from position, and do not present a flying brand hazard [10]. Note: Coverings that comply with test requirements are to be considered a "noncombustible" material, which no longer automatically achieves a Class A rating, and thus must be tested per *ASTM E 108* or *UL 790*.	• Cement shingles or sheets • Exposed concrete slab roof • Metal panels, sheets, tiles, shingles on noncombustible decks/framing • Brick or masonry • Slate shingles • Clay and concrete roofing tiles • Most modern asphalt fiberglass composition shingles (***Note:*** *Cellulosic fiber asphalt singles, roughly pre-1980s, would not be included since they had a Class C rating*) • Gravel-surfaced multi-ply roofs and ballasted single-ply roofs [11] • Other noncombustible materials tested in accordance with *ASTM E108* or *UL 790* • (Special) Fire-retardant treated wood shingles or shake roof assembly must be installed with any additional fire-resistant underlayment and specified sheathing, as needed to comply with *ASTM E108/UL 790* provisions
Class B	Roof assemblies in this classification are effective against moderate fire test exposure. Roof coverings on Class B assemblies provide a moderate degree of fire protection to the roof deck, do not slip from position, and do not present a flying brand (ember) hazard [10].	• Some fire-retardant treated shakes and shingles, without installation of additional fire-resistant underlayment

Class C	Class C roof assemblies are effective against light fire test exposures. Under such exposures, the roof coverings afford a degree of fire protection to the roof deck, do not slip from position, and are not expected to produce flying brands (embers) [10].	• Aluminum roof coverings • Recycled plastic/rubber roof covering • Some fire-retardant treated shakes and shingles
Non-rated	Roof assemblies in this classification failed the fire test or have not been tested at all.	• Untreated wood shakes

Note: Some roof coverings rely on an underlying material, or special installation techniques, to improve their fire rating [12]. These types of roofs are considered fire-rated roof assemblies. An example of a fire-rated roof assembly are fire-retardant treated wood shakes, aluminum and recycled plastic and rubber roof coverings. Examples of underlayment materials include a mineral surfaced cap sheet (formerly referred to as a Type 72 cap sheet) adequate to provide Class A membrane construction, and a fiberglass gypsum panel [12] with a thickness adequate for passing the *ASTM E108/UL 790* test.

Fire Test Standards

- *ASTM E84 Standard Test Method for Surface Burning Characteristics of Building Materials:* https://www.astm.org/e0084-21a.html
- *ASTM E108 Standard Test Methods for Fire Tests of Roof Coverings:* https://www.astm.org/e0108-20a.html
- *UL 723 Test for Surface Burning Characteristics of Building Materials:* https://www.shopulstandards.com/ProductDetail.aspx?UniqueKey=34224
- *UL 790 Standard Test Methods for Fire Tests of Roof Coverings:* https://standardscatalog.ul.com/ProductDetail.aspx?productId=UL790
- *ASTM C1177 Standard Specification for Glass Mat Gypsum Substrate for Use as Sheathing:* https://www.astm.org/c1177_c1177m-17.html
- *ASTM D2898 Standard Practice for Accelerated Weathering of Fire-Retardant-Treated Wood for Fire Testing:* https://www.astm.org/d2898-10r17.html
- *ASTM D3909 Standard Specification for Asphalt Roll Roofing (Glass Felt) Surfaced with Mineral Granules:* https://www.astm.org/d3909_d3909m-14r21.html

Referenced Codes and Standards

- 2024 International Wildland-Urban Interface (IWUI) Code:
  - Section 504.2, 505.2, 506.2 Roof Assembly.
  - Section 507 Replacement or Repair of Roof Coverings.
- 2022 California Building Code (CBC): Section 705A.2 Roof Coverings.
- 2022 *NFPA 1140* Standard for Wildland Fire Protection: Section 25.3 Roof Design and Materials.

Other Codes and Standards

Additional local requirements, policies, and programs will vary depending on location and adoption in individual jurisdictions.

- Check local, county, and state amendments for any additional requirements.
- Check local general plan, comprehensive plan, multi-hazard mitigation plan or zoning documents for any additional requirements.
- International Residential Code (IRC) (if applicable - check for wildfire amendments).

Typical Design, Vulnerability, and Mitigation Considerations

Table 3. Design, vulnerability, and mitigation considerations for roof construction by slope of roof.

Slope of Roof	Design, Vulnerability, and Mitigation Considerations		
	Covering	Underlayment	Decking
Steep Slope (> 3:12)	Clay and Concrete Tile: This material is noncombustible with a relatively high thermal mass which can limit the transfer of heat depending on the thickness, profile, and installation method of the tile. Normal weight tiles have a higher thermal mass and are therefore better than lightweight tiles. Barrel shaped tile perform better than flat or low-profile concrete/clay tiles. Where tiles are installed over wood battens, fire-retardant battens should be used to limit ignition from embers. At the eaves, hips and ridges of tile roofs, birds' nests and other debris can provide fuel hazard for embers to ignite. Install "bird stops" at roof edge and ridges [6]. Ribbed or Corrugated Cement Panels [11]: Similar to concrete tiles, cement panels are noncombustible with a relatively high thermal mass, which can limit heat transfer depending on the thickness, profile, and installation method of the panel [6]. Gaps between panels can still exist and should be sealed appropriately. Metal Shingles & Panels: While these materials are noncombustible, they have relatively high thermal conductivity which means heat from embers or direct flaming can transfer readily to the roof substrate. Thus, where metal shingles/panels are installed over wood battens, fire-retardant battens should be used. Where metal shingles or panels are installed over wood decking, minimum 5/8" Type X gypsum roof board per *ASTM C1177* should be installed over the decking (1/2" or 1/4" thickness boards are not Type X) [6]. Fiberglass-Reinforced Asphalt Shingles: While asphalt shingles can be rated as Class A roofing, this material still contains asphalt, a combustible material. Wood Shingles and Shakes: While this material is combustible, some wood shingle or shake roofs can be Class A rated if fire-retardant treated and pressure impregnated, and an approved underlayment that imparts adequate fire resistance to the assembly is installed. Without an underlayment the maximum rating is Class B [6], [13].	As embers can be blown under steep-slope roof coverings, an enhanced underlayment such as a mineral-surface cap sheet rated for use in a Class A rated assembly should be installed. For metal shingles or panels, the metal should not bear directly on the cap sheet due to corrosion concerns [6].	Most homes have roof decks comprised of wood (e.g., plywood or oriented strand board). For more protection, a layer of fiberglass gypsum panelized product between the decking and the roof covering should be installed [6], [13]. Where a roofing profile has an airspace under the roof covering installed over a combustible deck, a 72 lb. cap sheet complying with *ASTM D3909 Standard Specification for "Asphalt Rolled Roofing (Glass Felt) Surfaced with Mineral Granules"* can be installed over the roof deck for protection [14].

Low Slope (< 3:12)	Many low-sloped roofs have Class A roof covering options [6]. See Table 2 for various options. As low slope roofs may not have attic space providing insulative properties, various roof assemblies and insulative build-ups will likely be encountered. In this case, the construction of the entire roof assembly and not just the rating of the roof covering is essential to ensure resistance to wildfire exposures.	As most low-slope roofs will have a layer of insulation, the insulation can be comprised of a range of materials anywhere from highly combustible to noncombustible. Noncombustible insulation provides the most fire-resistant properties. However, polyisocyanurate roof insulation could be used, provided a 5/8" layer of gypsum roof board per *ASTM C1177* is installed immediately below the roof covering [6].	Same as steep sloped.

General Mitigation Strategies

- Replace any damaged, broken, or missing pieces or sections.
- Remove litter and other vegetation debris on roof annually before core fire season. Check underneath roof tiles near eaves or under ridge caps [15].
- Replace roof with Class A rated roofing material. Note: Class A covering alone is not enough; the entire roof system should be considered to include underlayment and any other components that impact wildfire vulnerability.
- For tile roofs, bird-stop or mortar open ends of tiles at the roof eaves, roof edge, hips, and ridges to reduce vulnerability to ember intrusion and ignition [6].
- For tile roofs, install non-corrosive metal flashing under tiles at roof valleys. For profiled tile, lead or flexible flashing should be installed (as recommended by the manufacturer).
- Replace roof coverings before significant deterioration occurs due to exposure to weathering.
- Replace any exposed combustible foam with noncombustible insulation [6].

Training Programs

NFPA - *Assessing Structure Ignition Potential from Wildfire*: https://www.nfpa.org/Training-and-Events/By-topic/Home-Ignition-Zone

Gaps in Knowledge

- Wildfire testing does not currently account for weathering of materials prior to fire exposure. This is of particular concern for FRT shakes and shingles.
- *ASTM E108* and *UL 790* are an exterior fire exposure based on a piloted ignition scenario of "in-plane" roof coverings or assemblies. This may not be reflective of anticipated fire exposures for wildfire conditions (e.g., embers, large radiative exposure from wildfire flaming, direct flame impingement, heat release rates characteristic of wildfires). Test conditions can oftentimes be less severe than actual wildfire exposures that are in uncontrolled environments. In addition, *ASTM E108/UL790* do not test edge of roof conditions, which is a key vulnerability.
- In some cases, it may be challenging to verify in-the-field if a roof assembly is rated to Class A, B, or C, as the listing is often not visible when installed and "opening-up" the assembly to verify through depth construction is generally not feasible. (Professional judgement and local knowledge of construction practices may be required to have confidence in "assembly" construction details.)
- Additional training is needed for inspectors to accurately identify roof coverings as Class A, B, or C.

- Additional training is also needed to provide field inspectors or property owners with an understanding of the limitations of current fire tests standards (e.g., *ASTM E108* and *UL 790* do not test roof edge conditions).

Other References

- Insurance Institute for Business & Home Safety (IBHS)
  - Ember Testing - https://ibhs.org/wildfire/building-vulnerability-to-ember-exposure/
  - HOME Preparedness - https://disastersafety.org/wp-content/uploads/2021/08/WFR-Home-Preparedness-Guide.pdf
- National Fire Protection Association (NFPA)
  - Firewise - https://www.nfpa.org/-/media/Files/Firewise/Fact-sheets/FirewiseFactSheetsRoofingMaterials.ashx
- Federal Emergency Management Agency (FEMA)
  - Mitigation Assessment Team Report: Marshall Fire Building Performance, Observations, Recommendations, and Technical Guidance (FEMA P-2320) - https://www.fema.gov/sites/default/files/documents/fema_p2320-marshall-fire-mAT-report-without-appendices.pdf
  - Decreasing Risk of Structure-to-Structure Fire Spread in a Wildfire (Marshall Fire MAT) - https://www.fema.gov/sites/default/files/documents/fema_marshall-fire-mat-decreasing-structure-fire-spread.pdf
- University of California, Agriculture and Natural Resources (UCANR)
  - Wildfire Preparedness, Prepare Your Home, Roof - https://ucanr.edu/sites/fire/Prepare/Building/Roof/
- Headwaters Economics
  - Building a Wildfire-Resistant Home: Codes and Costs - Headwaters Economics - Building a Wildfire-Resistant Home: Codes and Costs https://headwaterseconomics.org/wp-content/uploads/building-costs-codes-report.pdf

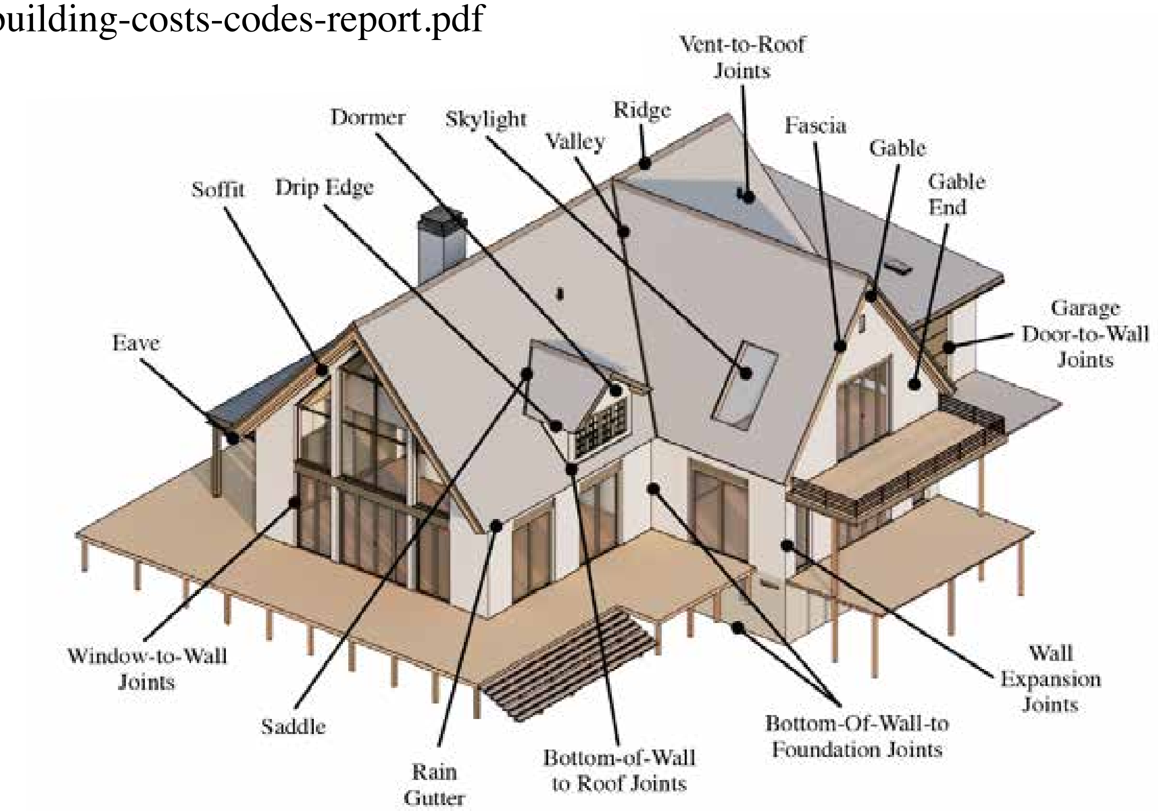


Figure 1.1. Parts of a roof. Roof construction elements specifically called out are those that are particularly vulnerable and are addressed in this section. Credit: Image adapted from Marshall Fire Mitigation Assessment Team: Wildfire-Resilient Detailing, Joint Systems, and Interfaces of Residential Building Components, FEMA, 2023. https://www.fema.gov/

Figure 1.2. Examples of roof construction vulnerabilities (Red arrows indicate debris accumulation (right) and curled shingles (left)). Image courtesy of Jensen Hughes/FEMA.

Figure 1.3. Example of complex roof design and overhanging vegetation, which create potential locations for ignition during a wildfire (Left red arrow indicates a complex roof design where debris can accumulate. Right red arrow indicates overhanging vegetation). Image courtesy of Jensen Hughes/FEMA.

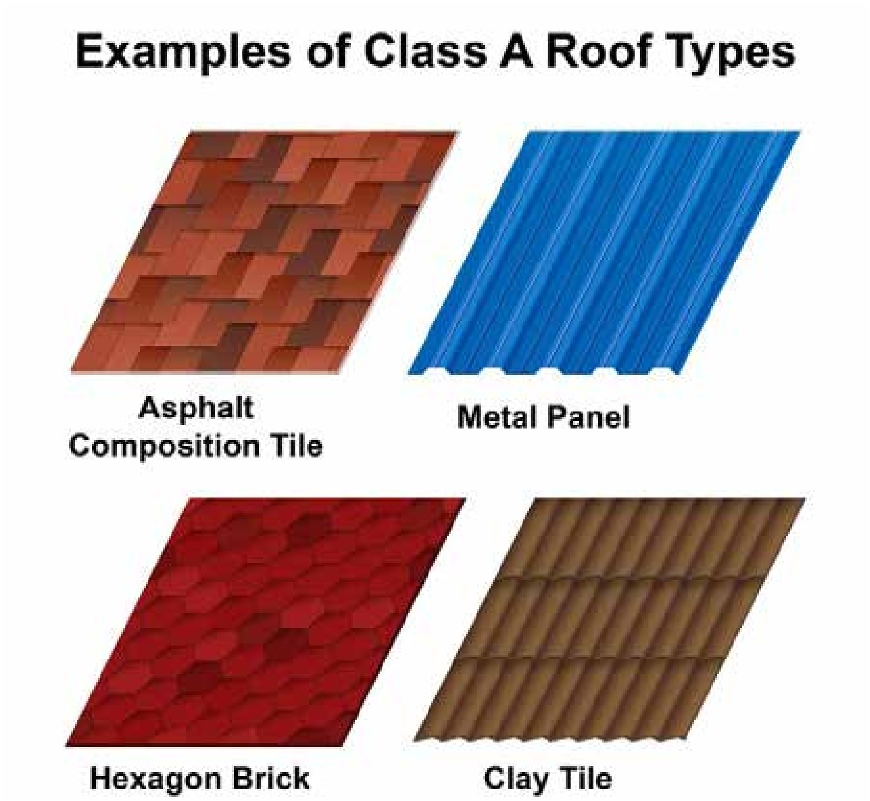


Figure 1.4. Examples of different roofing materials. Refer to Table 2 Roof Classification table for specific vulnerabilities of each roofing material. Adapted from image by macrovector_official.

Figure 1.5. Example of composite tile roof. Composite tile roof is one example of a noncombustible roof. However, tile roofs can contain gaps at the ridge line and edges, which should be filled with mortar or bird stop. Image courtesy of Jensen Hughes/FEMA.

1.1.2 ROOF VENTS & CHIMNEYS

Main Concern(s)

The intrusion of embers and flames via vents can be a major source of structure ignition during a wildfire [16], [17], [18], [19]. The main concern with roof vents is that they oftentimes introduce openings through the exterior envelope of a building where windborne embers, flames, or hot gases from wildfires or fires from surrounding landscaping and structures can enter the building, which can lead to ignition of interior contents and other combustible building materials. Both inlet and outlet vents, especially on the windward side of the building, are sources of ignition vulnerability, as fire behavior can create reverse flows due to over-pressures that can drive embers, flames, and hot gases into a building interior (e.g., attic, interstitial spaces). Chimneys, on the other hand, can provide a potential source for embers to travel from a fireplace to outside the structure, potentially causing a wildfire. Furthermore, roof vents and chimneys introduce numerous joints and surfaces where vegetative debris can accumulate around the vent perimeter, opening, or at the chimney chase, providing a source of combustible fuels for ignition.

Key Terminology

- **Chimney:** A primarily vertical structure containing one or more flues, for the purpose of carrying gaseous products of combustion and air from a fuel-burning appliance to the outdoor atmosphere [9].

- **Gas Fireplace Chimney:** A vertical or horizontal vent designed to release hot air from a gas burning fireplace to the outdoor atmosphere.

- **Ember (also known as fireband):** Smoldering or flaming particles of vegetation from tree branches, pieces of chaparral shrubs, or other combustibles (such as construction materials and furnishings in structures) that ignite and burn during a wildfire and are carried by winds in front of the wildfire [20].

- **Gable-end Vent:** A vent located in the gable-end wall, just below the roof ridge to allow flow into and out of attics. Gable-end vents normally have louver blades. This type of vent is commonly metal and normally has an insect screen [6].

- **Hip Vent and Ridge Vent:** A continuous vent installed along the full length of the hip or ridge of a roof, with the air slots underneath the hip or ridge vents located only at the top portion of the hip or ridge. These vents are typically comprised of metal or plastic and may have internal or external baffle media to minimize the entrance of wind-driven rain or snow [6], [13].

- **Mechanical Exhaust Vents (Whirly birds, Wind Turbines):** Cylindrical dome-shaped vents that sit on the roof of a building and spin in the wind, creating a vacuum that extracts warm air and moisture from the attic. Turbines sit higher above the roof surface, so they stand out more than other exhaust options, but they move air effectively. When there's no wind, their function is similar to that of a static exhaust vent [21].

- **Powered Exhaust Vent:** These types of vents are powered by electric, solar or a combination of both and are either roof-mounted or gable-mounted. Powered vents typically include thermostat control to provide optimum airflow rating.

- **Spark Arrestor Cap:** A metal assembly at the top of the chimney that prevents embers from leaving the chimney while also preventing embers from entering the chimney in the event of a wildfire.

- **Through-roof Vent:** A vent that penetrates the roof to allow exfiltration of attic air or connection to an HVAC system. They can also be known as a dormer or eyebrow vent, depending on the shape of the housing. These types of vents are typically comprised of metal, plastic, or rigid fiberglass.

- **Off-Ridge Vent:** A vent located just below a roof's ridge. These vents are typically comprised of plastic or metal and may have internal or external baffle media to minimize the entrance of wind-driven rain or snow.

- **Vent:** A device or assembly placed in an exterior opening of a building (located in an eave, gable, wall, or foundation) that allows for aeration (free exchange of air) for temperature and moisture control, particularly for unconditioned spaces [16].

Fire Classification and Ratings

Wall mounted and under-eave vents - The ember and direct flame impingement resistance of gable-end, crawl space, other wall-mounted vents and under eave area vents are defined by *ASTM E2886 Standard Test Method for Evaluating the Ability of Exterior Vents to Resist the Entry of Embers and Direct Flame Impingement*. This test standard prescribes two individual methods to evaluate the ability of the vent to resist: (1) the entry of embers and (2) flame intrusion. Full-scale tests at IBHS demonstrated that *ASTM E2886*-compliant vents limit the entry of large embers, and that the embers collected behind these vents (e.g., on the attic side) were small and incapable of igniting combustibles [22]. ***Note:*** *ASTM E2886* does not provide explicit quantitative acceptance criteria for ember intrusion or flame intrusion. However, ember intrusion is evaluated based on observation of occurrence of combustion of a cotton pad on the unexposed side of the vent given a 3-min exposure to tumbled Class C brands. Performance criteria for the 10-min flame intrusion test as well as integrity test are specified in *ASTM E2912*. Visual observations are made for the presence and duration of any flame penetration through the vent.

ASTM E2912 assesses the ability of non-mechanical fire dampers used in vented construction in its open state to limit passage of hot gases, radiation, and flames. Roof ridge, off-ridge (field) and all other non-wall mounted roof vents are not included in the scope of this standard. Acceptance criteria are typically not provided in ASTM standards, including this one [16]. Acceptance criteria are specified in the *California Building Code (CBC)*, Section 706A.2 and *NFPA 1140* Section 25.3.3.

All other roof vents - Currently there are no standard fire tests to evaluate ember intrusion and impact of direct flame impingement on non-wall mounted roof vents (e.g., roof ridge or hip vents, off-ridge vents, mechanical exhaust vents, powered exhaust vents, through-roof vents).

Table 4. Vent fire tests for roof vents and chimneys.

Vent Fire Test	Technical Description
Ember Penetration Test *(ASTM E2886)*	This test method evaluates the impact of ember exposure on vertically or horizontally mounted vents as described in *ASTM E2886* (e.g., gable-end, crawl space, under eave vents). The fire test apparatus allows embers to fall vertically and impinge on the vent mounted horizontally on ledges within the test chamber. An induction fan located at the bottom of the apparatus pulls the air stream through the vent, allowing any embers that pass through the vent to impinge on a combustible target material of cotton. Ember intrusion is evaluated based on observation of occurrence of combustion of a cotton pad on the unexposed side of the vent, given a 3-min exposure to tumbled Class C brands. Performance criteria for the 10-min flame intrusion test, as well as integrity test are specified in *ASTM E2912*. Visual observations are made for the presence and duration of any flame penetration through the vent. *[CBC and NFPA 1144 acceptance criteria - No flaming ignition of the cotton material on the unexposed side of the vent]*
Direct Flame Impingement Test and Integrity Test *(ASTM E2886)*	This test method evaluates the impact of direct flame impingement on vertically or horizontally mounted vents in a test assembly as described in *ASTM E2886*. Note that *ASTM E2886* references *ASTM E2912* as the test procedure to be used for the direct flame impingement test (or flame intrusion test) and integrity test. The flame source is directed into the test assembly and directly impinges the vent that is mounted in either a vertical or horizontal position for a 10-min period. Visual observations are made for the presence and duration of any flame penetration through the vent flame. ***Note:*** The integrity test is also specified in *ASTM E2912* for thermal transmission concerns. *[CBC and NFPA 1144 acceptance criteria - No flaming ignition and maximum temperature of the unexposed side of the vent shall not exceed 662°F or 350°C.]*
Non-Mechanical Fire Dampers Used in Vented Construction *(ASTM E2912)*	This fire test response standard assesses the ability of non-mechanical fire dampers used in vented construction in the open state to limit passage of hot gases, radiation, and flames during a prescribed fire test exposure. The fire exposure condition in this test method is sudden direct flame impingement, which produces the hot gases, radiation, and flames [23]. This test method does not circumvent or eliminate the fire-resistance rating requirements for construction [23].

Note: Gable end and other wall-mounted vents that have been included in a roof assembly tested per *ASTM E108* to achieve a Class A rating have only been tested for whether they contribute to flame spread, fail, detach from the roof or produce embers. *ASTM E108* does not assess if a vent can resist the penetration of embers or direct flames from wildfires. The vents would still need to be tested per *ASTM E2886*.

Factory-built chimneys and fireplaces - Chimneys and fireplaces should be fire-blocked in accordance with *UL 103* and *UL 127* (*Required for factory-built chimneys and fireplaces in 2024 IBC, Section 718.2.5.1*).

Fire Test Standards

- *ASTM E2886/E2886M-14 Standard Test Method for Evaluating the ability of Exterior Vents to Resist the Entry of Embers and Direct Flame Impingement:* https://www.astm.org/e2886_e2886m-20.html
- *ASTM E2912 Standard Test Method for Fire Test of Non-Mechanical Fire Dampers Used in Vented Construction:* https://www.astm.org/e2912-17.html
- *UL 103 Factory-Built Chimneys for Residential Type and Building Heating Appliances:* https://www.shopulstandards.com/ProductDetail.aspx?UniqueKey=21968
- *UL 127 Standard for Factory-Built Fireplaces:* https://www.shopulstandards.com/ProductDetail.aspx?UniqueKey=22727

Referenced Codes and Standards

- *2024 International Wildland-Urban Interface (IWUI) Code:*
  - Section 504.10 Vents
  - Section 605 Spark Arresters
- *2022 California Building Code (CBC):*
  - Section 706A Vents
  - Section 718.2.5.1 Factory-Built Chimneys
- *2022 NFPA 1140 Standard Wildland Fire Protection:*
  - Section 25.3.3 Vent Assemblies
  - Section 25.8 Chimneys and Flues

Other Codes and Standards

Additional local requirements, policies, and programs will vary depending on location and adoption in individual jurisdictions.

- Check local, county, and state amendments for additional wildfire codes and standards.
- Check local planning documents such as general or comprehensive plans, multi-hazard mitigation plan, zoning maps.
- International Residential Code (if applicable - check for wildfire amendments).

Table 5. Design and construction considerations for roof components.

Component Type	Design and Construction Considerations
Chimney	There are two main types of chimneys: masonry chimneys (stone and mortar, brick, or block construction) and prefabricated metal chimneys. Chimney lining materials include metal, cast cement or clay tiles. Chimneys should be covered and screened using a spark arrestor cap to prevent embers and hot gases from entering the chimney opening. Chimneys should be capped with a solid metal covering if they include gas furnaces with integrated flues. Chimneys that are provided with a spark arrestor cap or covering in conjunction with noncombustible interior construction are a low risk for interior ignition based on wildfire exposure. Chimney chase cladding has the potential to experience vulnerabilities due to vegetative debris accumulating on the roof around the chase. As a roof penetration, chimneys can pose additional vulnerabilities at the chimney-to-roof joints. Refer to Section 1.1.5 Roof Joints for guidance.
Gas Fireplace Vent	Gas fireplaces use vertical or horizontal vents to release hot gases and other products of combustion to the outside atmosphere. Gas fireplaces by nature do not pose a threat to wildfire ignition as there are no solid burning fuels to emit embers to the outside. These vents also pose little threat to ignition of the structure through ember penetration as the fireplace is constructed of noncombustible materials and designed to withstand high temperatures. 1/8” wire mesh screen can be provided on these vents to provide an additional level of protection.

Table 6. Design and construction considerations for roof vents.

Roof Vent Type	Design and Construction Considerations
Ridge	Typical ridge vents are not highly fire-resistant since most commercially available ridge vents are made of plastic materials. Ridge vents are nominally outlet vents. The greatest vulnerability to these vents is ember ignition of vegetative debris that can accumulate at the inlet of the vent, and the exposure to, or entry of, flames, should nearby combustible materials be ignited by embers. Wind-blown vegetative debris must be removed from the inlet of all ridge vents. Embers can enter the attic through unbaffled ridge vents. Even baffled ridge vents provide limited effectiveness as typical baffle media can melt should the vegetative debris ignite [24]. One option for mitigation for ember intrusion for existing ridge vents is to provide noncombustible, corrosion-resistant screening with openings no larger than 1/8” (1/16” is preferable). The exposure to flames, however, will not be mitigated by the screening. The most effective strategy is the use of noncombustible ridge vents that incorporate an external baffle. When roof coverings have a profile, an off ridge through-roof vent is the best option, as off-ridge vents can more easily be protected via methods such as screening.
Off-ridge	Off-ridge vents are constructed of metal, plastic, or rigid fiberglass and are located off-ridgeline. These vents may include a downturned end (gooseneck) to prevent water infiltration. These vents can allow passage of embers and hot air/gases into the attic if not appropriately screened (i.e., 1/8” or 1/16”preferred corrosion-resistant metal mesh) or provided with steel wool matrix infill (***Note:*** the matrix method is typically proprietary), which has been shown to be effective at minimizing ember entry into the attic space [6].

Gable-End	Gable-end vents are vertically mounted on exterior walls near the roof to allow air to flow out of attics. Gable-end vents are nominal outlet vents and often used in conjunction with soffit vents or under-eave vents, which typically serve as nominal inlet vents. Gable-end vents are typically constructed of metal and include 1/4” screening. Small animal screening is not typically fine enough to limit the intrusion of embers. Corrosion resistant, wire metal mesh of a maximum 1/8” (preferably 1/16”) should be installed to limit ember intrusion. Alternatively, shutters can be installed over gable-end vents when wildfire threatens. Where provided, shutters should include a gasket to provide a tight seal between the shutter and the vent. Gable-end vents are arguably the most vulnerable vent to entry of embers due to their relatively large surface area and their location on a vertical exterior wall.
Whirlybird (also called Turbine Vents)	These vent types are typically constructed of metal and can oftentimes present an avenue for embers to enter the attic space unless protected with a woven mesh guard (i.e., max. 1/8” mesh metal screening, stapled to the underside of the roof sheathing in the vent opening area). Turbine vents are very effective at minimizing the entry of embers when they are in good condition and the wind is blowing to better keep the vent spinning while keeping embers out of the attic. At low wind speeds, embers can pass through one side of the vent and drop into the attic because there is not enough momentum to pass through to the opposite side of the vent.
Unventilated Attics	Unventilated attics are the most conservative approach to preventing embers and hot gases from entering the attic. Unventilated attics are controversial and may not comply with local building codes. When unventilated attics are allowed by the building code or code compliance is not an issue, and when climatic and interior humidity conditions are conducive to an unventilated design, an unventilated attic is a reliable way to prevent embers and hot gases from entering the attic [6].

General Mitigation Strategies

- Debris should be removed from around vents and chimney chases periodically, and at a minimum before fire season.
  - Wind-blown vegetative debris must be removed from the inlet of all ridge- and off-ridge vents, paying particular attention to vents with plastic components as these materials are commonly used in ridge vents [24].
- Provide ember resistant vents protected with corrosion-resistant wire mesh with openings no larger than 1/8”, preferably 1/16”.
  - Common 1/4” screens are ineffective and should be replaced [24].
  - Do not use plastic-clad fiberglass mesh as they can melt and burn [24].
- Provide spark arrestor cap on all chimneys.
  - Chimneys serving fireplaces, barbecues, incinerators, or decorative heating appliances in which solid fuel is used, should be provided with a spark arrester [25].
  - Spark arrestors are required to be constructed of woven or welded wire screening of 12 USA standard gage wire having openings not exceeding 1/2” [25].
- Chimney outlets should have at least 10’ of clearance to vegetation and other obstructions [26].
- Avoid using off-ridge and ridge vents that have not been tested against *ASTM E2886*. Of the ridge and off-ridge outlet vent options, the following performed well [19]:
  - Miami-Dade wind-driven-rain-compliant ridge vent.
  - Turbine (off-ridge) vent with screening attached to the roof sheathing.
- Replace non-metal roof vents with corrosion-resistant metal vents and vent flashing.
- Ensure turbines can spin freely to minimize ember intrusion into the attic.
- Specify and install vent openings with a maximum net free area of 144 in2 [6].
- Place all vent openings at least 10’ from other buildings or property lines to avoid ignition from embers and hot gases from an adjacent building that has ignited [6].
- Ember and flame-resistant vents that have been tested and approved for use are available and listed. A sample list of compliant products can be found on the California Office of the State Fire Marshal, Building Materials Listing Program website. Other databases of listed products are not yet available.
- Do not block or cover any existing vent before considering whether its removal will hamper the flow of ventilation [15].
- Dryer vents should have a noncombustible louver or flap [22].

Training Programs

NFPA - Assessing Structure Ignition Potential from Wildfire: https://www.nfpa.org/Training-and-Events/By-topic/Home-Ignition-Zone

Gaps in Knowledges

- Vent fire testing does not account for weathering of materials prior to fire exposure or the impact of general wildfire environmental conditions (e.g., high winds, flying debris, impact from objects).
- *ASTM E2886* does not evaluate the ability of vents to completely exclude entry of flames or embers, nor does it test for transmission of smoke or hot gases.
- *ASTM E2886* does not include roof ridge and off-ridge (field) vents. Thus, there is no accepted procedure to evaluate ember intrusion and direct flame impingement of ridge and off-ridge vents. However, the functional parts of some approved vents have been installed in dormer-style off-ridge vents and should perform as well in this location as others.
- In most instances, it is challenging to verify, in-the-field, if an off-ridge vent has been fire-tested. (Professional judgement and discussion with the homeowner are required.) Training may be required to be able to identify fire-tested foundation vents and under-eave vents.
- Air flow calculations may need to be reconsidered or redesigned where fire rated vents are installed in existing structures, to ensure code required airflow is satisfied.

Other References

- Insurance Institute for Business & Home Safety (IBHS)
    - Ember Testing - https://ibhs.org/wildfire/building-vulnerability-to-ember-exposure/
    - Vulnerability of Vents - https://ibhs.org/wp-content/uploads/wpmembers/files/Vulnerability-of-Vents-to-Wind-Blown-Embers_IBHS.pdf
    - Ember Media - https://www.facebook.com/watch/?v=389602881106017
    - Preparedness - https://disastersafety.org/wp-content/uploads/2021/08/WFR-Home-Preparedness-Guide.pdf
- National Fire Protection Association (NFPA)
    - Firewise - https://www.nfpa.org/-/media/Files/Firewise/Fact-sheets/FirewiseFactSheetsAtticsCrawlSpaces.ashx
- Federal Emergency Management Agency (FEMA)
    - Home Builder’s Guide to Construction in Wildfire Zones, Technical Fact Sheet No. 8 - https://www.govinfo.gov/content/pkg/GOVPUB-HS5-PURL-gpo60104/pdf/GOVPUB-HS5-PURL-gpo60104.pdf
    - Mitigation Assessment Team Report: Marshall Fire Building Performance, Observations, Recommendations, and Technical Guidance (FEMA P-2320) - https://www.fema.gov/sites/default/files/documents/fema_p2320-marshall-fire-mAT-report-without-appendices.pdf
    - Decreasing Risk of Structure-to-Structure Fire Spread in a Wildfire (Marshall Fire MAT) - https://www.fema.gov/sites/default/files/documents/fema_marshall-fire-mat-decreasing-structure-fire-spread.pdf
    - Homeowner’s Guide to Reducing Risk of Structure Ignition from Wildfire - https://www.fema.gov/sites/default/files/documents/fema_marshall-fire-mat-homeowners-guide-reducing-risk-structure-ignition.pdf
    - Wildfire Resilient Detailing, Joint Systems, and Interfaces of Residential Building Components: https://www.fema.gov/sites/default/files/documents/fema_marshall-fire-mat-detailing-joints.pdf
- University of California, Agriculture and Natural Resources (UCANR)
    - Wildfire Preparedness, Prepare Your Home, Vents - https://ucanr.edu/sites/fire/Prepare/Building/Vents/
- California Office of the State Fire Marshal
    - Building Materials Listing - https://osfm.fire.ca.gov/what-we-do/fire-engineering-and-investigations/building-materials-listing

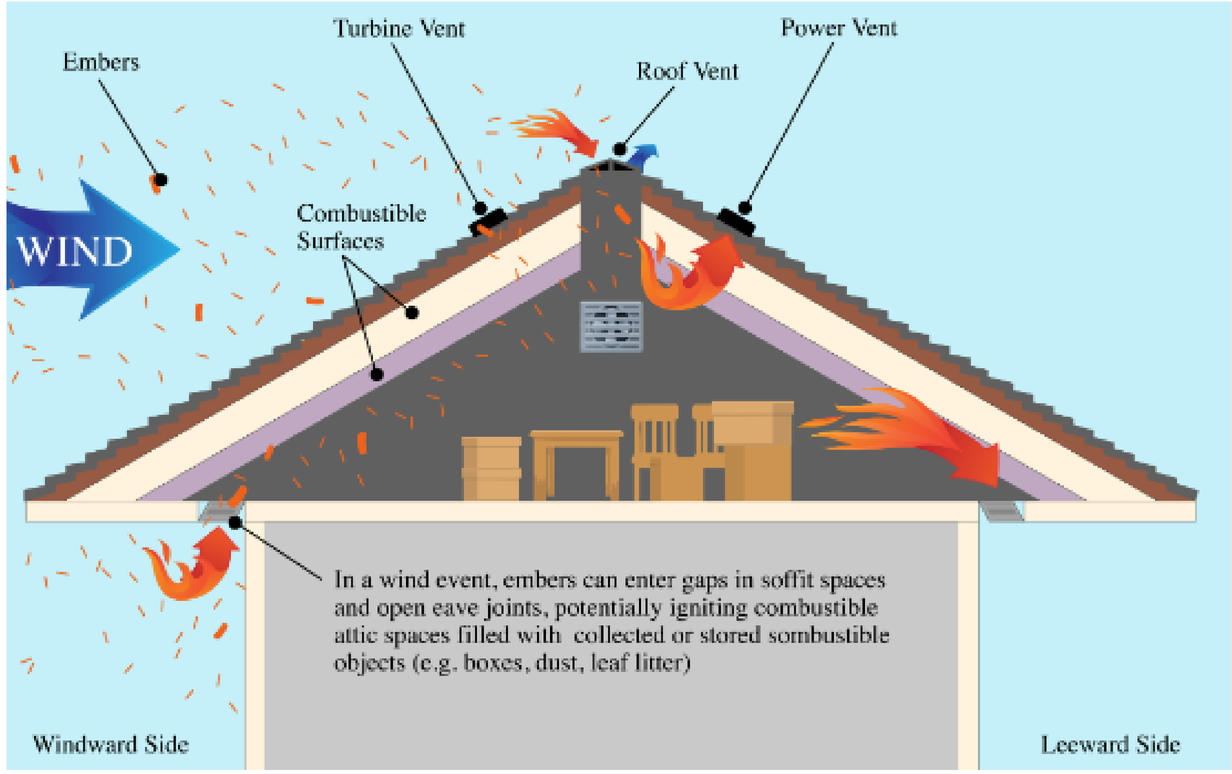


Figure 1.6. Schematic cross-section of a roof attic space illustrating the unique flow paths of embers during a wildfire that can enter the attic via various roof and soffit vents leading to potential ignition of interior building contents. Image annotated by Stephen Quarles. Original diagram from FEMA Marshall Fire MAT, FEMA, 2023. https://www.fema.gov/

Figure 1.8. Example of roof ridge vent and collected debris. This accumulation of debris is vulnerable to ignition if not regularly cleared. If ignited, this burning debris would provide a flaming exposure to the plastic vent. Image courtesy of the Insurance Institute for Business & Home Safety.

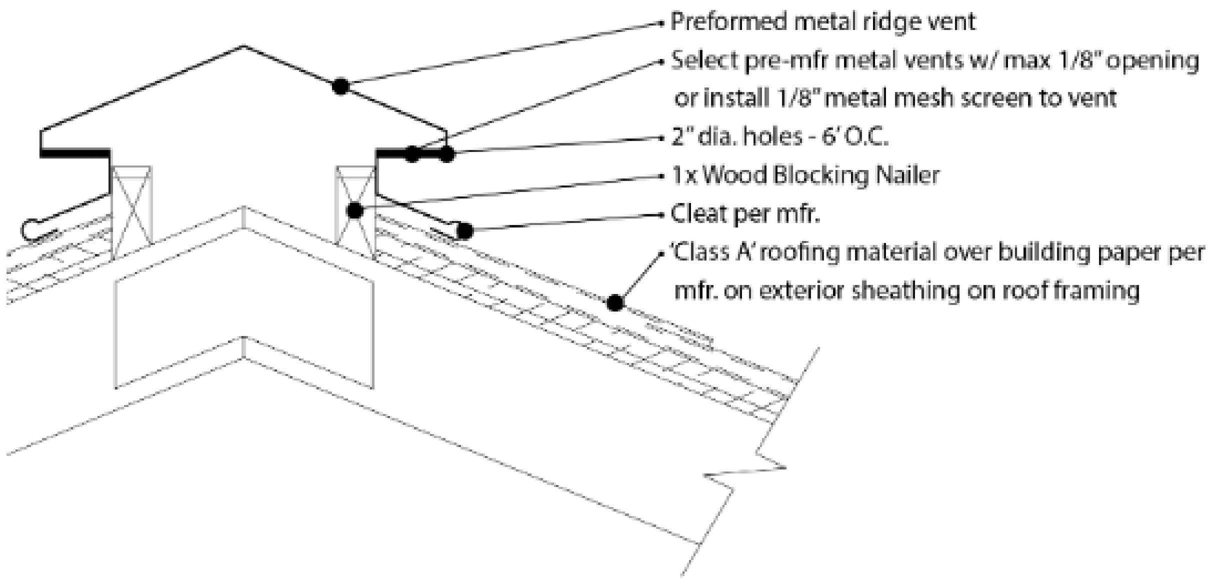


Figure 1.7. Example of roof ridge vent. Roof ridge vents are vulnerable to ember intrusion and can lead to ignition of the attic of a home. Image adapted from FEMA Marshall Fire MAT, Wildfire Resilient Detailing, Joint Systems, and Interfaces of Residential Building Components, FEMA, 2023. https://www.fema.gov/

Figure 1.9. Example of through-roof vent. If not screened, through-roof vents can provide an avenue for embers to enter the home. Image courtesy of Jensen Hughes/FEMA.

Figure 1.10. Gable-end vent. Gable-end vents such as the one in this photo should be screened. Image courtesy of Jensen Hughes/FEMA.

Figure 1.12. Off-Ridge vent. Off-ridge vents are typically best protected by having noncombustible screening.

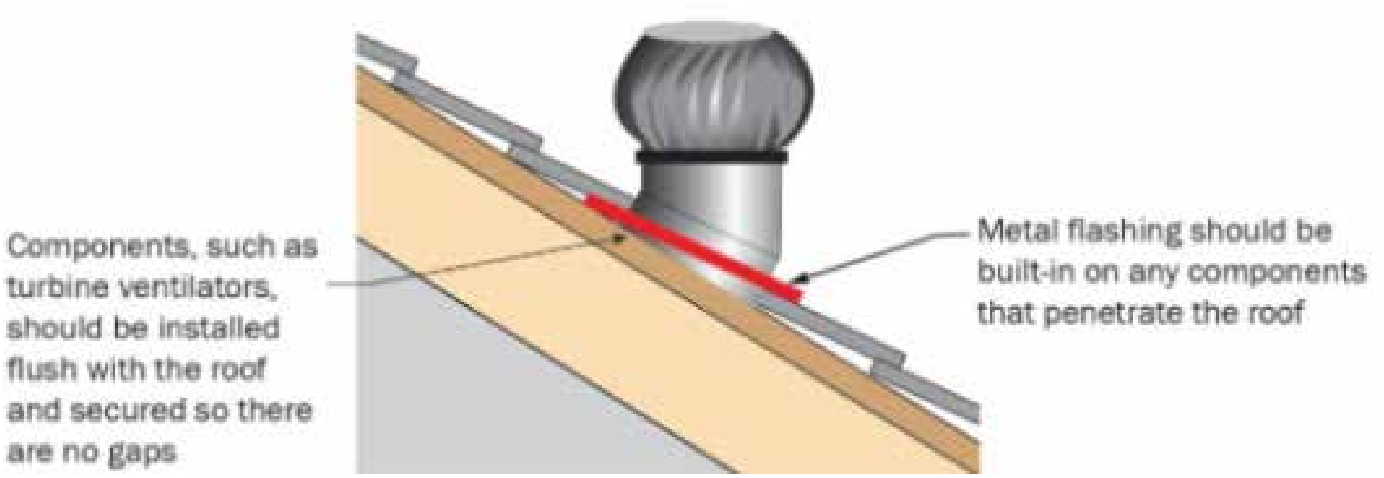


Figure 1.11. Example mechanical-style roof vent penetration detail. Image adapted from FEMA Marshall Fire MAT, Wildfire Resilient Detailing, Joint Systems, and Interfaces of Residential Building Components, FEMA, 2023. https://www.fema.gov/

1.1.3 SKYLIGHTS

Main Concern(s)

Similar to other "penetrations" through the plane of the roof, skylights present a number of potential vulnerabilities that could result in the ignition of the home during a wildfire, including: (1) direct opening to the interior of the building when operable skylights are left open, (2) depending on the construction materials of the skylight (such as skylights containing plastic glazing materials) may be of non-fire rated or combustible materials and (3) the roof-to-skylight junction can be a location for the accumulation of vegetative debris and, when a wildfire threatens, embers.

- During a wildfire incident, skylights if left open can provide a direct pathway for embers and/or hot gases to enter the interior space of the building and result in the ignition of internal furnishings.

- Skylights can be constructed of a range of combustible (e.g., plastic) and noncombustible materials (double pane glazing, tempered and laminated glazing), many of which can be compromised due to effects of radiant heat exposure and direct flame contact. Note however, that newer skylights typically consist of an outer pane of tempered glass and an inner pane of laminated glass. This provides a degree of protection from radiant heat exposure and direct flame contact. In these scenarios, debris accumulation is the more prominent concern.

- Skylights also create receptive surfaces and joints where vegetative debris can collect and subsequently be ignited from embers on top or next to the skylight framing. Vegetative debris and embers can more easily accumulate on low-sloped roof skylights creating potential hotspots [7]. Typical temperatures of these potential fire sources would be high enough to break tempered glass [27]. Most guidance recommends using a flat glass skylight rather than a plastic dome style because the plastic is combustible or will melt and allow for embers to enter the interior building space. However, there are situations based on the slope of the roof where flat glass could become more vulnerable [27]. A dual-pane skylight consisting of an outer pane of tempered glass and an inner pane of laminated glass will provide the best protection.

Key Terminology

- **Unit Skylight:** A factory-assembled, glazed, fenestration unit, containing one panel of glazing material that allows for natural lighting through an opening in the roof assembly while preserving the weather-resistant barrier of the roof [28].

- **Skylights and Sloped Glazing:** Glass or other transparent or translucent glazing material installed at a slope of 15 degrees or more from vertical. Unit skylights, tubular daylighting devices, glazing materials, solariums, sunrooms, roofs, and sloped walls are included in this definition [28].

- **Laminated Glazing:** An assembly consisting of two or more lites of glass bonded together by an interlayer [29].

- **Tempered Glazing:** General term for glass that has been subjected to a thermal treatment characterized by rapid cooling to produce a compressively stressed surface layer (includes fully tempered glass and heat-strengthened glass) [29].

Fire Rated Assemblies

Skylights can comply with several different requirements to resist the effects of fire. Applicable options are as follows [30], [31]:

- Be constructed of multi-pane glazing with a tempered pane.
- Be constructed of glass block units.
- Be comprised of fire-resistance rated glazing assembly per *ASTM E119*.
- Have a fire-resistance rating of not less than 20 minutes when tested in accordance with *NFPA 257* or *ASTM E119*.

Fire Test Standards

- *ASTM E119* Standard Test Methods for Fire Tests of Building Construction and Materials: https://www.astm.org/e0119-20.html
- *NFPA 257* Standard on Fire Test for Window and Glass Block Assemblies: https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=257
- SFM Standard 12-7A-2 Exterior Windows

Referenced Codes and Standards

- *2024 International Wildland-Urban Interface (IWUI) Code:* Sections 504.8, 505.8 Exterior Glazing
- *2022 California Building Code (CBC):*
  - 202 Definitions
  - 708A Exterior Windows, Skylights, and Doors
- *2022 NFPA 1140 Standard for Wildland Fire Protection:* 25.7 Exterior Openings

Other Codes and Standards

Additional local requirements, policies, and programs will vary depending on location and adoption in individual jurisdictions.

- Check local, county, and state amendments for additional wildfire codes and standards.
- Check local general plan, multi-hazard mitigation plan, zoning.
- International Residential Code (if applicable - check for wildfire amendments).

Typical Design, Vulnerability, and Mitigation Considerations

Table 7. Design, vulnerability, and mitigation considerations for skylights.

Types of Skylights	Design, Vulnerability, and Mitigation Considerations
Flat Skylights	Flat skylights are less likely to experience ember ignition on a steep-slope roof because vegetative debris and embers are less likely to accumulate [27]. The steeper the slope, the more likely that the flat skylight will respond like an exterior wall. In such cases, the primary source of potential wildfire vulnerability is due to ignition of proximate trees or plants that may impose radiant heat or direct flaming exposure to the skylight. Any debris accumulation should be regularly cleared, and flat skylights should be installed with noncombustible flashing to protect gaps and joints in the interface between the skylight and the roof. Utilizing types of glass that are more resistant to failure from radiant heat or direct flame exposure (see Table 8) further helps protect skylights.
Domed Skylights	The vulnerability of domed skylights depends on the number of combustible debris surrounding it. Domed skylights are particularly vulnerable to extended radiant heat exposure: the more combustible debris, the more vulnerable the domed skylight is. Debris should be regularly cleared around domed skylights [27].
Plastic Skylights	In most cases, a plastic skylight is more vulnerable than other types of skylights, as they are prone to melting during wildfire conditions. Where possible, plastic skylights should be replaced with flat, glass skylights and kept clear of combustible debris.

Table 8. Design, vulnerability, and mitigation considerations for skylight construction materials and components.

Types of Skylight Construction Materials or Components	Design, Vulnerability, and Mitigation Considerations
Dual-Pane Glass	Newer skylights feature dual-pane systems similar to multi-pane windows in an exterior wall. It is common to see that the outer pane uses tempered glass, and the inner pane uses laminated safety glass. Double-pane glass is also more energy efficient than single-pane glass [6]. Dual-Pane glass is generally considered less likely to fail from radiant heat or direct flaming exposure [27].
Laminated Glass	Laminated glazing typically consists of multiple plies of glass, interlayers, resins, and/or plastic glazing materials (such as polycarbonate sheet or acrylic) to achieve a variety of performance goals (e.g., UV protection, impact resistance, sound reduction, fade resistance, and solar & thermal control). The glass layers behave like a thicker pane of annealed glass during a fire event. If a firebrand strikes with enough momentum to break the glass, the interlayer (bonded composite material - commonly polyvinyl butyrate (PVB)) in the core of the glass maintains integrity and will keep the glazing in the frame, allowing the broken glass to continue to resist firebrand impacts, ember intrusion and hot gases. If a thermoplastic interlayer gets sufficiently hot (i.e., due to a fire in close proximity), the pane will delaminate whether the glass has been broken or not. If laminated glass is used, it should be installed in conjunction with an insulated glazing unit (IGU) [6]. Generally, laminated glass has a similar performance to annealed glass.
Tempered Glass	Because of the surface compression caused by the heat-strengthening process, tempered glass can withstand temperatures as high as 470°C (878°F). The resistance of tempered glass can be enhanced with a proprietary reflective coating. In the event tempered glass breaks, it shatters into many small, rounded chunks as opposed to shards. Tempered glass does come at a premium and will reportedly add 15% or more to the cost of the window [13]. A window containing tempered glass can be identified by the etched "bug" on the corner glass. For further protection, the glass can be installed in an insulated glazing unit (IGU) with a laminated glass inner pane [6].
Low-e Type Coating	Low-e type coating is a proprietary reflective coating available for application to annealed and tempered glass. The coating is primarily used for energy saving benefits, as it provides a higher level of resistance to radiant heat than other types of glazing, reducing the probability that the heat will be able to enter the building [6].

Insulated Glazing Unit (IGU)	An IGU consists of two or three panes of glass that are separated by a sealed air space. Double-pane annealed units last about twice as long as single-pane windows. If the first pane fails, the second pane remains in place to resist ember intrusion. Laminated glass and tempered glass can be combined in various ways into an IGU [6]. This helps to increase the skylight's resiliency to wildfire.
Skylight Frames	To avoid glass failure, frames for skylights should only be constructed of metal or metal-clad wood. Plastic and exposed-wood frames should not be used. Maintenance is critical for skylight frames. Both domed and flat skylights have similar framing systems (bases). Framing systems must be installed in conjunction with metal flashing to protect adjacent wood framing members from ember related damage. This additional flashing helps the skylight remain in place when threatened by wildfire exposure but must be maintained to avoid risks [6].

General Mitigation Strategies

- Ensure operable skylights are closed prior to leaving a property located in high fire prone areas.
- If "glass-type" skylights are specified, provide tempered glass for the outer pane and laminated glass for the inner pane.
- Regularly inspect the roof for vegetative debris accumulation on and around skylights. For all skylight types, debris can accumulate at roof-to-skylight intersections. If ignited by embers, flames can potentially wrap around and impinge upon the top surface of the skylight Debris is more likely to accumulate on top of a skylight installed on a flat roof [32].
- If plastic skylights are installed, it is recommended that they are replaced with double paned glazing units with outer pane as tempered glass and inner pane as laminated, or insulated glazing units. Glazing products that are wired glass and/or FM Approved are also acceptable where the use of tempered-laminated glass is not feasible [11]. Glazing products that are not recommended are single pane of annealed glass or plastic glazing [6].
- If skylight opens, install non-corrosive metal screening with openings at least 1/8" (1/16" preferred) [3].

Training

NFPA - *Assessing Structure Ignition Potential from Wildfire:* https://www.nfpa.org/Training-and-Events/By-topic/Home-Ignition-Zone

Other References

- National Fire Protection Association (NFPA) and the Insurance Institute for Business & Home Safety (IBHS)
  - Firewise Wildfire Research Fact Sheet on Skylights - https://www.nfpa.org/education-and-research/wildfire/firewise-usa/firewise-usa-resources
- University of California, Agriculture and Natural Resources (UCANR)
  - Wildfire Preparedness, Prepare Your Home, Skylights - https://ucanr.edu/sites/Wildfire/Roof/Skylights/
- Federal Emergency Management Agency (FEMA)
  - Home Builder's Guide to Construction in Wildfire Zones, Technical Fact Sheet No. 10 - https://www.govinfo.gov/content/pkg/GOVPUB-HS5-PURL-gpo60104/pdf/GOVPUB-HS5-PURL-gpo60104.pdf
  - Mitigation Assessment Team Report: Marshall Fire Building Performance, Observations, Recommendations, and Technical Guidance (FEMA P-2320) - https://www.fema.gov/sites/default/files/documents/fema_p2320-marshall-fire-mAT-report-without-appendices.pdf

Figure 1.13a. Example of flat roof with plastic dome-type skylights. Flat roof skylights are vulnerable to combustible debris accumulation, as well as gaps in the joints between the skylight and the roof. Note also the turbine vents to the left of the skylights.

Figure 1.14. Example of the vulnerability of skylights when left open during fire events provide an unobstructed path for ember intrusion. Image courtesy of Commercial Roof USA.

Figure 1.13b. Up close view of flat roof skylight with potential gapping between the skylight and the roof.

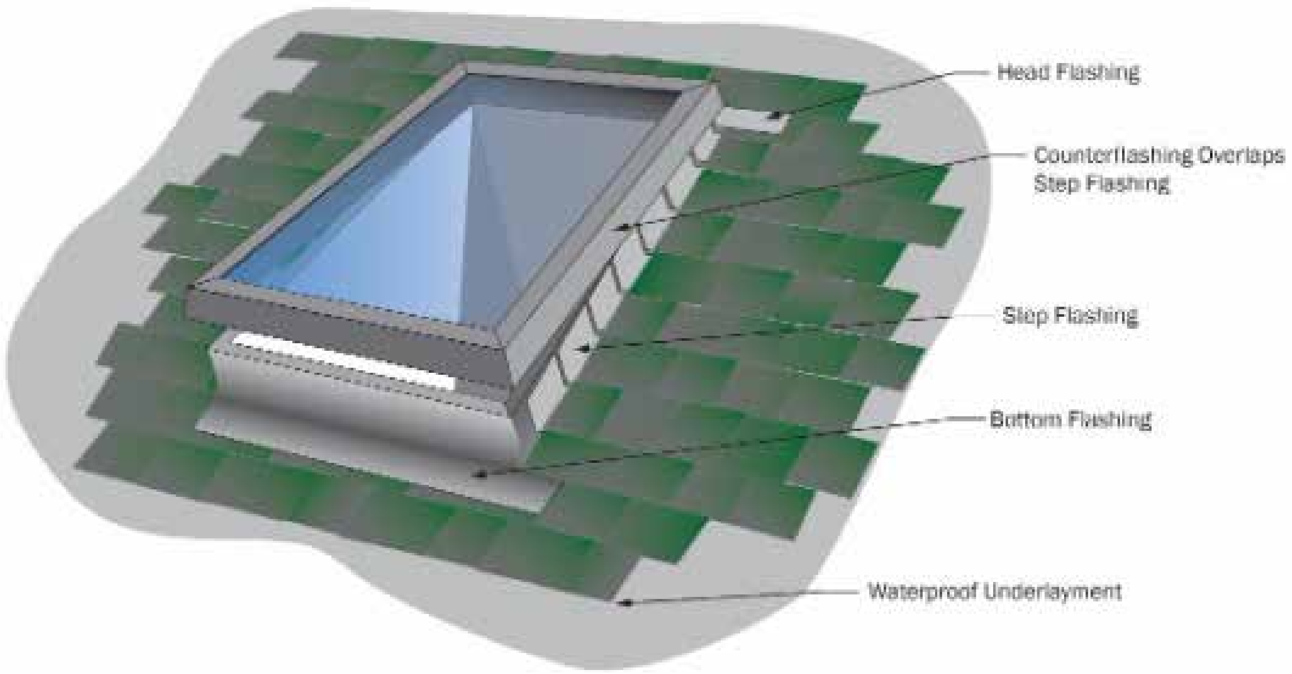


Figure 1.15. Sample flashing detailing for skylights to limit water damage, as well as ember penetration at the skylight-to-roof joint. Image adapted from FEMA Marshall Fire MAT, Wildfire Resilient Detailing, Joint Systems, and Interfaces of Residential Building Components, FEMA, 2023. https://www.fema.gov/

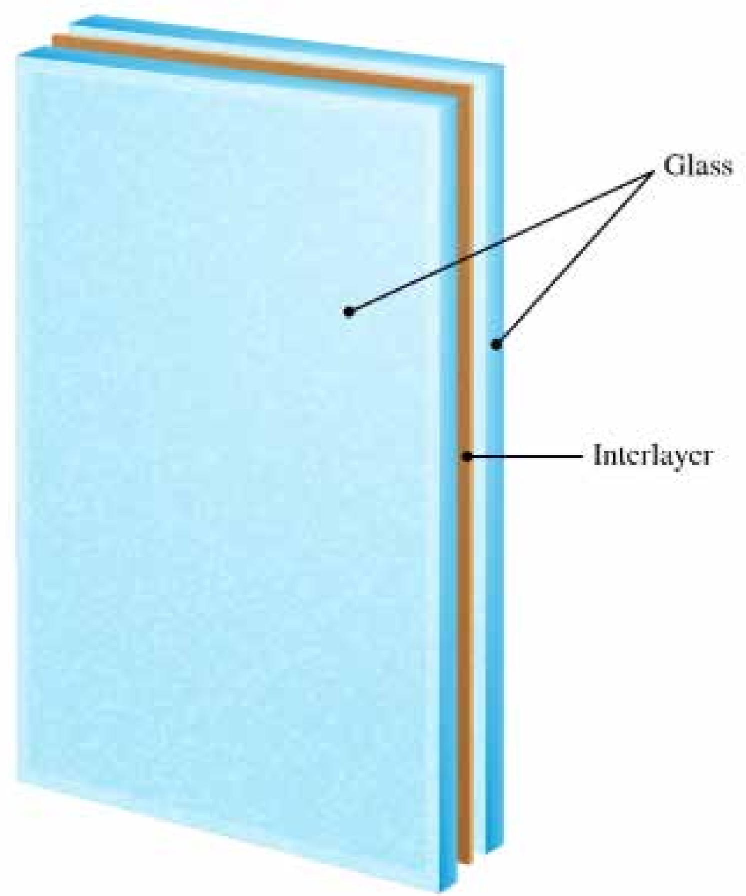


Figure 1.16. Basic laminated glass. The interlayer is commonly comprised of polyvinyl butyrate (PVB) and will help keep the glazing within the frame.

1.1.4 SOLAR PANELS

Main Concern(s)

Residential solar panel installations are a relatively new technology and building component/feature that has evolved significantly since 2014. While there have been significant strides in understanding fire hazards and risks from these systems and how to effectively design to mitigate those risks, little research and design standards have been undertaken to specifically address wildfire exposures and the associated risks that contribute to home ignition, fire load, or firefighter safety during wildfire operations for these systems.

General concerns include:

- Rooftop placement is isolated from routine occupant awareness, fixed fire protection systems, and detection features. These factors result in potential accumulation of debris, delayed fire detection, and no fire protection.
- Combustible portions of the module and other components provide fuel to support a fire and can reflect heat from a fire towards the roof, contributing to combustion and burn-rate.
- Defensive fire service actions have been found to have reduced impact because photovoltaic (PV) panels conceal and shield fire below. Fire service must take additional precautions when approaching a structure that includes rooftop solar installation, as power generated by the panels cannot be turned off. Fire service may not identify presence of PV panels if not visible from ground-level.
- In general, there is limited data on how PV systems behave under wildfire exposure. There is potential for these systems to contribute to a wildfire event during substantial exposure, based on the materials used and their constant energization when exposed to light.
- Rooftop PV systems may include penetrations for building service which may compromise the continuity and integrity of the building envelope, potentially leading to early failure during wildfire exposure.

Key Terminology

- **Photovoltaic (PV) Module:** An environmentally protected planar assembly of solar cells, optics, and ancillary parts, such as interconnections, terminals, (and protective devices such as diodes) intended to generate direct current power under unconcentrated sunlight. The structural (load carrying) member of a module can either be the top layer (superstrate) or the back layer (substrate) [33].
- **PV Panel:** This is the technical term for a solar panel, often used interchangeably with PV module (especially in one-module systems), but more accurately used to refer to a physically connected collection of modules (i.e., a laminate string of modules used to achieve a required voltage and current). A collection of photo-voltaic modules mechanically fastened together, wired, and designed to provide a field-installable unit [33].

- **PV System:** A complete set of components for converting sunlight into electricity by the photovoltaic process, including the array, rack support system, and balance of system components [33].

- **Photovoltaic-Thermal (PV/T) System:** A photovoltaic system that, in addition to converting sunlight into electricity, collects residual heat energy and delivers both heat and electricity in usable form. Also called a total energy system or solar thermal system.

- **Solar Panel:** Synonymous with PV panel.

Fire Rating and Classification

PV systems (PV modules with mounting systems) are available with Class A, B, and C ratings. Classification of roof mounted PV systems is based on *UL 1703* and *61730* (PV Modules, legacy US standard and update to international standard) as well as *UL 2703* (PV mounting systems). The combination of roof mounted solar modules and racking components is required to be considered as a system. The system is required to meet or exceed the fire classification of the roof assembly on which they are mounted. PV modules are also categorized by roof slopes they are tested for.

Module classification under *UL 1703* is still supported, but eventually will be withdrawn in favor of the updated *UL 61730*. *UL 1703* and *61730* assign module types that are based on panel material/thickness, encapsulation method, substrate material/thickness, frame, and fire test performance for external fire exposure.

Fire Test Standards

There are currently no fire test standards for solar panels exposure to wildfires. The following are closely related fire test standards for roof mounted PV systems. If solar panels are integral with the roof covering, then they must comply with *ASTM E108*.

- *ASTM E108* Standard Test Methods for Fire Tests of Roof Coverings: https://www.astm.org/e0108-20a.html
- *UL 790* Fire Test of Roof Coverings: https://standardscatalog.ul.com/ProductDetail.aspx?productId=UL790
- *UL 1703* Standard for Flat-Plate Photovoltaic Modules and Panels: https://standardscatalog.ul.com/ProductDetail.aspx?productId=UL1703
- *UL 61730*-1 and *UL 61730*-2 Photovoltaic (PV) Module Safety Qualification - Part 1: Requirements for Construction and Part 2: Requirements for Testing: https://www.shopulstandards.com/ProductDetail.aspx?UniqueKey=43587, https://www.shopulstandards.com/ProductDetail.aspx?productId=UL*61730*-2_2_S_20221028
- *UL 2703* Mounting Systems, Mounting Devices, Clamping/Retention Devices, and Ground Lugs for Use with Flat-Plate Photovoltaic Modules and Panels: https://standardscatalog.ul.com/ProductDetail.aspx?productId=UL2703
- *ASTM E2908* Standard Guide for Fire Prevention for Photovoltaic Panels, Modules, and Systems: https://www.astm.org/e2908-12r18.html

Referenced Codes and Standards

There are currently no building codes or standards for solar panels exposed to wildfires. However, the following codes and standards are closely related.

- *2024 International Wildland-Urban Interface (IWUI) Code:* Section 504.2, 505.2 Roof Assembly
- *2022 California Building Code (CBC):* Chapter 7A, Section 705A.2 Roof Coverings, Section 3111 Solar Energy Systems
- *2022 NFPA 1140 Standard for Wildland Fire Protection:* Section 25.3 Roof Design and Materials

Other Codes and Standards

Additional local requirements, policies, and programs will vary depending on location and adoption in individual jurisdictions.

- Check local, county, and state amendments for additional wildfire codes and standards.
- Check local general plan, multi-hazard mitigation plan, zoning.
- International Residential Code (if applicable - check for wildfire amendments).

Typical Design, Vulnerability, and Mitigation Considerations

Table 9. Vulnerability and mitigation considerations for solar panel systems.

Types of Solar Panel Systems	Vulnerability and Mitigation Considerations
In-Roof (Building Integrated)	Solar panel systems integrated into the roof assembly can result in complicated geometry and joints that can be challenging to protect and clear of vegetative debris. In-roof system geometry should be kept simple to minimize debris collection. Further testing/information is needed, with more information to be determined in future editions.
Rooftop, Pre-2014 PV Systems	Mounting and support systems and attachments were not well-regulated or assessed for compatibility. Installations prior to 2014 can vary broadly in their installation and mounting systems. Further testing/information is needed, with more information to be determined in future editions.
Rooftop, Post-2014 PV System Installation	For flat installations, solar panels should be installed with sufficient clearance from the roof for clearing of vegetative debris. For sloped installations with potential for debris accumulation, provide means to prevent accumulation (that don't reduce PV performance) or physical means to clear debris (such as removal tools or under panel water spray).

General Mitigation Strategies

- Install Class A rated PV panels for the greatest protection.
- Maintain the panels free of debris and damage. This includes providing sufficient clearance between the panels and roof for clearing debris and inspecting the underside for damage.
- Install invertor and energy storage components within the building to minimize ignition hazards. These elements should not be installed outside within 5' of exterior walls.
- Where permitted by the local authority having jurisdiction and manufacturer, install mesh enclosures (also referred to as mesh guards) to protect the underside of the panel systems. These are typically intended to keep birds and rodents away from the panel systems, however, can also help to prevent debris accumulation, when regularly maintained.
- Improper design, installation or components can cause hot spots and/or electrical failures that can lead to ignition of the system and adjacent materials during high load. Self-installed systems can significantly increase the risk of fire. PV system installation must be appropriately designed and installed using classified and listed products. Compliant PV systems have a very low incident rate of ignition.
- Roof attachments and methods must be compatible with the roof system and use appropriate precautions. Incorrect attachment methods can compromise fire performance, waterproofing ability, and in extreme cases, structural performance.

Training

NFPA - *Assessing Structure Ignition Potential from Wildfire:* https://www.nfpa.org/Training-and-Events/By-topic/Home-Ignition-Zone

Gaps in Knowledge

- There is limited information available on how solar panels behave in a wildfire event, as this is dependent on the module, mounting hardware and roof as a system. Actual performance of a rack-mounted PV system exposed to fire or flame is strongly dependent on the mounting geometry of the PV array and properties of the components that make up the specific PV module type [34].
- Fire classification requirements were updated in 2014 (*UL 1703*) and later updated for international standard consistency (*UL 61730*) with substantial focus on fire performance considerations. Since PV systems continue to be an innovative field, technology and requirements will continue to evolve.
- Battery and inverter equipment locations do not typically consider exterior exposure risks and may be located on the building exterior.

Other References

- Federal Emergency Management Agency (FEMA)
  - Home Builder's Guide to Construction in Wildfire Zones - https://www.govinfo.gov/content/pkg/GOVPUB-HS5-PURL-gpo60104/pdf/GOVPUB-HS5-PURL-gpo60104.pdf
  - Mitigation Assessment Team Report: Marshall Fire Building Performance, Observations, Recommendations, and Technical Guidance (FEMA P-2320) - https://www.fema.gov/sites/default/files/documents/fema_p2320-marshall-fire-mAT-report-without-appendices.pdf
- Fire Safety Journal
  - "Experimental Study of Flame Spread Underneath PV Panels" - https://doi.org/10.1016/j.firesaf.2020.103027
- Solar ABCs / UL
  - Fire Classification Rating Testing of Stand-Off Mounted Photovoltaic Modules and Systems - http://www.solarabcs.org/about/publications/reports/flammability-testing/pdfs/SolarABCs-36-2013-1.pdf

- Flammability Testing of Standard Roofing Projects - http://www.solarabcs.org/about/publications/reports/flammability-testing/pdfs/Flammability_Interimreport.pdf

- National Fire Protection Association (NFPA)
  - Development of Fire Mitigation Solutions for PV Systems Installed on Building Roofs Phase 1 - https://www.nfpa.org/News-and-Research/Data-research-and-tools/Electrical/Development-of-Fire-Mitigations-Solutions-for-PV-Systems-Installed-on-Building-Roofs-Phase-1
  - Property Insurance Research Group Forum on PV Panel Fire Risk - https://www.nfpa.org/News-and-Research/Data-research-and-tools/Proceedings/Property-Insurance-Research-Group-Forum-on-PV-Panel-Fire-Risk
  - Photovoltaic and Energy Storage Systems Online Training Series - https://www.nfpa.org/News-and-Research/Resources/Emergency-Responders/High-risk-hazards/Photovoltaics-Systems

Figure 1.17. Solar panel array on roof. Configurations such as the one shown are prone to debris accumulation under the array. Image courtesy of Jensen Hughes/FEMA.

1.1.5 ROOF JOINTS

Main Concern(s)

In general, joints create gaps in the continuity of a fire rated or fire resistive roof assembly, presenting a potential avenue for embers, hot gases, or flame to breach the exterior roof envelope. Joints can also create places for the accumulation of combustible debris that can be easily ignited by embers, hot gases, or direct flaming, or where embers collect and create a concentrated source of heat. Both scenarios can potentially lead to ignition of the roof underlayment or other combustible interstitial spaces at the joints. Overtime, the size and/or condition of joints may also change from expansion, contraction, and general wear-and-tear due to moisture, freeze-thaw cycles, temperature gradients and other weathering. This can further create potential pathways for ignition, potentially short-circuiting the fire resistance provided by a Class A roof assembly [15]. Unfortunately, there is currently no wildfire-specific fire test for roof joint protection systems or products. Note: One practical challenge with roof joints is that they may not be visible (e.g., between panel joints on the roof deck) or easily accessible, therefore making it difficult to verify if appropriate joint protection is provided.

Key Terminology

- **Joint:** An opening in or interface between adjacent assemblies or building components that is created to accommodate building construction tolerances or movements due to thermal, seismic, wind, or any other loadings [35].

- **Fire-Resistant Joint System:** An assemblage of specific materials or products that are designed and tested in accordance with a standard fire test to resist, for a prescribed period of time, the passage of fire through joints made in or between fire-resistance rated assemblies [35]. (***Note:*** There are currently no fire-resistant joint system tests for wildfire exposures.)

- **Roof Ridge:** The roof ridge, or ridge of a roof is the horizontal line running the length of the roof where the two roof planes meet. This intersection creates the highest point on a roof, sometimes referred to as the peak [36].

- **Roof Valley:** A roof valley is formed where two roof slopes or planes meet. A valley occurs where two roof planes intersect. Valleys are places where leaves and needles often accumulate and where embers can land [12].

- **Flashing:** A thin metal that is installed at joints to protect against intrusion of unwanted elements such as water and embers.

- **Expansion Joint:** A physical discontinuity that spans the entire breadth of an element in a building, creating two separate sections of the element instead of one bigger one. They are designed and configured to allow the different building sections to move independently of each other, so the structures don’t become overstressed and crack or break under various loads (e.g., thermal expansion/contraction, moisture-related dimensional change, seismic movement) [37].

- **Through Penetration:** A breach in both sides of a roof, floor, floor-ceiling, or wall assembly to accommodate an item passing through the breaches (Definition adapted from 2022 CBC) [14].

Fire Classification and Ratings

Currently, there is no fire test standard for joint systems that exist throughout the exterior envelope of a building to evaluate fire performance to ember intrusion, direct flame impingement, or thermal transmission of heat from wildfires. Fire rated joints are necessary to maintain a roof system's fire rating, integrity, and continuity to wildfire exposure. While a variety of fire tests exist for joints for interior building fire exposures (e.g., *ASTM E1966* or *UL 2079*), none are explicitly designed for exterior fire exposures such as wildfires in combination with weathering. A range of joint systems (e.g., static joints, movement joints, roof expansion joints) and building component interfaces (e.g., chimney-to-roof, vent-to-roof, skylight-to-roof, roof panel-to-roof panel, edge-of-roof joint, roof-to-wall) for exterior wildfire exposures are still needed.

Fire Test Standards

Currently, there is no fire test standard for joint systems (roof joints or otherwise) to evaluate fire performance to ember intrusion, direct flame impingement or thermal transmission of heat from wildfires.

Referenced Codes and Standards

- *2024 International Wildland-Urban Interface (IWUI) Code:* No explicit requirements
- *2022 California Building Code (CBC):* No explicit requirements
- *2022 NFPA 1140 Standard for Wildland Fire Protection:* No explicit requirements

Other Codes and Standards

Additional local requirements, policies, and programs will vary depending on location and adoption in individual jurisdictions.

- Check local, county, and state amendments for additional wildfire codes and standards.
- Check local general plan, multi-hazard mitigation plan, zoning.
- International Residential Code (if applicable - check for wildfire amendments).

Table 10. Design, vulnerability, and mitigation considerations for roof joints.

Joint Types at Roof	Design, Vulnerability, and Mitigation Considerations
Roof Expansion Joint	An expansion joint allows the roof membrane to expand and contract in sync with the roof deck, without compromising the roof system. An expansion joint at the roof is typically provided with a cover. These covers are specifically designed to prevent air or water from entering the building through the roof, and usually extend all the way from one side of the roof to the other [37]. Expansion joints typically accommodate thermal expansion and contraction due to changes in the ambient temperature (think about a potential 50-degree change in temperature between night and day and how much thermal expansion that would cause), or expansion/contraction due to moisture changes in the materials, such as in wood [37]. There are numerous types of details and systems to accommodate this movement (whether vertical or horizontal). The materials used at the expansion joint can consist of a range of combustible and noncombustible materials (e.g., foam, neoprene, sealant). If the materials are combustible or have metal flashing without sufficient, noncombustible thermal insulation, they can present a vulnerability in the roof for embers, hot gases or flames to enter. ***Note:*** Expansion joints are less common in most residential home construction but may be more prevalent in larger custom homes or in commercial structures, particularly in seismic regions. Some expansion joints may not be visible, therefore making it difficult to verify if appropriate joint protection is provided. However, where joints are visible, it is important to verify that flashing and joint protection are in good condition..
Valley Joints	To increase the resistance of the valley to heat and flames there are a few important installation considerations. If metal valley flashing is used, an underlying mineral surfaced cap sheet must be incorporated into the assembly. With Class A asphalt composition shingles, use of metal flashing can be avoided by interweaving the shingles. A cut valley design could also be used [12].
Roof-to-Wall Joint	The more intersections and shapes included in the roof design, the more opportunity there will be for vegetative debris and/or embers to accumulate at the various interfaces. Vegetative debris collection at these interfaces or joints can lead to spot fires from embers, exposing any combustible siding at roof-to-wall intersections to flames. If combustible siding is installed flush (or within an inch) to the roof plane, the siding could be ignited directly by embers (i.e., without initial ignition of vegetative debris) [12]. Dormers and other designs that result in roof-to-wall intersections that are clad with a combustible siding product should be reinforced with an underlayment of a fire-rated gypsum product to increase the resistance of the siding to the penetration of flames. Referred to as Type X, many of the gypsum board manufacturers produce a product that can be used in this application. Whereas this assembly provides enhanced protection against fire penetration, it will not affect vertical and lateral flame spread on the exterior wall. (If possible, replacing the bottom 6 inches of combustible siding with noncombustible materials such as fiber-cement board would also reduce the flame spread concern). When a combustible siding product is used, a corrosion resistant metal flashing should also be used at roof-to-wall intersections to improve the resistance of siding to ignition from embers that can accumulate at these locations. Installation details are important to avoid moisture related degradation that could occur should water get behind the flashing. An example detail is shown above [12]. Provide fire-resistant caulking at any gaps at the joint between top-of-wall (wall-to-roof) joints. Where the wall siding is comprised of combustible materials, install noncombustible metal flashing and counter flashing (see Figures 1.22 and 1.23) that protects the roof-to-wall joint for at least 6 vertical inches above the roof surface. The metal flashing should be lapped above the roof covering material extending vertically up along the exterior side of the wall siding before being “let in” behind the siding at the lap joint, with combustible siding kept 4-6 inches above the roof surface. Corrosion-resistant metal flashing is one material that might be used to accomplish this. Alternatively, “local” replacement of siding with a noncombustible material (e.g., a fiber cement siding product) would also be acceptable [38].

Chimney-to-Roof Joints	Where chimneys are constructed with an exterior chase of combustible siding or other combustible materials, install noncombustible metal flashing and counter flashing that protects the roof-to-chimney chase joint for at least 6 vertical inches above the roof surface. The metal flashing should be lapped above the roof covering material extending vertically up along the exterior side of the chimney chase before being "let in" behind the chase siding at the lap joint with combustible siding kept 4-6" above the roof surface. Corrosion-resistant metal flashing is one material that might be used to accomplish this. Alternatively, "local" replacement of siding (i.e., chase area only) with a noncombustible material would also be acceptable [38].
Vent-to-Roof Joints	Debris accumulation can occur at vent-to-roof interfaces and needs to be cleaned to minimize potential for ignition. Metal flashing should be used to protect the vent-to-roof interface, if not already installed. Seal gaps and penetrations around vents with fire-resistant caulk, noncombustible mortar, compressed mineral wool, metal flashing, or fire-rated expanding foam. Where available/applicable, roof penetrations should be sealed per manufacturer's instructions. For enhanced protection, use a rated exterior penetration firestop system. However, special considerations should be taken if employing this protection, such as ensuring the system is listed for use in the appropriate type of roof system [38]. Debris accumulation is also a concern at vent openings. (Refer to Section 1.1.2 *Roof Vents*.)
Skylight-to-Roof Joints	Debris can also accumulate at the edge of skylights. If that debris were to ignite, then the materials and connections at the roof-to-skylight intersection could be vulnerable. Seal gaps and penetrations around skylights with fire-resistant caulk, noncombustible mortar, compressed mineral wool, metal flashing, or fire-rated expanding foam. If metal valley flashing is used, an underlying mineral surfaced cap sheet must be incorporated into the assembly [30]. Where available/applicable, roof penetrations should be sealed per manufacturer's instructions. For enhanced protection, use a rated exterior penetration firestop system. However, special considerations should be taken if employing this protection, such as ensuring the system is listed for use in the appropriate type of roof system [38]. Refer to Section 1.1.3 *Skylights* for additional vulnerabilities and mitigations related to skylights.

General Mitigation Strategies

- Debris should be removed from around all joints created at the roof (e.g., expansion joints, vents/chimney-to-roof joints).
- Noncombustible materials (e.g., compressed mineral wool) in lieu of combustible materials should be provided to fill expansion joints.
- Fire-resistant sealants should be provided in lieu of non-fire rated caulking.
- Metal flashing should be installed at vent-, chimney-, and skylight-roof joints to limit ember penetration or spot fires from ignited roof debris from penetrating into the roof substrate. Where the roof underlayment is combustible, refer to appropriate protection measures in the roof construction/covering section for detailing.
- For new construction, limit the number of joints and elevation changes in the roof design [38].
- Where apparent, seal small gaps between the roof and any roof penetrations with appropriate joining strips (silicone recommended). Do not use polymer joining strips unless fire rated [15].

Training

NFPA - *Assessing Structure Ignition Potential from Wildfire:* https://www.nfpa.org/Training-and-Events/By-topic/Home-Ignition-Zone

Gaps in Knowledge

- Currently, there is no fire test standard for joint systems (roof joints or otherwise) to evaluate fire performance to ember intrusion, direct flame impingement, or thermal transmission of heat from wildfires.
- It is unclear how susceptible various roof-joints are to wildfire exposures.

Other References

- University of California, Agriculture and Natural Resources (UCANR)
  - Wildfire Preparedness, Prepare Your Home, Roof - https://ucanr.edu/sites/fire/Prepare/Building/Roof/
- Federal Emergency Management Agency (FEMA)
  - Mitigation Assessment Team Report: Marshall Fire Building Performance, Observations, Recommendations, and Technical Guidance (FEMA P-2320) - https://www.fema.gov/sites/default/files/documents/fema_p2320-marshall-fire-mAT-report-without-appendices.pdf
  - Homeowner's Guide to Reducing Risk of Structure Ignition from Wildfire - https://www.fema.gov/sites/default/files/documents/fema_marshall-fire-mat-homeowners-guide-reducing-risk-structure-ignition.pdf
  - Wildfire Resilient Detailing, Joint Systems, and Interfaces of Residential Building Components - https://www.fema.gov/sites/default/files/documents/fema_marshall-fire-mat-detailing-joints.pdf
- General Roof Expansion Joint References
  - National Research Council (NRC) - Built-up Roof joints - https://nrc-publications.canada.ca/eng/view/ft/?id=ccde0331-086c-41a9-8fff-7b82e29f8144
  - Brick Industry Association - Brick Join - https://www.gobrick.com/docs/default-source/read-research-documents/technicalnotes/18a-accommodating-expansion-of-brickwork.pdf
  - Copper Development Association - Roof-to-Wall - https://www.copper.org/applications/architecture/arch_dhb/arch-details/building_expansion/roof_edges.html
  - AISC - Basic construction details (Non-Fire) - https://www.aisc.org/globalassets/modern-steel/archives/2005/04/2005v04_expansion_joints.pdf

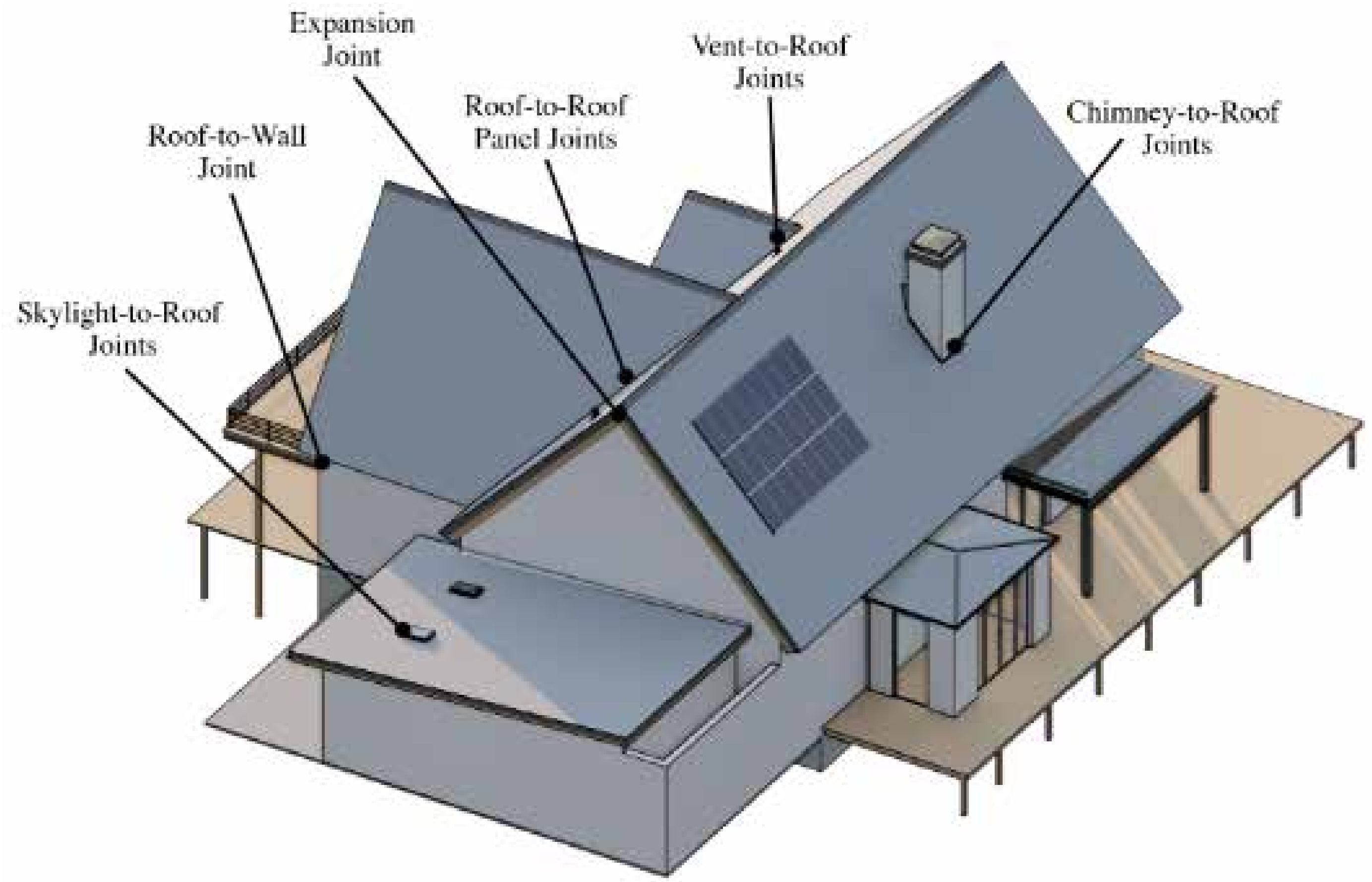


Figure 1.18. Schematic of various joints at the roof.

Figure 1.19. Collection of vegetative debris at roof valley joints that create potential fire hazards if ignited by embers. A localized fire can readily penetrate an unprotected joint.

Figure 1.20. Collection of vegetative debris at roof-to-wall joints that create potential fire hazards if ignited by embers. Accumulated debris can be ignited by embers and ignite the combustible siding where the exterior wall meets the roof. Image courtesy of Stephen Quarles.

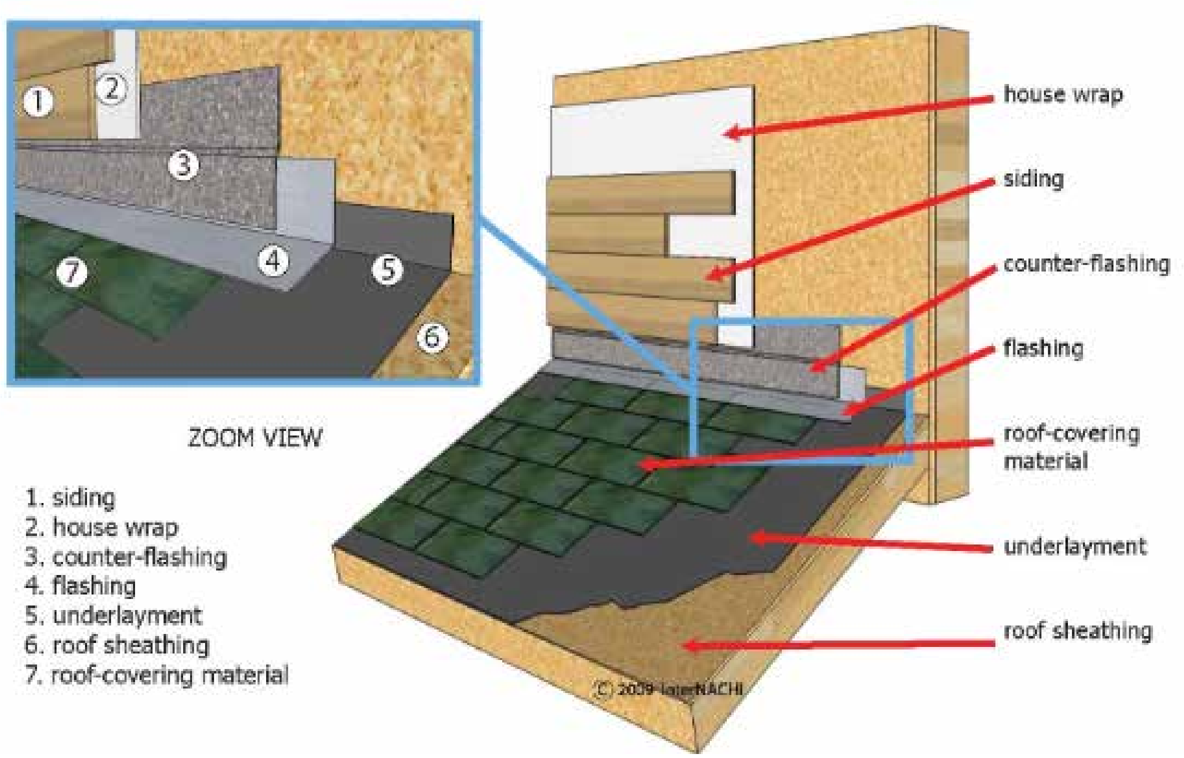


Figure 1.22. Example of roof-to-wall flashing details. Flashing and counter-flashing should be non-corrosive metal. Image courtesy of InterNACHI.

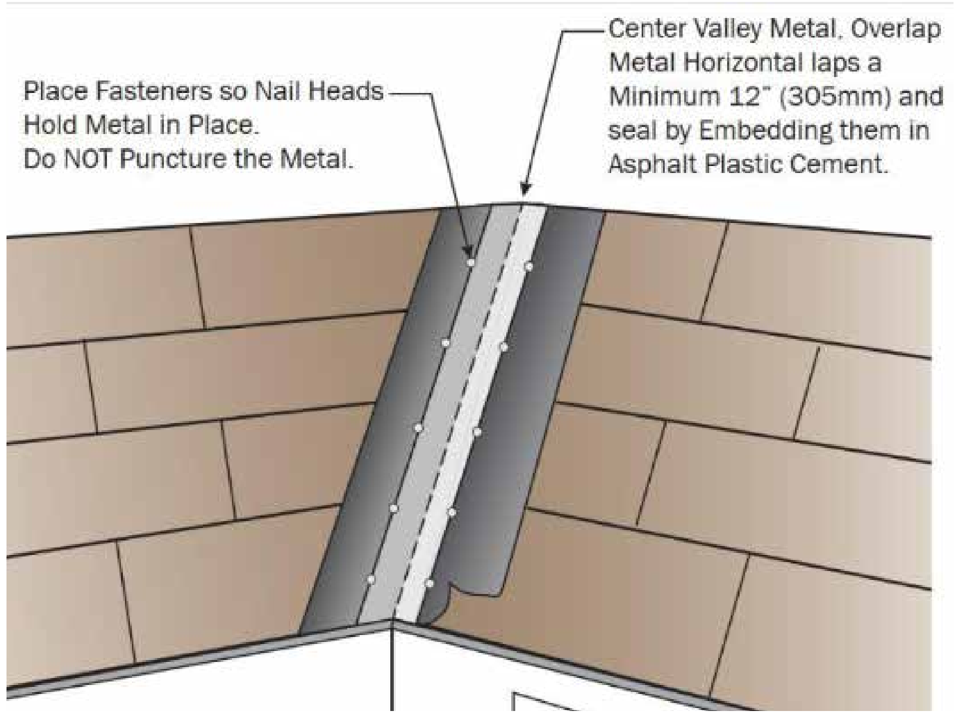


Figure 1.21. Example of roof valley joint protection. Image adapted from FEMA Marshall Fire MAT, Wildfire Resilient Detailing, Joint Systems, and Interfaces of Residential Building Components, FEMA, 2023. https://www.fema.gov/

Figure 1.23. Sample flashing details at chimney-to-roof joint. Note: Flashing shown in this figure is intended to be non-corrosive, metal flashing. Image adapted from FEMA Marshall Fire MAT, Wildfire Resilient Detailing, Joint Systems, and Interfaces of Residential Building Components, FEMA, 2023. https://www.fema.gov/

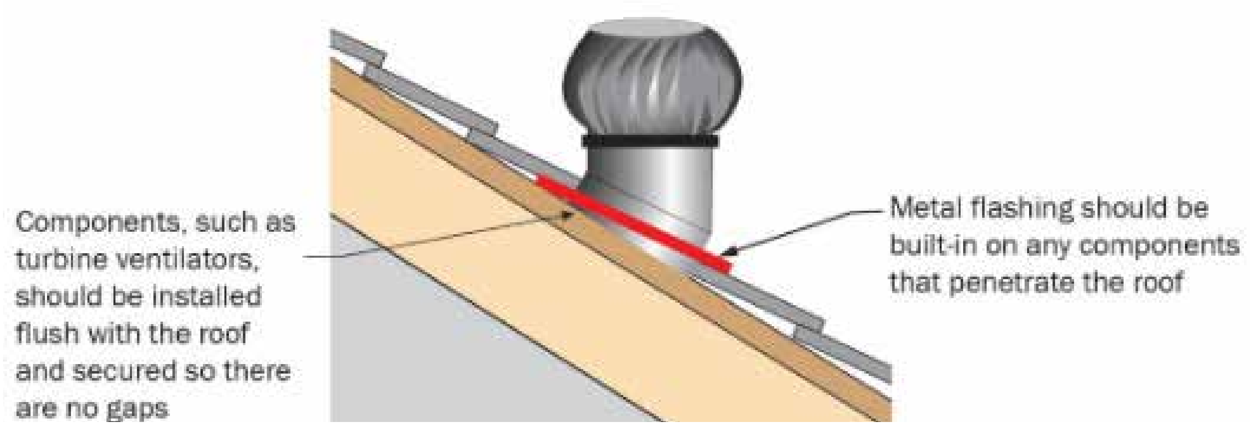


Figure 1.24. Sample flashing detail at vent-to-roof joint. Image adapted from FEMA Marshall Fire MAT, Wildfire Resilient Detailing, Joint Systems, and Interfaces of Residential Building Components, FEMA, 2023. https://www.fema.gov/

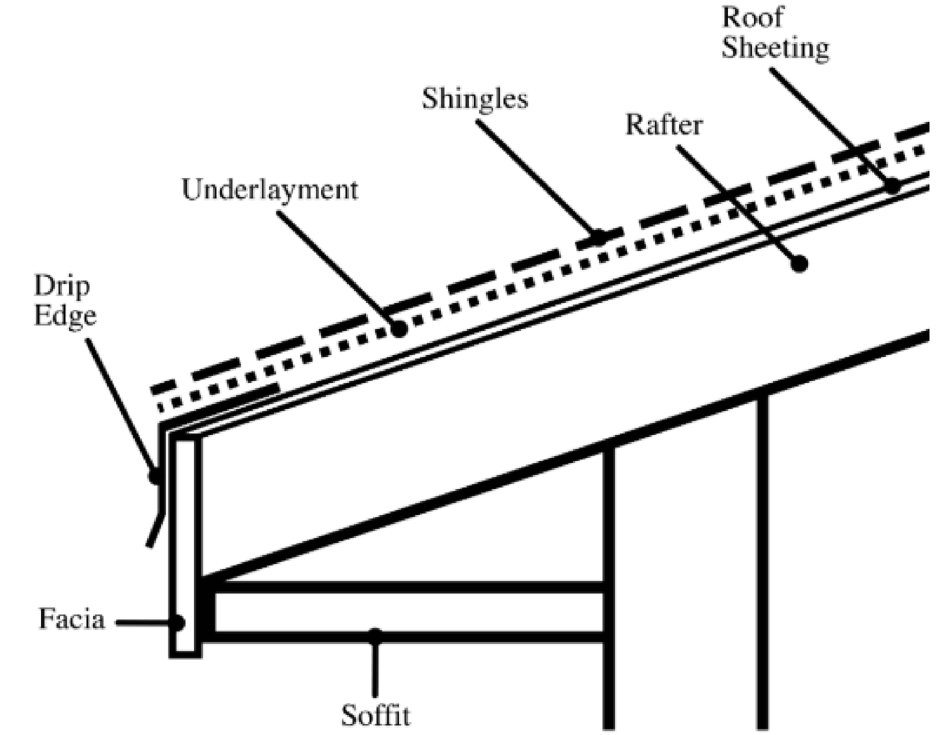


Figure 1.25a. Sample edge of roof detailing for fire resistance.

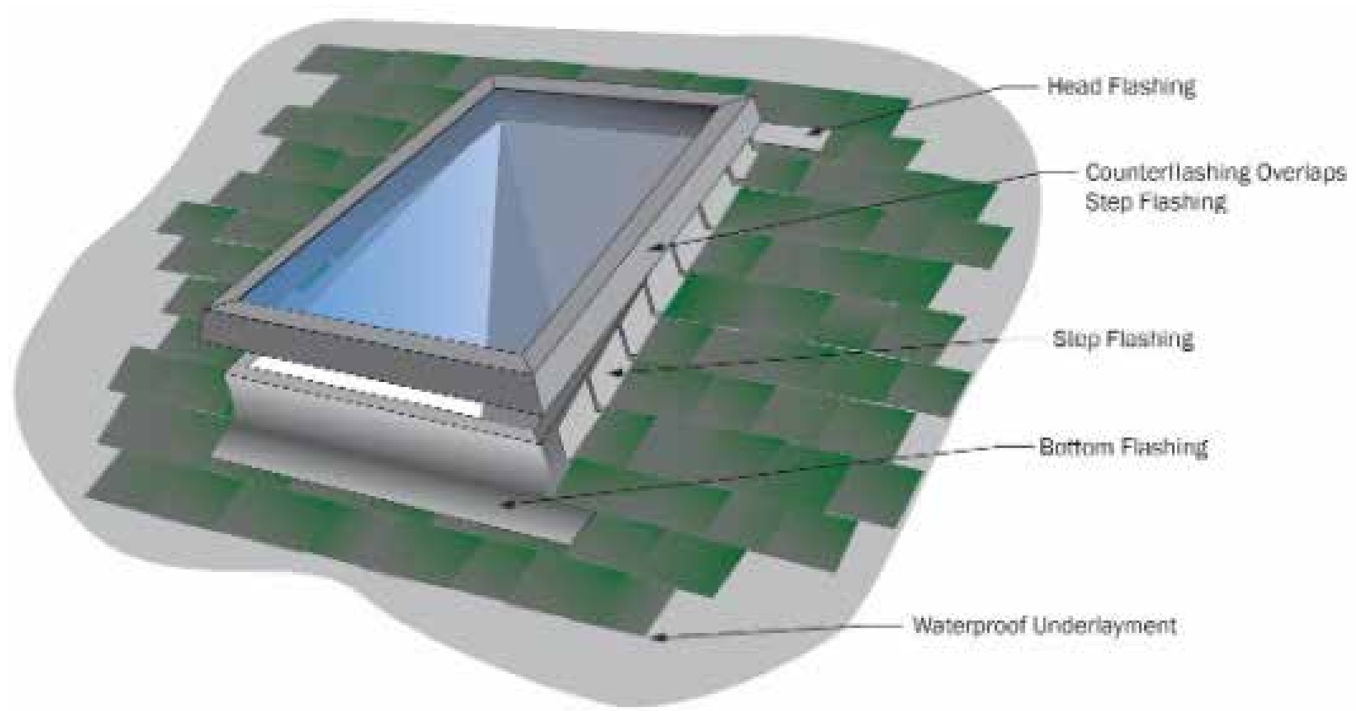


Figure 1.25. Sample flashing details at skylight-to-roof joint. Image adapted from FEMA Marshall Fire MAT, Wildfire Resilient Detailing, Joint Systems, and Interfaces of Residential Building Components, FEMA, 2023. https://www.fema.gov/

1.1.6 ROOF EDGE

Main Concern(s)

The roof edge is a portion of a structure that is highly vulnerable to ignition due to (1) proximity to gutter systems and associated vegetative debris, (2) openings or breaches in the continuity of roof construction along the edges, and (3) proximity to trees, plants, and other man-made fuels surrounding the structure (e.g., wood piles, tool, or storage shed). Most gutter systems are located at the roof edge. As described in the gutter section, these building elements can collect vegetative debris, when not protected with a gutter guard or cleared out regularly. In the event of a wildfire, this vegetative debris will be a receptive fuel bed for embers, creating a localized fire hazard near the roof edge. In addition, roof edges are also typically sources of breaches in the continuity of roof assemblies, as roof edges may not be fully encapsulated. That is, the roof edge can have gaps between the roof covering and underlayment, which create a source of weakness for embers and flames (from ember ignited vegetative debris) to enter the combustible substructure of the roof. Roof edges can also be exposed to direct flame impingement and high temperatures where surrounding vegetation and other man-made fuels come into close proximity or directly touch the roof edge.

Key Terminology

- **Metal Drip Edge:** Metal flashing installed at the edge of the roof designed to keep water or embers away from the fascia board and roof sheathing.

- **Fascia or Gutter Boards:** Vertical roof trim located along the perimeter of a building, usually below the roof level, to cover the rafter tails at the eaves and to seal off the top of the siding along the rake [36].

Fire Rated Assemblies

Currently, there are no fire rated assemblies for roof edge detailing. However, several strategies for mitigation exist (see Table 11).

Fire Test Standards

Currently, there is no fire test standard for edge of roof detailing to evaluate fire performance to ember intrusion, direct flame impingement, or thermal transmission of heat from wildfires.

Referenced Codes and Standards

- *2024 International Wildland-Urban Interface (IWUI) Code:* No explicit requirements
- *2022 California Building Code (CBC):* 705A.2 Roofing
- *2022 NFPA 1140 Standard for Wildland Fire Protection:* 25.3.7 Roof Design and Materials

Other Codes and Standards

Additional local requirements, policies, and programs will vary depending on location and adoption in individual jurisdictions.

- Check local, county, and state amendments for additional wildfire codes and standards.
- Check local general plan, multi-hazard mitigation plan, zoning.
- International Residential Code (if applicable - check for wildfire amendments).

Typical Design, Vulnerability, and Mitigation Considerations

Table 11. Design, vulnerability, and construction considerations for roof edges.

Types of Roof Edges (Based on Roof Covering)	Design, Vulnerability, and Construction Considerations
Profiled and Flat Tile	Flat and barrel-shaped tiles and cement roof coverings can have gaps between the roof covering and sheathing, where birds and rodents can build nests that are readily ignitable by embers or direct flame. Wind-blown debris will also be blown into this under-roof area. In the event a fire develops in these locations, they can spread to structural support members, short circuiting the protection offered by a Class A roof covering. ***Note:*** An assembly rated covering will incorporate a fire-resistant material above the sheathing and below the roof covering, which will serve, in part, to resist flaming from ignited debris but is not a guarantee at the roof edge. Plugging these openings between the roof covering and the roof deck, is commonly called "bird stopping". Metal flashing at the roof edge also provides additional protection for the roof edge. Regularly inspect and maintain these areas. Refer to Section 1.1.1 *Roof Construction & Coverings* for additional considerations.
Pressure Impregnated, FRT Wood Shake or Shingles	FRT shakes and shingles for use in exterior applications will have a Class B or Class C "stand alone" rating. Use of an additional fire-resistant underlayment is needed for these materials to achieve a Class A fire rating. FRT shakes / shingles intended for use in exterior locations, such as a roof, must undergo either accelerated weathering (typically via ASTM D2898) or natural weathering (as specified by California Office of the State Fire Marshal) before conducting ASTM E108. Refer to Section 1.1.1 Roof Construction & Coverings for additional considerations.
Metal Panel or Shingle	Code-compliant underlayment should be installed continuous to the roof edge to increase fire-resistance. Where aluminum is used, it should be used as part of a Class A assembly, as the standalone material is not inherently Class A [39]. Refer to Section 1.1.1 *Roof Construction & Coverings* for additional considerations.

Asphalt Fiberglass Composition Shingles	Asphalt fiberglass composition shingles are fire-resistant and can achieve a Class A roof rating. Even with Class A roof materials, the roof edge is a critical area to address. Fiberglass asphalt is still susceptible to ignition if edges are not properly protected. ***Note:*** *Asphalt composition shingles have a Class A fire rating as long as the fiber is fiberglass and not a cellulosic material. The roofing industry transitioned to fiberglass many years ago, so it is unlikely that an asphalt composition shingle is made of cellulosic fibers. Asphalt is combustible, so this roof covering is not considered noncombustible, but it does meet the criteria for a Class A covering.* Metal flashing at the roof edge can provide additional protection. If gypsum roof board has been provided for the roof below the asphalt shingles, this gypsum layer should be continuous to the roof edge. Refer to Section 1.1.1 *Roof Construction & Coverings* for additional considerations.

General Mitigation Strategies

- Install a metal drip edge or flashing at the roof edge to minimize ember entry to the roof underlayment via materials burning in a rain gutter or wind-blown embers impinging on the area at the edge of the roof [12].
- Replace any damaged, broken, or missing pieces or sections of roof at the roof edge.
- Remove litter and other vegetation debris at the roof edge and in gutters as needed.
- For profiled tile roofs, bird-stop or mortar open ends of tiles at the roof edges to reduce vulnerability to ember ignition.
- For tile roofs, install corrosion-resistant metal flashing under tiles at roof edge. A cap sheet should be installed under the metal flashing.
- For profiled tile, lead or flexible flashing can be installed (as recommended by the manufacturer) [6]. Where underlayment is combustible provide an additional fire-resistant layer (e.g., gypsum board, mineral fiber, glass fiber, or other approved materials) between the roof covering and underlayment.
- Replace roof coverings and underlayment at roof edge before significant deterioration with age and exposure to weathering.
- Trim back vegetation touching, overhanging, or in close proximity to the roof edge (i.e., within 10 feet vertically and horizontally).

Training

NFPA - *Assessing Structure Ignition Potential from Wildfire:* https://www.nfpa.org/Training-and-Events/By-topic/Home-Ignition-Zone

Gaps in Knowledge

- Currently, there is no fire test standard for edge of roof detailing to evaluate vulnerability to ember accumulation in the gaps at the roof edge (for open eave and soffitted eave construction) and ember intrusion (via gaps in soffitted eave construction), direct flame impingement, or thermal transmission of heat from wildfires or proximate landscaping. The roof edge includes roof covering, underlayment, sheathing, fascia, and gutter and how these systems interact.
- As there are no fire tests for roof edges, it is unclear how weathering of materials prior to fire exposure or the impact of general wildfire environmental conditions (e.g., high winds, flying debris, impact from objects) will impact performance over time. However, many of the vulnerabilities related to weathering of a roof edge can be identified during inspection, e.g. warped edge materials that would make the area vulnerable to embers or flame, rusted drip edge, etc.

Other References

- University of California, Agriculture and Natural Resources (UCANR)
  - Wildfire Preparedness, Prepare Your Home, Roof - https://ucanr.edu/sites/fire/Prepare/Building/Roof/
- Federal Emergency Management Agency (FEMA)
  - Home Builder's Guide to Construction in Wildfire Zones, Technical Fact Sheet No. 5 - https://www.govinfo.gov/content/pkg/GOVPUB-HS5-PURL-gpo60104/pdf/GOVPUB-HS5-PURL-gpo60104.pdf
  - Mitigation Assessment Team Report: Marshall Fire Building Performance, Observations, Recommendations, and Technical Guidance (FEMA P-2320) - https://www.fema.gov/sites/default/files/documents/fema_p2320-marshall-fire-mAT-report-without-appendices.pdf
  - Decreasing Risk of Structure-to-Structure Fire Spread in a Wildfire (Marshall Fire MAT) - https://www.fema.gov/sites/default/files/documents/fema_marshall-fire-mat-decreasing-structure-fire-spread.pdf
  - Homeowner's Guide to Reducing Risk of Structure Ignition from Wildfire - https://www.fema.gov/sites/default/files/documents/fema_marshall-fire-mat-homeowners-guide-reducing-risk-structure-ignition.pdf
  - Wildfire Resilient Detailing, Joint Systems, and Interfaces of Residential Building Components - https://www.fema.gov/sites/default/files/documents/fema_marshall-fire-mat-detailing-joints.pdf
- National Fire Protection Association (NFPA)
  - Firewise Fact Sheets, Roofing Materials - https://www.nfpa.org/-/media/Files/Firewise/Fact-sheets/FirewiseFactSheetsRoofingMaterials.ashx

Figure 1.26. (top left) Weathered and poorly maintained cement tile roof with gaps and exposed wood shingles/sheathing; (bottom left) Asphalt singles with metal drip edge, and proximate gutter with vegetative debris. (top right) Poorly maintained, barrel-shaped tile roof with large gaps and no birdstopping. (bottom right). Wood shingle roof edge with gaps and lack of metal drip edge detailing. Image courtesy of Jensen Hughes/FEMA.

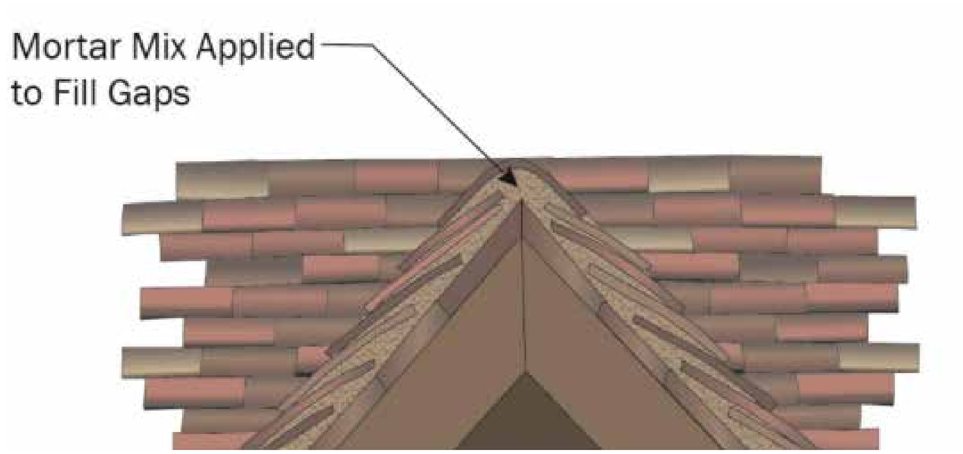


Figure 1.27. Example of mortar mix used to seal gaps at roof ridge edges. Image adapted from FEMA Marshall Fire MAT, Wildfire-Resilient Detailing, Joint Systems, and Interfaces of Residential Building Components, FEMA, 2023. https://www.fema.gov/

Figure 1.28a. (top) Vulnerabilities at roof edges (bottom) Fascia board ignition leading to roof joist ignition. These images demonstrate that gaps in the roof edge can lead to ignition of the structure. The top photo points to the contribution of the facia in creating a "box" that can trap heat. Image courtesy of Insurance Institute for Business & Home Safety.

Figure 1.28b. Example of fascia and roof edge that ignited, and began burning roof construction. Image courtesy of Jensen Hughes/FEMA.

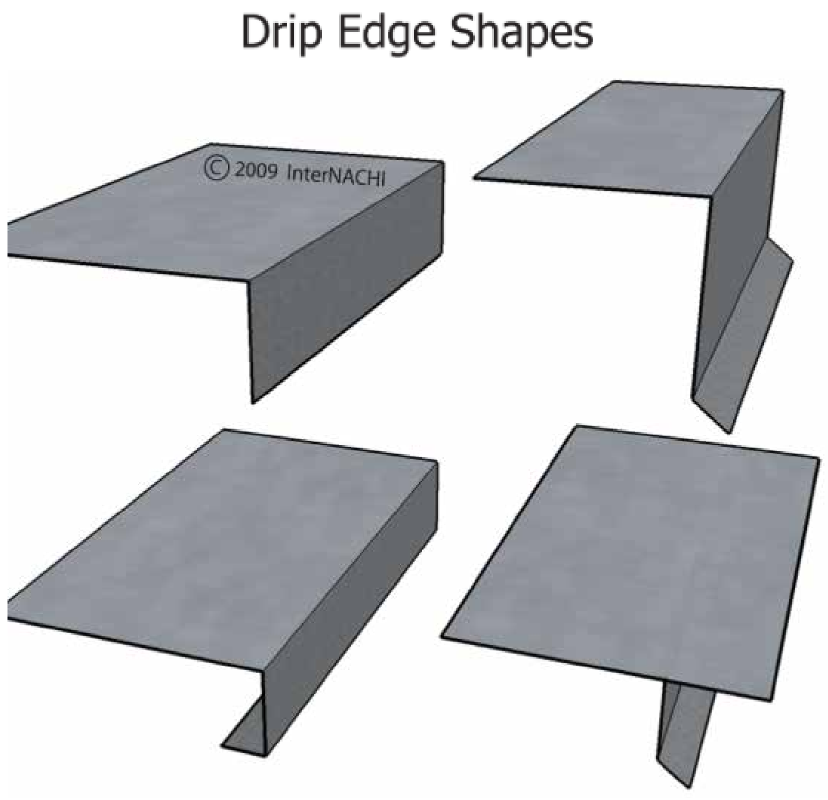


Figure 1.29. Roof drip edge examples. Image courtesy of InterNACHI.

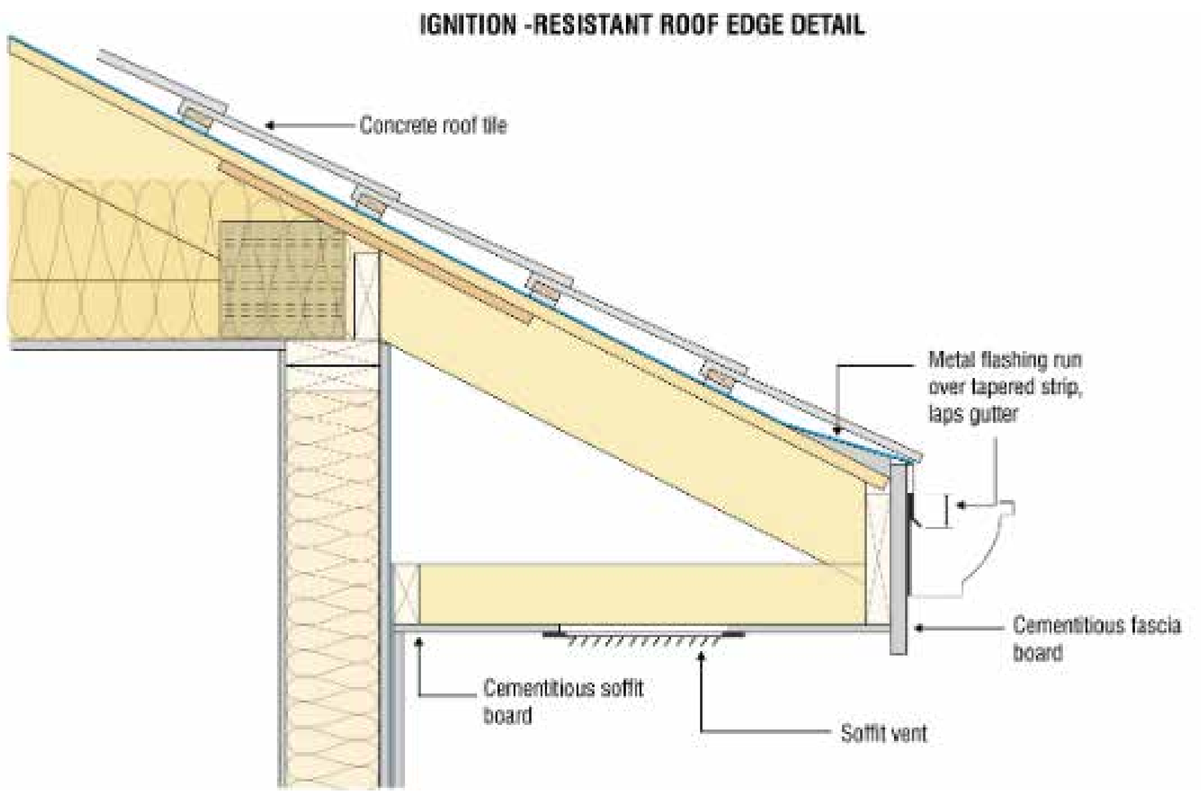


Figure 1.31. Example of ignition-resistant edge of roof detailing.

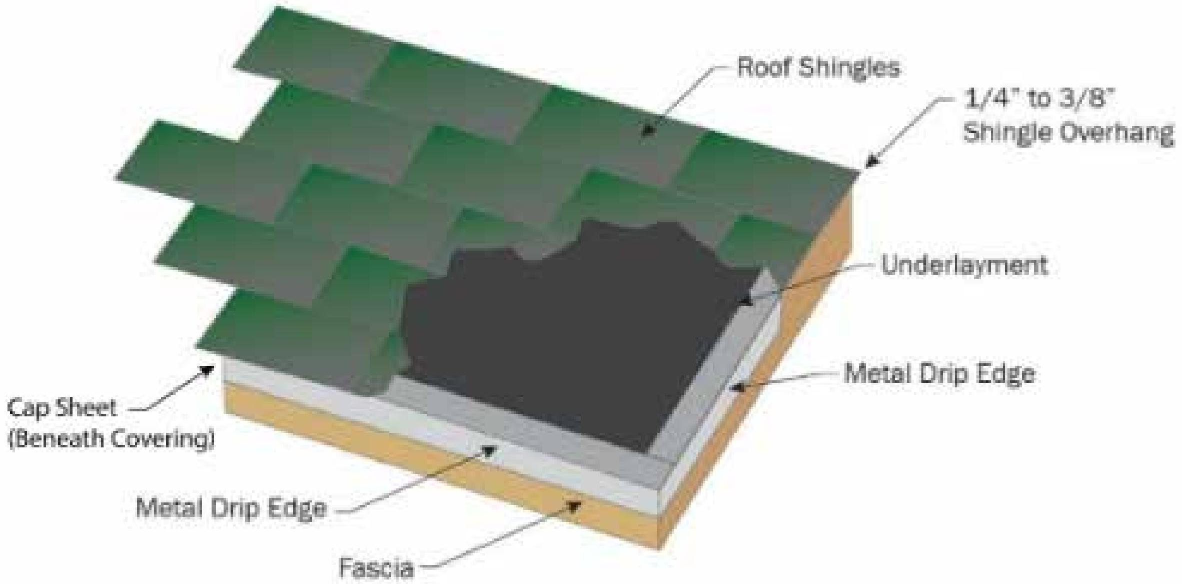


Figure 1.30. Sample edge of roof detailing for fire resistance. Image adapted from FEMA Marshall Fire MAT, Wildfire-Resilient Detailing, Joint Systems, and Interfaces of Residential Building Components, FEMA, 2023. https://www.fema.gov/

Figure 1.32. Sample bird-stopping at open ends of tiles at roof edges. Bird-stopping helps prevent debris accumulation and ignition of the roof. Image courtesy of Jensen Hughes/FEMA.

1.1.7 GUTTERS

Main Concern(s)

Combustible debris such as leaves and pine needles can accumulate in gutters, especially from nearby or overhanging trees. Due to difficulty in accessing upper stories of a home, gutters two and three floors high are even more problematic since they will be difficult to access and clean out on a regular basis. If ignited, combustible debris in the gutter will expose the edge of roof construction, typically the fascia and or roof sheathing. Depending on the condition of the wood and presence (or absence) of metal flashing at the edge of the roof, debris in the gutter may make it easier for fire to enter the interstitial roof space and potentially into the attic [40]. In addition, the material of the gutter is also a concern. Many gutters are constructed of plastic. Plastic gutters are typically made from polyvinyl chloride (PVC), which can melt and fall to the ground when exposed to flames or elevated radiant heat. While PVC will self-extinguish once the debris around and in it burns out (the chlorine acts as a fire retardant), the fact that the gutter may contain burning debris as it collapses creates another mechanism for fire spread along the façade of the building or to combustible fuel beds below.

Key Terminology

- **Gutters:** A shallow trough fixed beneath the edge of a roof to catch and direct rainwater.
- **Fascia or gutter boards:** Horizontal roof trim located along the perimeter of the roof of a building, usually below the roof level, to cover the rafter tails at the eaves and to seal off the top of the siding along the rake [41].
- **Gutter guard:** Gutter guard is a generic term used to describe anything that goes over gutters to limit the accumulation of vegetative debris (e.g., leaves, needles, twigs) in the gutter. There are a range of gutter guards including brush inserts, foam inserts, DIY screen, micro-mesh, hood, etc. Gutter guards can be combustible or noncombustible.

Fire Rated Assemblies

Currently, there are no fire-rated gutter assemblies.

Fire Test Standards

Currently, there is no fire test standard to evaluate the performance of gutter assemblies (e.g., gutter, gutter covers/devices, attachment details) to ember exposure, direct flame impingement or thermal transmission of heat from wildfires.

Referenced Codes and Standards

- *2024 International Wildland-Urban Interface (IWUI) Code:* Section 505.4 Gutters and Downspouts
- *2024 International Building Code:* Section 1502.3 Gutters
- *2022 California Building Code (CBC):*
  - Section 1502.4 Gutters
  - Section 705A.4 Roof Gutters
- *2022 NFPA 1140 Standard for Wildland Fire Protection:* Section 25.3.2 Roof Design and Materials

Other Codes and Standards

Additional local requirements, policies, and programs will vary depending on location and adoption in individual jurisdictions.

- Check local, county, and state amendments for additional wildfire codes and standards.
- Check local general plan, multi-hazard mitigation plan, zoning.
- International Residential Code (if applicable - check for wildfire amendments).

Typical Design, Vulnerability, and Mitigation Considerations

Table 12. Typical design, vulnerability, and mitigation considerations for gutters.

Types of Gutters	Design, Vulnerability, and Mitigation Considerations
Metal (Noncombustible) Gutters	Metal gutters are considered noncombustible and will generally stay in place during a wildfire provided they are appropriately attached to the roof edge. IBHS testing further proves this, as it was found that noncombustible gutters provide protection for fascia boards or rafter tails [22]. In the event vegetative debris in the metal gutter catches fire, the resulting fire poses a threat to the roof edge where the fascia, roof covering, and underlayment could potentially ignite and lead to a fire in the interstitial space of the roof or even enter the attic space. Proper edge of roof detailing is prudent to limit this risk. Refer to Section 1.1.6 *Roof Edge* for more details.
Plastic / Vinyl Gutters	Plastic or Vinyl gutters can melt when exposed to the high temperatures that occur from a wildfire whether due to direct flames from the wildland fire or proximate trees, or from hot gases and flames due to ember ignition of vegetative debris in the gutters. Additionally, a fire in a combustible gutter can also result in the gutter and its contents falling to the ground leading to ignition of nearby combustibles (i.e., mulch, vegetation, siding, etc.) proximate to the base of the home or structure. The fallen, melted gutter can also potentially impede on egress or create additional toxic smoke from the PVC materials [15]. Plastic or vinyl gutter should be replaced with noncombustible, corrosion-resistant gutters such as galvanized steel, copper, or aluminum [7].

General Mitigation Strategies

- Clean out debris from gutters, regularly, especially during fire season.
- Install metal flashing at the roof edge to provide additional protection to the roof edge [40]. Refer to Section 1.1.6 *Roof Edge*.
- Install corrosion-resistant, noncombustible gutters such as galvanized steel, copper, or aluminum [7] to replace plastic gutters.
- Install noncombustible gutter guards or covers to minimize the amount debris that may enter.
- Inspect gutter guards regularly to assure that they have not become dislodged.
- Replace or protect combustible construction proximate to the gutters and roof edge detailing (i.e., fascia, underlayment, roof framing, and battens) [15]. See Section 1.1.6 *Roof Edge* for additional mitigations.
- Where feasible/permitted, provide scuppers or interior roof drains instead of rainwater gutters [11].

Training

NFPA - *Assessing Structure Ignition Potential from Wildfire:* https://www.nfpa.org/Training-and-Events/By-topic/Home-Ignition-Zone

Gaps in Knowledge

- Observations in real fire incidents suggest that metal drip edges aid in limiting ignition of the structure at the roof edge in a wildfire, particularly when vegetative debris catches fire in the gutter. Further testing is still needed.
- There are no fire test standards to evaluate the performance of gutter assemblies (i.e., gutters, fascia, roof edge details, gutter covers, and attachment details) when exposed to wildfire conditions.
- Little to no fire testing has been conducted to obtain the rate of fire spread from the gutter to the structure.
- Little to no fire testing has been conducted to find if plastic or vinyl gutters will propagate from embers if there is no combustible debris in the gutter. (Note: IBHS and NIST research on vinyl fencing indicates that ignition is difficult) [2].

Other References

- National Fire Protection Association (NFPA)
  - Firewise Construction 2012 - https://static.colostate.edu/client-files/csfs/pdfs/firewise-construction2012.pdf
- Fire Safe Marin
  - Gutters - https://firesafemarin.org/harden-your-home/fire-resistant-gutters/
- Ready For Wildfire
  - Gutters - https://www.readyforwildfire.org/cf-action/home-hardening-gutter/
- University of California, Agriculture and Natural Resources (UCANR)
  - Wildfire Preparedness, Prepare Your Home, Gutters - https://ucanr.edu/sites/fire/Preparedness/Building/Gutters/

- Federal Emergency Management Agency (FEMA)
  - Mitigation Assessment Team Report: Marshall Fire Building Performance, Observations, Recommendations, and Technical Guidance (FEMA P-2320) - https://www.fema.gov/sites/default/files/documents/fema_p2320-marshall-fire-mAT-report-without-appendices.pdf
  - Decreasing Risk of Structure-to-Structure Fire Spread in a Wildfire (Marshall Fire MAT) - https://www.fema.gov/sites/default/files/documents/fema_marshall-fire-mat-decreasing-structure-fire-spread.pdf
  - Homeowner’s Guide to Reducing Risk of Structure Ignition from Wildfire - https://www.fema.gov/sites/default/files/documents/fema_marshall-fire-mat-homeowners-guide-reducing-risk-structure-ignition.pdf

Figure 1.33. Debris in gutters (as pictured) can ignite and lead to ignition of the sheathing and fascia board. Image courtesy of Jensen Hughes/FEMA.

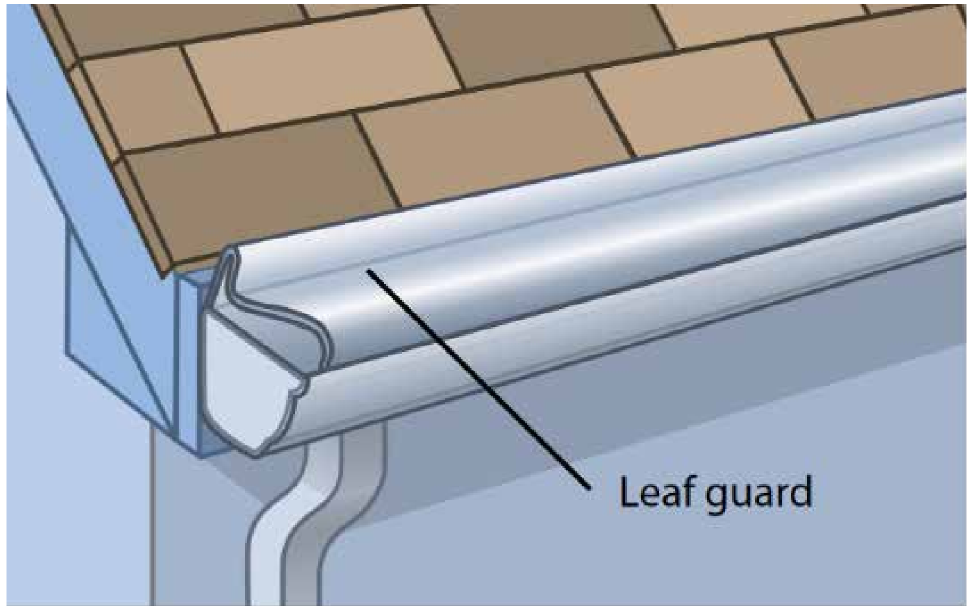


Figure 1.34. Gutter covers allow rainwater into the gutter but keep combustible debris out. Image adapted from Home Builder's Guide to Construction in Wildfire Zones, FEMA, 2008. https://www.fema.gov/

Figure 1.35. Debris accumulation on top of gutter guard. Notice that the guard is preventing debris from entering the gutter, but still leads to accumulation. This is evidence that roof edge protection is still necessary.

Figure 1.36. Heavy debris loading in gutter and on roof. This is caused by the overhanging vegetation. Where possible, overhanging vegetation should be removed to lower the severity of debris accumulation. Image courtesy of Jensen Hughes/FEMA.

ROOF TO EXTERIOR WALL

STRUCTURAL HARDENING

1.2.1 ROOF EAVE & SOFFIT CONSTRUCTION

Main Concern(s)

Roof eaves and associated soffits comprise the overhanging part of the lower edge of the roof that extends beyond the exterior walls of a building. These combined building features provide shading, water protection, and architectural style, but are also an area of the building that is highly susceptible to ignition from heat buildup in the under-eave area and ember intrusion through vents during a wildfire. Below is a list of the major concerns for eaves in a wildfire:

- Windborne embers, convective heat, and radiant heat can be trapped under roof eaves and associated upper portion of exterior walls, creating localized severe fire conditions [6]. These aspects of fire exposure can be further exacerbated where buildings have wider overhangs or are located on sloping terrain [22].

- Depending on how the under-eave area is constructed (e.g., “soffitted”, “open-eave”) and of what materials (e.g., combustible or noncombustible), the impact of direct flame, hot gases, radiation, ember accumulation, as well as ember intrusion at vent openings, gaps, and other joints will vary.
  - Where roof eaves, overhangs, and soffits are of combustible materials (as is oftentimes the case with residential buildings), the likelihood of ignition is increased, particularly with an open eave design [42].
  - Open-eaves typically have exposed roof framing, as well as more gaps/joints as part of the construction, presenting more opportunities for ember accumulation or intrusion through vents and flame and hot gas accumulation.
  - Metal soffit panels conduct heat and can distort, allowing the passage of embers and hot gases. Untreated wood soffit panels can ignite, and vinyl panels can melt or deform and fall away [42].
  - Soffits will often have inlet vents as part of the attic ventilation system. Unscreened soffits vents can allow embers and hot gases to enter the attic, potentially leading to ignition of the combustible materials in the attic [6]. Refer to Section 1.2.2 *Soffit or Under-Eave Vents* for more details.

- Once an eave, overhang, or soffit has ignited, fire can readily spread laterally, providing greater potential for fire spread into the attic [6].

- Fires in these areas are also often difficult to identify and extinguish [15].

Key Terminology

- **Boxed-in eave:** Design where roof eave soffit is boxed-in with a horizontal underside or sloping rafter tails. The underside of the rafter tails are finished with an exterior covering.

- **Fascia or gutter boards:** Horizontal roof trim located along the perimeter of a building, usually below the roof level, to cover the rafter tails at the eaves and to seal off the top of the siding along the rake [41].

- **Open eave:** Design where exposed roof rafters extend beyond the exterior wall, creating an unenclosed space on the underside of the roof deck. Blocking is used to fill the space between the top of the exterior wall and the roof sheathing [43].

- **Soffit:** Encloses the underside of roof overhangs.

Fire Classification and Ratings

Fire test standards that detail tests to evaluate resistance of fire penetration and direct flame impingement of eaves, overhangs, and other projections, as well as tests to evaluate ember/flame resistance of vents, exist and are listed below. Soffits may be included in assemblies that receive fire resistance ratings, but the soffit itself does not.

Fire Test Standards

- *ASTM E2957 Standard Test Method for Resistance to Wildfire Penetration of Eaves, Soffits, and Other Projections:* https://www.astm.org/e2957-17.html
- *SFM Standard 12-7A-3 Materials and Construction Methods for Exterior Wildfire Exposure: Horizontal Projection Underside:* https://www.hcd.ca.gov/building-standards/state-housing-law/wildland-urban-interface/docs/2010-part-2-cbc-ch7a.pdf
- *ASTM E2886 Standard Test Method for Evaluating the Ability of Exterior Vents to Resist the Entry of Embers and Direct Flame Impingement:* https://www.astm.org/e2886_e2886m-20.html

Referenced Codes and Standards

- *2024 International Wildland-Urban Interface (IWUI) Code:*
  - Sections 504.3, 505.3 Protection of Eaves
  - Sections 504.10.1, 505.10.1 Vent Locations
- *2024 International Building Code (IBC):* Section 705: Exterior Walls
- *2022 California Building Code (CBC):*
  - 707A.5 Open Roof Eaves
  - 707A.6 Enclosed Roof Eaves and Roof Eave Soffits
- *2022 NFPA 1140 Standard for Wildland Fire Protection:* 25.3 Roof Design and Materials

Other Codes and Standards

Additional local requirements, policies, and programs will vary depending on location and adoption in individual jurisdictions.

- Check local, county, and state amendments for additional wildfire codes and standards.
- Check local general plan, multi-hazard mitigation plan, zoning.
- International Residential Code (if applicable - check for wildfire amendments).

Table 13. Design, vulnerability, and construction considerations for eaves, overhangs, and soffits.

Common Types of Eaves, Overhangs, and Soffits	Design, Vulnerability, and Construction Considerations
Open Eave Construction	Open-eaves have exposed roof framing along with numerous joints at the head-of-wall and blocking-to-rafter interface. These features create additional locations where hot gases, heat, and embers can accumulate in a wildfire, leading to ignition of the exposed under-eave components, particularly where construction materials are combustible or non-fire resistant. In addition, the higher number of joints and gaps at the interface of each component introduces an increased number of pathways for embers, flames, and/or hot gases to enter the roof, attic, or interstitial spaces of the building leading to concealed fires. In addition, structures with open eaves typically have inlet vents near the head-of-wall or in the blocking of the under-eave space. This introduces additional pathways for embers to enter the building attic space. Refer to Table 14 discussing eave/soffit construction materials. Refer to Sections 1.2.2 *Soffit* or *Under-eave Vents* and 1.2.3 *Joints* for additional details.
Boxed-in, Enclosed, or Soffited Eaves	Soffited or enclosed eaves create a continuous plane at the underside of the roof edge overhang. This construction feature reduces the number of pockets where hot gases, flames or embers can accumulate during a fire. Additionally, enclosed eaves also create fewer joints or pathways for embers, flames, and/or hot gases to enter the roof, attic, or interstitial spaces. Refer to Table 14 discussing eave/soffit construction materials. Refer to Sections 1.2.2 *Soffit* or *Under-eave Vents* and 1.2.3 *Joints* for additional details.

Table 14. Design, vulnerability, and construction considerations for eave, overhang, and soffit materials.

Common Types of Eave, Overhang, and Soffit Materials	Design, Vulnerability, and Construction Considerations
Noncombustible Roof Eave or Soffit	Roof eaves or soffits can be constructed of a range of noncombustible materials including fiber-cement panels, metal panels, stucco, and vinyl panels. Several of these materials are susceptible to damage from wildfires, including metal panels and vinyl panels. Metal panels may distort, and vinyl panels can melt and fall away. This could potentially allow passage of embers and hot gases. Note: With a long enough exposure, all potential soffit materials can be vulnerable. Refer to Sections 1.2.2 *Soffit* or *Under-eave Vents* and 1.2.3 *Joints* for additional details.

Combustible Roof Eave or Soffit	Roof eaves and soffits can be constructed of a range of combustible materials including wood sheathing. As windborne embers, convective heat, and radiant heat can be trapped under overhangs, eaves, and soffits due to unique fire induced flows during wildfire incidents, untreated wood panels or other exposed combustible surfaces for eaves and soffits can be highly vulnerable to ignition. Where timber is desired, it should be comprised of fire-retardant treated wood. All combustible fuel loads (e.g., combustible furniture, unattended vegetation, non-fire adapted plants, BBQs, etc.) below the soffit should be removed to minimize any fire hazards directly below. In addition, flame can easily travel up combustible wall siding and into the joints or vents located in the roof eave/soffit area, if not well protected. Refer to Sections 1.2.2 *Soffit* or *Under-eave Vents* and 1.2.3 *Joints* for additional details.

General Mitigation Strategies

- Enclose open overhangs with soffits that have a minimum one-hour fire-resistance rating, ignition-resistant material, or fire-retardant materials rated for exterior use to minimize the chance of embers and hot gases contacting the joists, rafters or trusses, or the underside of the roof decking [42].
- Where possible, replace open eaves with soffited eaves.
- Use flat, horizontal soffits instead of attaching the soffits to the sloped joists, which creates sloped soffits. A flat soffit reduces the potential for entrapment of embers and hot gases [6]. However, either flat or slopped soffits are better than open eaves.
- Evaluate the fire-resistance of existing soffits and replace soffits that are not fire-resistant according to the guidance provided in FEMA Technical Fact Sheet No.8 located within The Home Builder's Guide to Construction in Wildfire Zones [6].
- In very high Fire Severity Zones, install exterior 5/8" fire-resistant gypsum board between the existing and new soffit materials for enhanced fire resistance [6].
- For fascia materials, use noncombustible or fire-resistant materials (e.g., fire-retardant-treated lumber, fiber-cement board, etc.) [6].
- If the fascia is combustible, cover the fascia board with a noncombustible or fire-resistant material like fire-retardant-treated lumber, fiber-cement board, etc [6]. Note that unless steps are taken to minimize chances of fire reaching the under-eave area, heat trapping and ignition with lateral flame spread will happen, with noncombustible fascia or not.
- Fill joints and gaps with fire rated caulking and other appropriate firestopping materials.
- Do not store firewood, construction materials, or other combustible materials under any overhang.
- Regularly inspect and clear accumulated debris from eaves and overhangs. Identify and repair any vulnerable areas.
- Avoid planting combustible vegetation under eaves and overhangs. That is, create and maintain a near-home noncombustible zone. This should be maintained regardless of the combustibility of the soffit materials used. Refer to Zone 0 in Part II of this Handbook.

Training Programs

NFPA - *Assessing Structure Ignition Potential from Wildfire:* https://www.nfpa.org/Training-and-Events/By-topic/Home-Ignition-Zone

Gaps in Knowledge

- Fire testing does not account for weathering of materials prior to fire exposure or the impact of general wildfire environmental conditions (e.g., high winds, flying debris, impact from objects).
- "Ignition-resistant" eaves and soffits that have been tested against criteria from SFM Standard 12-7A-3 may be difficult to verify in-field. While a database of listed products based on this standard is maintained by the California Office of the State Fire Marshal, training is required to be able to identify these products in-field.

- Incorrect language is often used when referencing fire-resistance of soffits. The soffit itself does not receive a rating. It must be part of an approved assembly. Note that building codes do allow for compliance via ignition-resistant or noncombustible materials. However, these would not be considered to have a rating.

Other References

- National Fire Protection Association (NFPA)
  - Wildfire Research Fact Sheet-Under Eave Construction - https://www.nfpa.org/-/media/Files/Firewise/Fact-sheets/FirewiseFactSheetsUnderEaves.ashx
  - Reducing Wildfire Risks in the Home Ignition Zone - https://www.nfpa.org/-/media/Files/Training/certification/CWMS/ReducingWildfireRisksHIZ.ashx
- Colorado State Forest Service
  - FireWise Construction Site Design and Building Materials 2012 - https://static.colostate.edu/client-files/csfs/pdfs/firewise-construction2012.pdf
- Insurance Institute for Business & Home Safety (IBHS)
  - Wildfire Home Assessment and Checklist - https://www.iafc.org/docs/default-source/pdf/wildfire-checklist_ibhse1e8b15c78366c709642ff00005f0421.pdf?sfvrsn=5bdedd0d_0
- University of California, Agriculture and Natural Resources (UCANR)
  - Wildfire Preparedness, Prepare Your Home, Eaves - https://ucanr.edu/sites/fire/Preparedness/Building/eaves/
- Federal Emergency Management Agency (FEMA)
  - Home Builder's Guide to Construction in Wildfire Zones, Technical Fact Sheets No. 8 and No. 6 - https://www.govinfo.gov/content/pkg/GOVPUB-HS5-PURL-gpo60104/pdf/GOVPUB-HS5-PURL-gpo60104.pdf
  - Mitigation Assessment Team Report: Marshall Fire Building Performance, Observations, Recommendations, and Technical Guidance (FEMA P-2320) - https://www.fema.gov/sites/default/files/documents/fema_p2320-marshall-fire-mAT-report-without-appendices.pdf
  - Decreasing Risk of Structure-to-Structure Fire Spread in a Wildfire (Marshall Fire MAT) - https://www.fema.gov/sites/default/files/documents/fema_marshall-fire-mat-decreasing-structure-fire-spread.pdf
  - Homeowner's Guide to Reducing Risk of Structure Ignition from Wildfire - https://www.fema.gov/sites/default/files/documents/fema_marshall-fire-mat-homeowners-guide-reducing-risk-structure-ignition.pdf

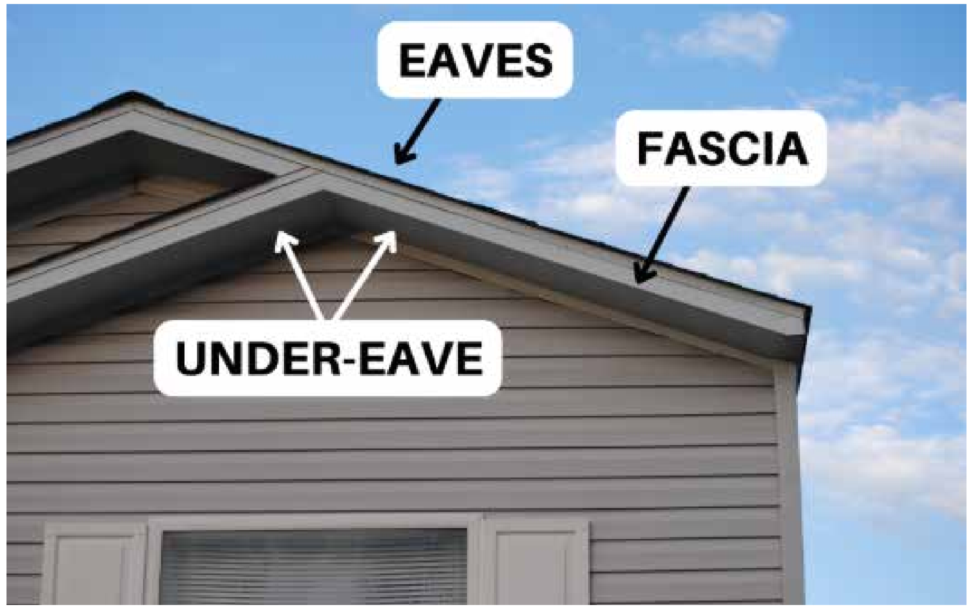


Figure 1.37. Structure showing the location of the roof eaves fascia, and under-eave areas. Under-eave areas can be soffited or open. Image courtesy of Jensen Hughes/FEMA

Figure 1.39. Example of open-eave construction, where the roof rafter rails are exposed and of combustible construction. Gaps between the blocking and rafter rails provide a pathway for ember entry. Image adapated from Home Builder's Guide to Construction in Wildfire Zones, FEMA, 2008. https://www.fema.gov/

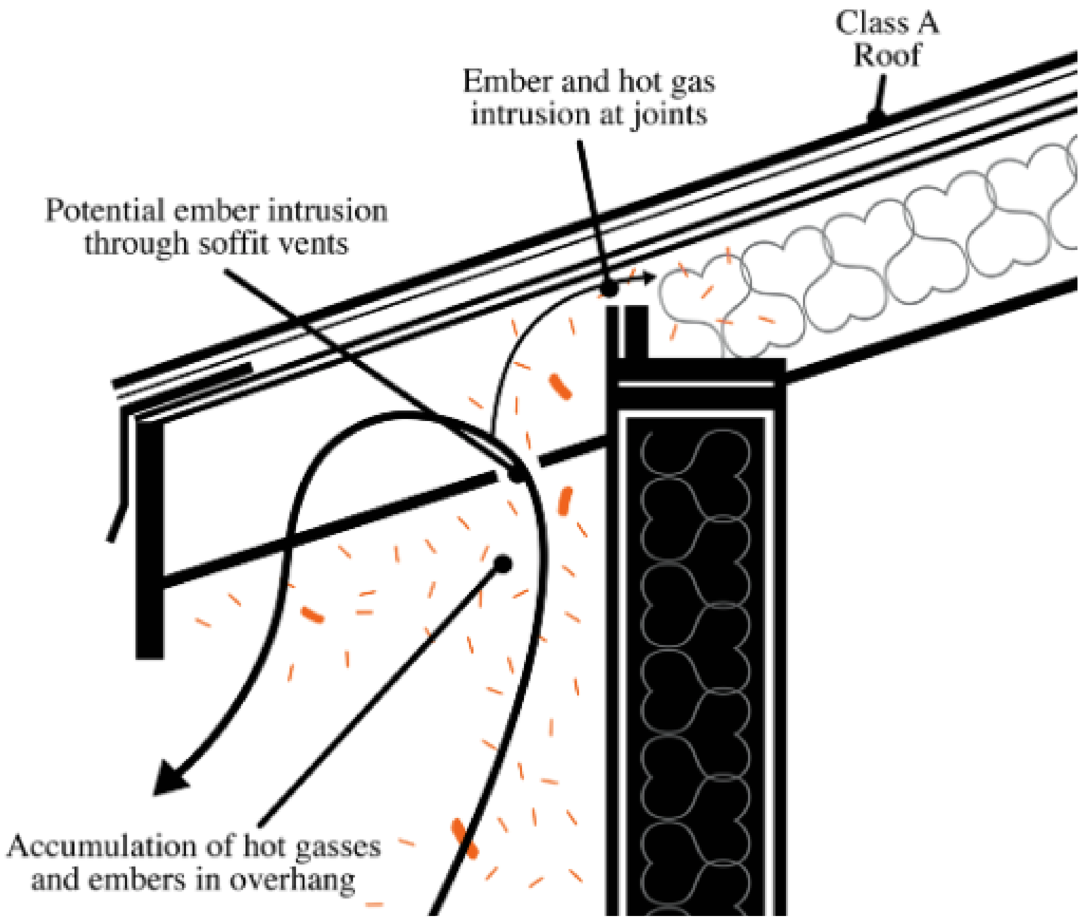


Figure 1.38. Examples of how embers can penetrate the structure's exterior via an unprotected soffit.

Figure 1.40. Example of a boxed-in or closed-eave. Image courtesy of Jensen Hughes/FEMA.

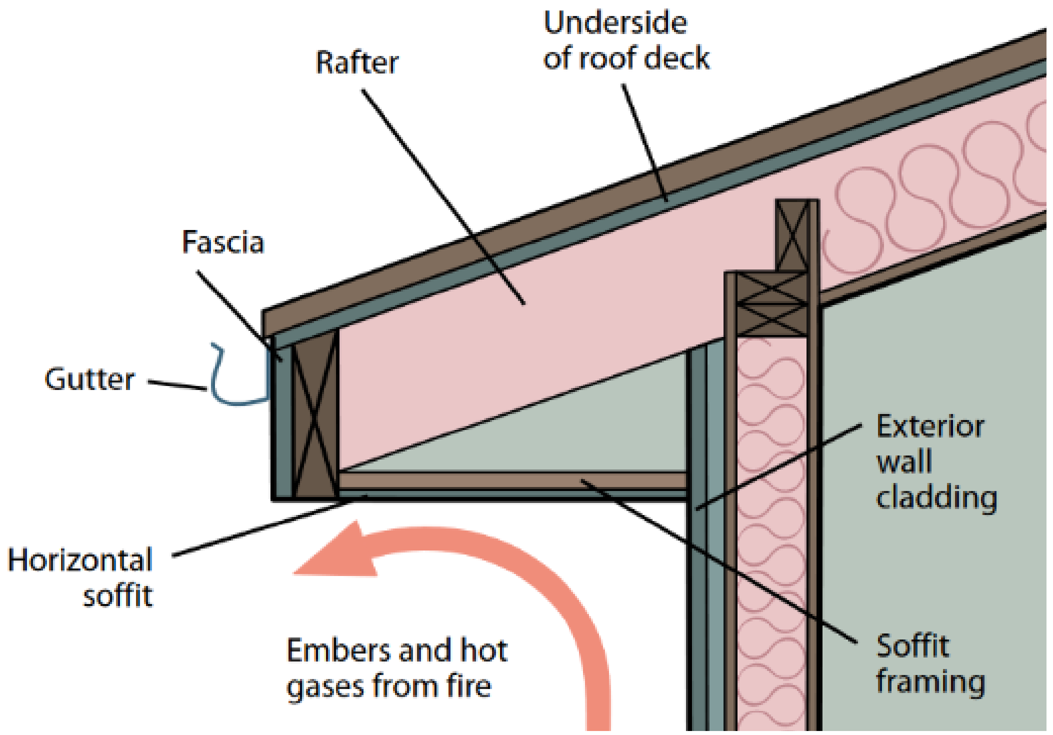


Figure 1.41. Example of an enclosed overhang with a horizontal soffit. Image adapted from Home Builder's Guide to Construction in Wildfire Zones, FEMA, 2008. https://www.fema.gov/

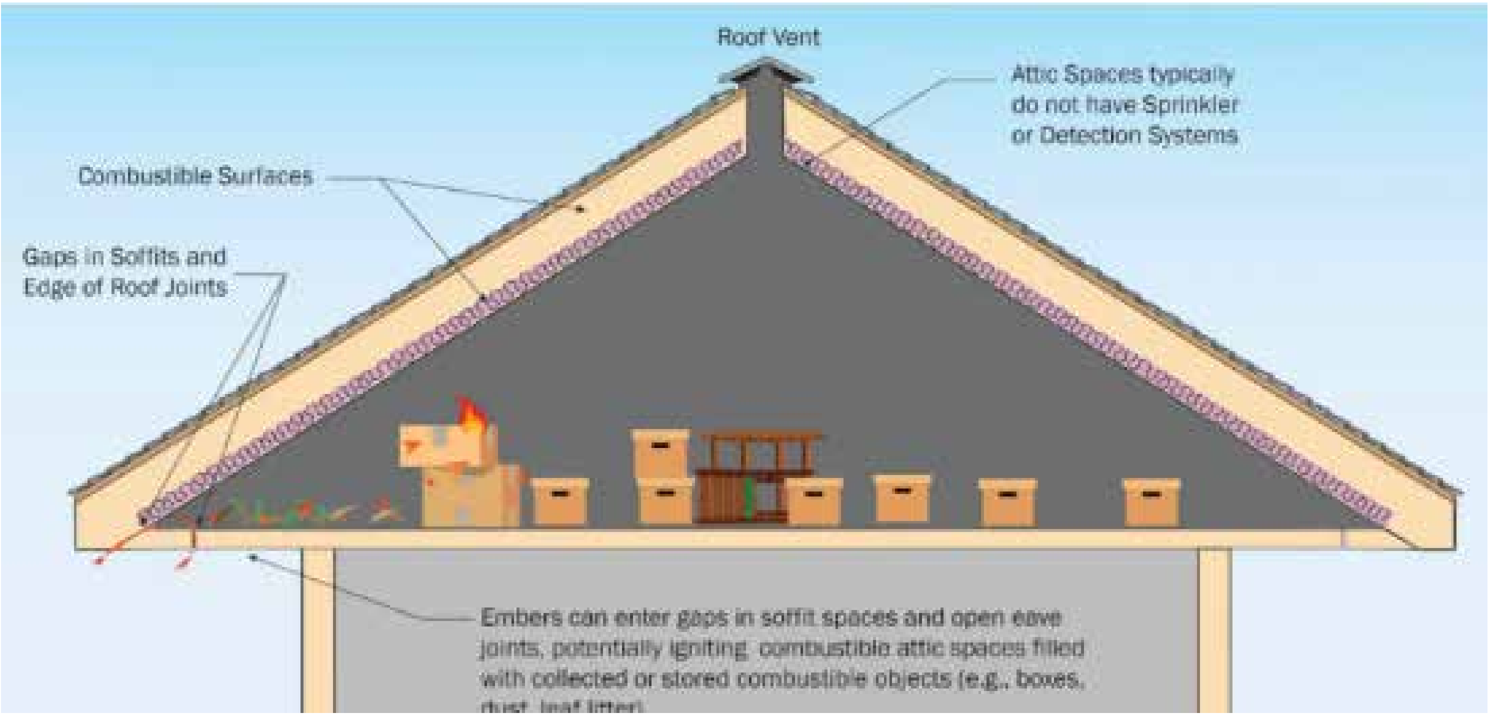


Figure 1.42. This illustration shows where gaps in open eaves, soffit spaces and edge of roof construction can lead to ember penetration. This can also cause potential ignition of various combustible surfaces, collected materials or storage goods common in attic spaces.Image adapted from FEMA Marshall Fire MAT, Wildfire Resilient Detailing, Joint Systems, and Interfaces of Residential Building Components, FEMA, 2023. https://www.fema.gov/

1.2.2 SOFFIT OR UNDER-EAVE VENTS

Main Concern(s)

Windborne embers, convective heat, and radiant heat can be trapped under overhangs, eaves, and soffits due to unique fire induced flows during wildfire incidents. Eaves, overhangs, and soffits typically have vents as part of the attic ventilation system. If soffit vents are unprotected, embers and hot gases can readily enter the attic or other parts of the structure leading to ignition of interior building contents. Oftentimes, fires that initiate via embers into attics or other concealed spaces can go undetected for long periods of time.

Key Terminology

- **Soffit Vent:** A continuous or intermittent vent installed along a soffit as part of the attic ventilation system of a building [6].
- **Eaves:** Eaves are located at the down-slope edge of a sloped roof and serve as the transition between the roof and fascia/wall [6].
- **Overhangs:** Overhangs are extensions of the roof beyond the exterior wall (i.e., the joists, rafters, or trusses, and the decking they support cantilever past the wall) [6].

Fire Rated Assemblies

The ember and direct flame impingement resistance of under eave area vents are defined by *ASTM E2886 Standard Test Method for Evaluating the Ability of Exterior Vents to Resist the Entry of Embers and Direct Flame Impingement*. This test standard prescribes two individual methods to evaluate the ability of the vent to resist: (1) the entry of embers and (2) flame intrusion. Full-scale tests at IBHS demonstrated that *ASTM E2886*-compliant vents limit the entry of large embers, and that the embers collected behind these vents (e.g., on the attic side) were small and incapable of igniting combustibles [22]. ***Note:*** *ASTM E2886* does not provide explicit quantitative acceptance criteria for ember intrusion or flame intrusion. However, ember intrusion is evaluated based on observation of occurrence of combustion of a cotton pad on the unexposed side of the vent given a 3-min exposure to tumbled Class C brands. Performance criteria for the 10-min flame intrusion test as well as integrity test are specified in *ASTM E2912*. Visual observations are made for the presence and duration of any flame penetration through the vent. Acceptance criteria are typically not provided in ASTM standards, including this one [16]. Acceptance criteria are specified in the *California Building Code (CBC)* Section 706A.2, and *NFPA 1140* Section 25.3.3.

Table 15. Vent fire tests for soffit and under-eave vents.

Vent Fire Test	Technical Description
Ember Penetration Test	This test method provides for a direct ember exposure to vents. The fire test apparatus allows for embers to fall vertically and impinge on the vent mounted-horizontally on ledges within the test chamber. An induction fan located at the bottom of the apparatus pulls the air stream through the vent, allowing any embers that pass through the vent to impinge on a combustible target material of cotton. Ember intrusion is evaluated based on observation of occurrence of combustion of a cotton pad on the unexposed side of the vent, given a 3-min exposure to tumbled Class C brands. Performance criteria for the 10-min flame intrusion test, as well as integrity test are specified in *ASTM E2912*. Visual observations are made for the presence and duration of any flame penetration through the vent. *[CBC and NFPA 1144 acceptance criteria - No flaming ignition of the cotton material on the unexposed side of the vent.]*
Direct Flame Impingement Test and Integrity Test *(ASTM E2886)*	This test method evaluates the impact of direct flame impingement on vertically or horizontally mounted vents in a test assembly as described in *ASTM E2886*. Note that *ASTM E2886* references *ASTM E2912* as the test procedure to be used for the direct flame impingement test (or flame intrusion test) and integrity test. The flame source is directed into the test assembly and directly impinges the vent that is mounted in either a vertical or horizontal position for a 10-min period. Visual observations are made for the presence and duration of any flame penetration through the vent flame. Note: The integrity test is also specified in *ASTM E2912* for thermal transmission concerns. *[CBC and NFPA 1144 acceptance criteria - No flaming ignition and maximum temperature of the unexposed side of the vent shall not exceed 662°F or 350°C.]*
Non-Mechanical Fire Dampers Used in Vented Construction	This fire-test-response standard assesses the ability of non-mechanical fire dampers used in vented construction in its open state to limit passage of hot gases, radiation, and flames during a prescribed fire test exposure. The fire exposure condition in this test method is sudden direct flame impingement, which produces these hot gases, radiation, and flames [16]. This test method does not circumvent or eliminate the fire-resistance rating requirements for construction [16].

Note: Vents tested per *ASTM E108* to achieve a Class A rating have only been tested for whether they contribute to flame spread, failure/detachment from the roof or production of embers. *ASTM E108* does not access if a vent can resist the penetration of embers or direct flames from wildfires.

Fire Test Standards

- *ASTM E2886/E2886M-14 Standard Test Method for Evaluating the Ability of Exterior Vents to Resist the Entry of Embers and Direct Flame Impingement:* https://www.astm.org/e2886_e2886m-20.html
- *ASTM E2912 Standard Test Method for Fire Test of Non-Mechanical Fire Dampers Used in Vented Construction:* https://www.astm.org/e2912-17.html

Referenced Codes and Standards

- *2024 International Wildland-Urban Interface (IWUI) Code:* Section 504.10, 505.10 Vents
- *2022 California Building Code (CBC):* 706A Vents
- *2022 NFPA 1140 Standard for Wildland Fire Protection:*
  - Section 25.7.4 Exterior Openings
  - 25.3.3 for Vents

Other Codes and Standards

Additional local requirements, policies, and programs will vary depending on location and adoption in individual jurisdictions.

- Check local, county, and state amendments for additional wildfire codes and standards.
- Check local general plan, multi-hazard mitigation plan, zoning.
- International Residential Code (if applicable - check for wildfire amendments).

Typical Design, Vulnerability, and Mitigation Considerations

Table 16. Design, vulnerability, and mitigation considerations for soffit vents.

Soffit Vent Type	Design, Vulnerability, and Mitigation Considerations
Continuous	Continuous soffit vents have recently become popular because they allow the most amount of fresh air to enter the attic space. These devices come in a variety of shapes and sizes. However, the most common is generally long and narrow. Soffit vents typically have a screen attached to them to prevent rodents from working their way into your attic. These screens may not be small enough to limit the passage of embers. The noncombustible mesh should be no more than 1/8”, preferably 1/16”. Research has shown that 1/8” mesh screening can still lead to embers with sufficient energy to ignite fine fuels in the attics. With finer mesh screening additional vents may be needed to comply with building code ventilation requirements.
Individual	Individual soffit vents are the most widely used soffit vent type and are useful for problematic areas of a house (e.g., bedrooms, kitchens, and partitioned attics). Soffit vents typically have a screen attached to them to prevent rodents from working their way into your attic. 1/4” mesh screens allow for the passage of embers with sufficient energy to ignite fine fuels located in the attic. The noncombustible mesh should be no more than 1/8”, preferably 1/16”. Research has shown that 1/8” mesh screening can still lead to embers with sufficient energy to ignite fine fuels in the attics. With finer mesh screening additional, vents may be needed to comply with building code ventilation requirements. Use of finer mesh screens will require additional maintenance to remove wind-blown debris that will accumulate on the screen face.

General Mitigation Strategies

- Cover existing vents with wire mesh screen having openings with a maximum of 1/8”, preferably 1/16”. Research has shown that 1/8” mesh screening can still lead to embers with sufficient energy to ignite fine fuels in the attics.
- Install ember resistant vents manufactured with wire mesh screening with a maximum of 1/8”, preferably 1/16”. Research has shown that 1/8” mesh screening can still lead to embers with sufficient energy to ignite fine fuels in the attics.
- Common 1/4” screens are ineffective and should be replaced.
- Replace screens that have been painted over or detached from the substrate.
- Do not use fiberglass or plastic mesh because they can melt and/or burn.
- Use fire-rated caulking around penetrations to seal openings.
- Protect vents in eaves or cornices with baffles to block embers, backed by 1/16” wire mesh (mesh alone is not enough) [24].
- If possible, move soffit vents away from the exterior wall.

Training

NFPA - A*ssessing Structure Ignition Potential from Wildfire:* https://www.nfpa.org/Training-and-Events/By-topic/Home-Ignition-Zone

Gaps in Knowledge

- Fire testing does not account for weathering of materials prior to fire exposure or the impact of general wildfire environmental conditions (e.g., high winds, flying debris, impact from objects).
- *ASTM E2886* does not evaluate the ability of vents to completely exclude entry of flames or embers, nor does it test for transmission of smoke or hot gases. This may be considered reasonable considering the functional use of the vent. That said, current test standards are likely inadequate in how a vent should be evaluated to both satisfy ventilation requirements and limit negative effects of fire, smoke and embers from leading to structure ignition.
- *ASTM E2886* nor the building code provides acceptable performance criteria for ember intrusion, flame, or smoke resistance for vent openings.
- In most instances, it is challenging to verify, in-the-field, if an off-ridge vent has been fire-tested. (Professional judgement and discussion with the homeowner are required.) Training may be required to be able to identify fire-tested foundation vents and under-eave vents.
- Air flow calculations may need to be reconsidered or redesigned where fire rated vents are installed in existing structures, to ensure code required airflow is satisfied.

Other References

- Insurance Institute for Business & Home Safety (IBHS)
  - Ember Testing - https://ibhs.org/wildfire/building-vulnerability-to-ember-exposure/
  - Ember Testing - https://ibhs.org/wp-content/uploads/wpmembers/files/Vulnerability-of-Vents-to-Wind-Blown-Embers_IBHS.pdf
  - Ember Testing - https://www.facebook.com/watch/?v=389602881106017
  - Preparedness - https://disastersafety.org/wp-content/uploads/2021/08/WFR-Home-Preparedness-Guide.pdf

- National Fire Protection Association (NFPA) Firewise
  - https://www.nfpa.org/-/media/Files/Firewise/Fact-sheets/FirewiseFactSheetsAtticsCrawlSpaces.ashx
  - https://disastersafety.org/wp-content/uploads/2021/08/WFR-Home-Preparedness-Guide.pdf
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  - Wildfire Preparedness, Prepare Your Home, Vents - https://ucanr.edu/sites/fire/Prepare/Building/Vents/
- Federal Emergency Management Agency (FEMA)
  - Home Builders Guide to Construction in Wildfire Zones - https://www.govinfo.gov/content/pkg/GOVPUB-HS5-PURL-gpo60104/pdf/GOVPUB-HS5-PURL-gpo60104.pdf
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  - Decreasing Risk of Structure-to-Structure Fire Spread in a Wildfire (Marshall Fire MAT) - https://www.fema.gov/sites/default/files/documents/fema_marshall-fire-mat-decreasing-structure-fire-spread.pdf
  - Homeowner’s Guide to Reducing Risk of Structure Ignition from Wildfire - https://www.fema.gov/sites/default/files/documents/fema_marshall-fire-mat-homeowners-guide-reducing-risk-structure-ignition.pdf

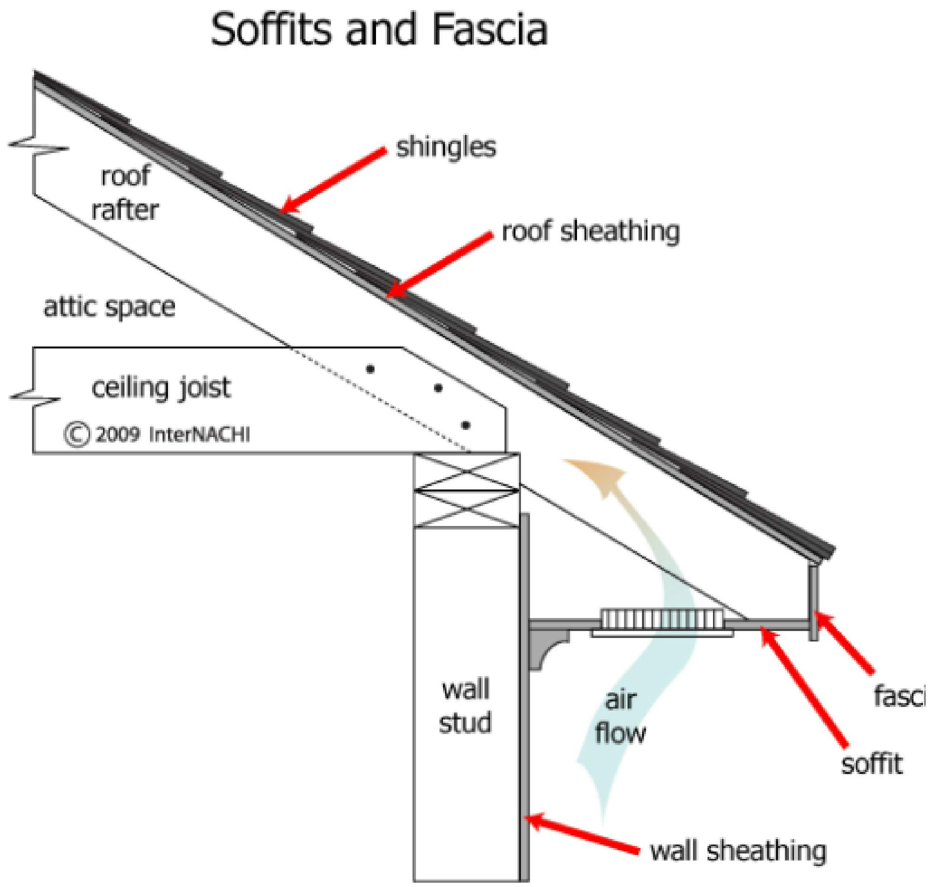


Figure 1.43. Cross-sectional diagram of a soffitted eave with soffit vent illustrating the potential air flow path where embers can enter a roof attic space or other interstitial space. Image courtesy of InterNACHI.

Figure 1.44b. Example of individual type soffit vents. Image courtesy of Jensen Hughes/FEMA.

Figure 1.44a. Example of frieze block soffit vents with 1/4” metal mesh cover. Image courtesy of Jensen Hughes/FEMA.

Figure 1.45. Example of a continuous soffit vent. Image courtesy of Jensen Hughes/FEMA.

1.2.3 JOINTS (HEAD-OF-WALL TO ROOF AND BOTTOM-OF-WALL TO ROOF)

Main Concern(s)

In general, joints and other penetrations create gaps in the continuity of a fire rated or fire resistive roof or wall assembly, providing a potential avenue for embers, hot gases, or flame to breach the exterior envelope of a building. Due to unique fire induced flows at the underside of eaves that can lead to an accumulation of hot gas and embers, head-of-wall to roof joints are particularly vulnerable to ember intrusion and exposure to hot gases. Embers can oftentimes accumulate at head-of-wall to roof joints, creating a concentrated source of heat. For bottom-of-wall to roof joints that may occur in more complex roofs (i.e., high number of vertical-to-horizontal transitions), the concern with hot gases accumulating near the joint are reduced. However, bottom-of-wall to roof joints are more susceptible to direct flaming and ember accumulation from the ignition of debris that typically collected in these locations. In addition, head/bottom-of-wall-to-roof joints are also locations where there can be different fire classification/rating levels and construction materials (which can result in one system being compromised by the other). Lastly, there is currently no fire test for any types of roof joints (including head-of-wall or bottom-of-wall joints to roof) to wildfire exposure - embers, direct flaming, or hot gases. Unprotected joints can undermine fire-resistant or ignition-resistant wall assembly.

Key Terminology

- **Joint:** The opening in or between adjacent assemblies that is created due to building tolerances or is designed to allow independent movement of the building in any plane caused by thermal, seismic, wind or any other loading [35].
- **Fire-Resistant Joint System:** An assemblage of specific materials or products that are designed, tested and fire-resistance rated in accordance with a standard fire test to resist for a prescribed period of time the passage of fire through joints made in or between fire-resistance rated assemblies [35]. (Note: There are currently no fire-resistant joint system tests for wildfire exposures.)
- **Head-of-Wall:** A head-of-wall joint is the linear gap between the top of a wall assembly and bottom of a floor or roof assembly [44].
- **Bottom-of-Wall:** A bottom-of-wall joint is the linear gap between the bottom of a wall assembly and top of a roof or floor assembly.
- **Flashing:** A thin piece of metal that is installed at joints to protect against intrusion of unwanted elements such as water, and to protect combustible surfaces from ignition by embers that accumulate at wall intersections.

Fire Classification and Ratings

Currently, there is no fire test standard to evaluate ember intrusion, ember accumulation, direct flaming impingement, or thermal transmission of heat via convection or radiation from wildfires for joint systems (head-of-wall or bottom-of-wall-to roof joint system). Fire rated joints are necessary to maintain a roof or wall system's fire rating, integrity, and/or continuity to wildfire exposure. While a variety of fire tests exist for joint systems in interior building fire exposures (e.g., *ASTM E1966* or *UL 2079*), none are applicable to the fire conditions presented by wildfires. A range of joint systems (e.g., static joints, movement joints) and joint conditions (e.g., header or top-of-wall, footer, or bottom-of-wall details) for exterior wildfire exposures are still needed.

Fire Test Standards

Currently, there is no fire test standard to evaluate ember intrusion, direct flame impingement, or thermal transmission of heat via convection or radiation from wildfires for joint systems.

Referenced Codes and Standards

- *2024 International Wildland-Urban Interface (IWUI) Code:* No explicit requirements
- *2022 California Building Code (CBC):* No explicit requirements
- *NFPA 1140 Standard for Wildland Fire Protection:* No explicit requirements

Other Codes and Standards

Additional local requirements, policies, and programs will vary depending on location and adoption in individual jurisdictions.

- Check local, county, and state amendments for additional wildfire codes and standards.
- Check local general plan, multi-hazard mitigation plan, zoning.
- International Residential Code (if applicable - check for wildfire amendments).

Typical Design, Vulnerability, and Mitigation Considerations

Table 17. Design, vulnerability, and mitigation considerations for head/bottom-of-wall-to-roof joints.

Joint Types at Head/ Bottom-of-Wall-to-Roof	**Design, Vulnerability, and Mitigation Considerations**
General: Roof-to-Wall Joint	The more intersections and shapes included in the roof design, the more opportunity there will be for leaf, needle, and other vegetative debris to accumulate. Flame exposure to siding at roof-to-wall intersections can occur if vegetative debris is ignited by embers. If the siding is installed close to the roof, the siding could be ignited directly by embers (i.e., without initial ignition of vegetative debris) [12].

General Mitigation Strategies

- Debris should be removed from around all joints created at the roof (e.g., expansion joints, vents/chimney-to-roof joints).
- Corrosion-resistant metal flashing should be installed at bottom-of-wall-to-roof joints to limit ember accumulation and ignition or direct flame infiltrating the exterior wall or under-eave area in the case of a dormer or split-level design. Where the roof or wall underlayment is combustible, refer to appropriate protection measures in the roof and wall construction/covering section for detailing. The metal flashing should be lapped above the roof covering material, extending vertically up along the exterior side of the wall siding before being “let in” behind the siding at the lap joint, with combustible siding kept 4-6” above the roof surface [38].

- Use noncombustible construction where possible, in both new construction and retrofits [38].
- Provide fire-rated caulking in any gaps at the joint between the wall and the top of roof.
- In new construction, limit the complexity of roof design [38].

Training

NFPA - *Assessing Structure Ignition Potential from Wildfire:* https://www.nfpa.org/Training-and-Events/By-topic/Home-Ignition-Zone

Gaps in Knowledge

- Currently, there are no fire testing standards to evaluate ember intrusion, direct flame impingement, or thermal transmission of heat via convection or radiation from wildfires for joint systems.
- It is unclear how susceptible various head/bottom-of-wall-to-roof joints are to wildfire exposures.

Other References

- University of California, Agriculture and Natural Resources (UCANR)
  - Home Survival in Wildfire-Prone Areas: Building Materials and Design Considerations - https://anrcatalog.ucanr.edu/pdf/8393.pdf
- Federal Emergency Management Agency (FEMA)
  - Mitigation Assessment Team Report: Marshall Fire Building Performance, Observations, Recommendations, and Technical Guidance (FEMA P-2320) - https://www.fema.gov/sites/default/files/documents/fema_p2320-marshall-fire-mAT-report-without-appendices.pdf
  - Homeowner's Guide to Reducing Risk of Structure Ignition from Wildfire - https://www.fema.gov/sites/default/files/documents/fema_marshall-fire-mat-homeowners-guide-reducing-risk-structure-ignition.pdf
  - Wildfire Resilient Detailing, Joint Systems, and Interfaces of Residential Building Components - https://www.fema.gov/sites/default/files/documents/fema_marshall-fire-mat-detailing-joints.pdf

Figure 1.46. Example of a complex roof with several wall-to-roof joint conditions, which introduces locations for the collection of vegetative debris and embers. Image courtesy of Jensen Hughes/FEMA.

Figure 1.47. Example of metal flashing at a bottom-of-wall-to-roof joint.

Figure. 1.48. Image adapted from FEMA Marshall Fire MAT, Wildfire Resilient Detailing, Joint Systems, and Interfaces of Residential Building Components, FEMA, 2023. https://www.fema.gov/

WALL SYSTEMS

STRUCTURAL HARDENING

1.3.1 EXTERIOR WALL CONSTRUCTION & CLADDING

Main Concern(s)

Exterior wall assemblies for most residential buildings (i.e., single-family homes, duplexes, and 1-3 story townhomes) are typically not required to have any fire-resistance rating, unless separation distances are 5' or less to the property line. In addition, the exterior walls are also likely to be constructed using a combination of combustible and noncombustible cladding, and structural and insulation materials. Even in areas with adopted wildfire building codes, exterior walls will most likely only have ignition-resistant cladding such as stucco, fiber cement siding, masonry tiles, and not be a fire-resistance rated wall assembly. As such, the risk of structure ignition resulting from wildfire exposures, neighboring structures, or other proximate fuels in the landscape, particularly in a wind-driven events, are increased.

The main concerns with exterior wall assemblies are: (1) the large surface area and proximate location to a variety of fire sources (i.e., wildlands, adjacent structures, other proximate man-made fuels, and ornamental vegetation) increasing exposure to severe fire conditions (radiation, directing flame, hot gases, and embers) and (2) if the cladding and overall wall assembly is of combustible materials, not fire rated, not well maintained (i.e., gaps and unprotected joints), or is proximate to hazards, plants, trees and dead/dying debris, then it is far more vulnerable to ignition from wildfire. Additional concerns are described below:

- Exterior walls often have combustible structural elements (e.g., wood studs) and various combustible sublayers such as plywood sheathing, house wrap and insulation. If the integrity and continuity of the exterior cladding system is not well-maintained, small openings or gaps in the siding and trim can develop over time. This can provide an accumulation point for embers and entry point for hot gases or flames, both of which could result in fire penetrating the outer membrane of the cladding system, leading to ignition of combustible interior materials. A fire in combustible interstitial spaces can go unnoticed for long periods, allowing the fire to grow to uncontrollable levels before being detected.

- Any opening in exterior surfaces provides an entry point for ember intrusion including pet doors, HVAC plumbing, unsealed spigots, mail slots.

- Combustible items attached to exterior cladding will impact the integrity of the cladding, including plastic conduit for utility access to the structure, ornamental fixtures such as decorative shutters made of plastic or wood, combustible fences, or trellis elements.

- Wood shake or shingle cladding, due to its nature and method of construction, introduces numerous edges where embers can collect, potentially leading to structure ignition. In addition, combustible wall siding can lead to rapid fire spread along the surface of the entire wall, potentially reaching other vulnerable components, including windows, vents and the under-eave area.

All these concerns present challenges to limiting structure-to-structure spread, particularly for high-density housing. Several academic studies support these known vulnerabilities [22]. One such study, by Maranghides and Johnsson, reported that flames jetting out of a window ignited a mock wall assembly from 6 feet away in 80 seconds, in a test performed with no wind [45].

Key Terminology

- **Exterior cladding:** The construction material applied over others in the exterior wall assembly [46].

- **Fire-resistance rating:** The time a building element, component, or assembly maintains the ability to confine a fire, continues to perform a given structural function, or both, as determined by standard fire tests.

- **Exterior wall assemblies:** A system of wall components, including wall covering materials, that provides protection of the building structural members and occupants, including framing and sheathing materials, and conditioned interior space, from the detrimental effects of the exterior environment [47].

Fire Classification and Ratings

The fire resistance of external wall assemblies to interior and exterior fire exposures is defined by *ASTM E119* or *UL 263*. This standard test method is applicable to assemblies of masonry units and to composite assemblies (e.g., concrete, steel) of structural materials for buildings, including loadbearing and other walls and partitions, columns, girders, beams, slabs, and composite slab and beam assemblies for floors and roofs [48].

This test standard is one of the most widely adopted methods for comparing the performance of building construction materials, elements, and assemblies to a standard fire exposure. It is used to measure and describe the response of a material or assembly to heat under controlled conditions (exposure via gas burners and is largely radiative with convective component). The test method includes measurements of exposed and unexposed surface temperature, as well as the ability of an element or assembly to maintain structural stability, integrity, and insulation when exposed to a severe, standard fire exposure. The standard fire exposure simulates severe interior building fire conditions during flashover conditions. Depending on how the wall assembly performs against the performance criteria for stability, integrity, and insulation, the assembly can achieve anywhere from a 30-min to 4-hour fire resistance rating.

Note: The test standard, however, does not by itself incorporate all factors required for fire hazard or fire risk assessment of the materials or assemblies under actual fire conditions. This is due to limitations of the size of the specimens tested, size of the furnace, standard fire exposure, etc [48].

Table 18. Performance categories for wall assemblies in ASTM E119 and UL 263.

Performance Category	Technical Description
Stability	The ability of a wall assembly to sustain the applied load during the fire-resistance test, as well as a hose stream test.
Integrity	The ability of a wall assembly to limit the passage of flame or gases hot enough to ignite cotton waste, and the passage of water from a hose stream test.
Insulation	The ability of the wall assembly to limit transmission of heat to the unexposed side such that the temperature on the unexposed surface does not exceed more than 250°F (139°C) above the initial temperature.

Note: In most cases, fire-rated walls are rated as “assemblies.” This means that the entire wall assembly creates the containment, including the covering, underlayment, studs or interior structural support, interior-side underlayment, specified screw types deemed acceptable, and spaces, etc.

Fire Test Standards

- *ASTM E119 Standard Test Methods for Fire Tests of Building Construction and Materials:* https://www.astm.org/e0119-20.html
- *SFM Standard 12-7A-5 Materials and Construction Methods for Exterior Wildfire Exposure:* Ignition-Resistant Material
- *UL 263 Fire Tests of Building Construction and Materials:* https://global.ihs.com/doc_detail.cfm?document_name=UL%20263&item_s_key=00097028
- *ASTM E2707 Standard Test Method for Determining Fire Penetration of Exterior Wall Assemblies Using a Direct Flame Impingement Exposure:* https://up.codes/viewer/california/ibc-2018/chapter/new_7A/sfm-materials-and-construction-methods-for-exterior-wildfire-exposure#new_705A
- *ASTM E84 Standard Test Methods for Surface Burning Characteristics of Building Materials*
- *UL 723* Test for Surface Burning Characteristics of Building Materials
- *NFPA 268 Standard Test Method for Determining Ignitability of Exterior Wall Assemblies Using a Radiant Heat Energy Source*
- *NFPA 285 Standard Test Method for Evaluation of Fire Propagation Characteristics of Exterior Wall Assemblies Containing Combustible Components*

Referenced Codes and Standards

- *2024 International Wildland-Urban Interface (IWUI) Code:* Section 504.5, 505.5 Exterior Walls
- *2024 International Building Code (IBC):*
  - Section 705 Exterior Walls
  - Section 1402 Performance Requirements
  - Section 1405 Combustible Materials on the Exterior Side of Exterior Walls
- *2022 California Building Code (CBC):* Section 707A.3 Exterior Wall Coverings
- *2022 NFPA 1140 Standard for Wildland Fire Protection:*
  - Section 25.6 Exterior Vertical Walls
  - Section 25.7 Exterior Openings

Other Codes and Standards

Additional local requirements, policies, and programs will vary depending on location and adoption in individual jurisdictions.

- Check local, county, and state amendments for additional wildfire codes and standards.
- Check local general plan, multi-hazard mitigation plan, zoning.
- International Residential Code (if applicable - check for wildfire amendments).

Typical Design, Vulnerability, and Mitigation Considerations

Table 19. Design, vulnerability, and mitigation considerations for exterior wall assemblies.

Exterior Wall Assembly Types	Vulnerability and Mitigation Considerations
Fire-Resistance Rated	Most exterior walls in residential construction are not fire-resistance rated. That is, they do not achieve a 1-, 2-, or 3-hour fire resistance rating when tested to a standard *ASTM E119* test. However, multi-family residential structures and commercial buildings are more likely to have fire-resistance rated wall assemblies, particularly for larger and taller buildings. In general, fire-rated exterior wall assemblies in combination with noncombustible or ignition-resistant cladding should reduce the likelihood of building ignition and fire penetration into the interior of the building during a wildfire. It should be noted, however, that fire testing of exterior wall assemblies does not account for wildfire exposures or pre-weathering conditions, and therefore may not achieve the intended fire rating due to the unique aspects of wildfires compared to interior building fires (e.g., ember intrusion, exposure to the elements). In addition, current wildfire building codes and referenced standard test methods do not account for the need for continuity of fire resistance-rated walls assemblies at joints, interfaces, or other penetrations (e.g., windows, doors) to wildfire conditions. These details can oftentimes be the source of structure ignition. Refer to Section 1.2.3 *Joints* for more details. ***Note:*** Any unapproved changes or modifications to the "listed" wall assembly, that can occur over the lifetime of a building, may cause the wall to not withstand the exposure time for which it was rated.
Non-Fire-Resistance Rated	Most single-family homes, duplexes, and 1-3 story townhomes are constructed with non-fire-resistance rated wall assemblies. That is, they have not been tested to achieve a fire resistance rating per *ASTM E119* test standard. Most building codes and standards permit the exterior walls of smaller residential building types to be of any construction material and to be non-fire resistance rated. Where wildfire building codes have been adopted, exterior walls are required under specific conditions to have a cladding system (not the entire wall assembly) of ignition-resistant or noncombustible materials. Refer to Table 20 for more details. While most exterior wall assemblies in residential construction may not be fire-resistance rated, ignition-resistant cladding materials (e.g., stucco and fiber-cement siding) should provide some resilience to wildfires. ***Note:*** Ignition-resistant materials are still vulnerable to ignition when exposed to extended periods of severe fire conditions from wildfires or structure fires. Extra scrutiny should be placed on protecting gaps and joints in the exterior cladding of the home and at the interfaces of the walls to other building elements (e.g., head-of-wall detail, bottom-of-wall-to-foundation), as embers can accumulate and potentially lead to ignition of combustible interior cavity spaces, where a fire can go undetected for long periods of time. Refer to the Section 1.2.3 *Joints* for more details.

Table 20. Design, vulnerability, and mitigation considerations for exterior wall cladding.

Exterior Wall Cladding Types	Vulnerability and Mitigation Considerations
Concrete, Fiber-Cement Panels or Siding, Exterior Fire-Retardant Treated Wood (FRTW) Siding or Panels, Stucco, Masonry, and Metal	These cladding materials are considered to be ignition-resistant or noncombustible and, in some cases, inherently fire resistant (e.g., concrete). These materials will not melt when used as exterior wall covering materials. FRTW is still a combustible material and will burn. However, some noncombustible cladding materials, such as metal siding, are thermally conductive and can result in ignition of combustible materials in the assembly, if the heat exposure is extended. Cementitious materials will also undergo dehydration cracking with extended thermal exposures, exposing underlying materials in the wall assembly.
Non-FRTW Siding, Vinyl Siding, Metal Siding Susceptible to Warping (i.e., Aluminum or Sheet Metal Siding)	These materials are more likely to melt or burn when used as exterior wall covering materials. This would allow the fire to reach underlying wall components and penetrate into the interior of the building [6].
Log/Heavy Timber Construction	The fire performance of log/heavy timber construction is heavily dependent on the type of wood utilized. Generally, heavy timber construction is less hazardous than typical light-weight combustible materials, as heavy timber will char slower due to the larger/thicker dimensions, and provided the log joints are well protect and maintained. However, not all heavy timber construction carries flame spread characteristics suitable for use on exterior wall coverings in wildfire prone areas. Consult manufacturer for information on if a fire-resistant outer layer (siding or coating) should be applied.

Note: While noncombustible or ignition-resistant exterior wall coverings may provide an initial barrier to flames, heat can still pass through the coverings and ignite other components of the exterior wall assembly. For the most effective protection, ensure that the exterior wall assembly has been tested against criteria from *ASTM E119* or *UL 263* for a fire-resistance rating.

Note: As wildfire codes do not require or provide guidance on when and where fire-resistance rated wall assemblies should be provided and to what hourly rating, local fire experts or AHJs should use progressional judgement on hourly rating suggestions given the severity of the anticipated wildfire or proximate structure fire exposure.

General Mitigation Strategies

- Maintain an ember-resistance zone for at least 5 feet from all exterior walls of the structure. Remove combustibles fuel loads including wood mulch, propane tanks, trash containers, plastic storage bins, BBQs, vegetation of all kinds (if possible, otherwise remove all high fire hazard vegetation).
- Maintain landscaping and general housekeeping within the home ignition zone. Refer to defensible space requirements.
- Consider upgrading the exterior wall cladding to include a 5/8” Type X exterior rated gypsum board between the wall cladding and underlayment or upgrade to a 1-hour fire rated wall assembly, where the building or home is within 30’ of the property line or adjacent structure.
- Consider using fiberglass batt insulation or mineral wool inside exterior wall cavities to reduce potential for ignition of combustible concealed spaces. Ensure gaps in exterior walls, particularly cladding/bottom-of-wall to foundation detail, is flashed/sealed with fire resistant caulk completely [64].
- Refer to Section 1.4 *Sprinkler Systems* for mitigation strategies related to potential exterior sprinkler system applications.
- Protect any point which may allow ember penetration to structure.
- Regularly inspect exterior siding for gaps and holes. Where gaps or holes are present, use fire resistant caulk to seal the opening.

Training Programs

NFPA - *Assessing Structure Ignition Potential from Wildfire:* https://www.nfpa.org/Training-and-Events/By-topic/Home-Ignition-Zone

Gaps in Knowledge

- Current building codes do not require fire resistance ratings for exterior walls for single family residences, duplexes, or 1-3 story townhomes regardless of fire separation distances to adjacent properties or structures. While fire separation distances exist in building codes, they are primarily designed for structure-to-structure spread from adjacent properties, they do not explicitly apply to outbuildings on the same property. The underlying basis for the separation distances and ratings are likely valid but need to be specified/confirmed for residential buildings.
- While the standard *ASTM E119* fire resistance test is based on interior building fires or structure-to-structure fires, it was not specifically designed to account for the unique aspects of wildfire fire exposures. That is, it does not capture the impact of embers or direct flame impingement. That said, interior building fire exposures are generally more severe to exterior fire exposures, and therefore would provide a reasonable proxy for anticipating a rated-wall assembly's performance in a wildfire.
- *ASTM E119* fire testing does not account for weathering of materials prior to fire exposure. *UL 263* has an accelerated weather exposure protocol prior to fire testing.
- In most instances, it's challenging to verify in-the-field if an exterior wall assemblies fire resistance rating of 1-hour, 2-hour, etc. (Professional judgement required.)

Other References

- Insurance Institute for Business & Home Safety (IBHS)
  - Preparedness - https://disastersafety.org/wp-content/uploads/2021/08/WFR-Home-Preparedness-Guide.pdf
- National Fire Protection Association (NFPA)
  - Roofing Materials - https://www.nfpa.org/-/media/Files/Firewise/Fact-sheets/FirewiseFactSheetsRoofingMaterials.ashx
- Federal Emergency Management Agency (FEMA)
  - Home Builder's Guide to Construction in Wildfire Zones - https://www.govinfo.gov/content/pkg/GOVPUB-HS5-PURL-gpo60104/pdf/GOVPUB-HS5-PURL-gpo60104.pdf
  - Mitigation Assessment Team Report: Marshall Fire Building Performance, Observations, Recommendations, and Technical Guidance (FEMA P-2320) - https://www.fema.gov/sites/default/files/documents/fema_p2320-marshall-fire-mAT-report-without-appendices.pdf
  - Decreasing Risk of Structure-to-Structure Fire Spread in a Wildfire (Marshall Fire MAT) - https://www.fema.gov/sites/default/files/documents/fema_marshall-fire-mat-decreasing-structure-fire-spread.pdf
- FM-Global
  - Property Loss Prevention Data Sheet 9-19 - https://www.fm.com/resources/fm-data-sheets

Figure 1.49. Example of combustible, wood shingle cladding on exterior wall, which presents a potential ignition hazard in a wildfire. Image courtesy of Jensen Hughes/FEMA.

Figure 1.50a. Example of fiber cement board cladding on exterior wall. Image courtesy of Jensen Hughes/FEMA.

Figure 1.50b. Example of brick cladding. Brick cladding is one example of noncombustible siding that can be used. Image courtesy of Jensen Hughes/FEMA.

Figure 1.51. Example of stucco cladding. Stucco cladding is one example of noncombustible siding that can be used. Image courtesy of Jensen Hughes/FEMA.

Figure 1.52. Example of vinyl siding. Vinyl siding can melt or burn when exposed to high temperatures and should be avoided. The vulnerability of vinyl siding is increased when flammable materials such as grass and mulch directly abut the home. Image courtesy of Jensen Hughes/FEMA.

Figure 1.53. Example of corrugated steel siding on exterior wall. Corrugated steel siding is a good noncombustible exterior cladding option, however care should be taken to ensure there are no gaps between steel siding panels. Image courtesy of Jensen Hughes/FEMA.

1.3.2 DOORS

Main Concern(s)

Like other exterior openings, doors can compromise a home's ability to survive a wildfire when precautions are not taken to prevent them from being an entry point for embers and/or flames. During a wildfire, a door can be compromised due to an extended radiant heat exposure from surrounding vegetation or due to flames when embers have ignited vegetative debris near the door [49]. Deteriorating weather stripping and glass panes are the most vulnerable parts of the door. If the weather stripping has deteriorated around the door causing a poor seal, embers and flames can penetrate around the door into the structure. If the glass in a door breaks during a wildfire, embers and flame can easily enter a structure [50]. Similarly, non-fire rated combustible doors and combustible door frames can ignite or fail, leading to ember intrusion and ultimately ignition of other material inside of the structure. Therefore, doors must be able to resist the following exposures:

- A radiant exposure severe enough to break the glass in a door or ignite the door or door frame. Burning vegetation in close proximity to a door could also ignite non-fire rated combustible doors and combustible door frames [50].

- A flame contact exposure that could result from embers igniting vegetation and/or exterior cladding that burns up to the door(s) [50].

See Section 1.3.4 *Windows* for additional guidance on glass panels in doors.

Key Terminology

- ***Weather Strip:*** A strip of material to cover the joint of a door or window and the sill, casing, frame, or threshold to exclude rain, snow, and cold air [51].

- ***Sidelite:*** The side panels on either side of the door. Filled with glass or wood and usually provided on both sides of a primary door, though can exist solo. Sidelites can be provided in the same overall frame as the door or may be independently framed.

Fire Rated Assemblies

Fire ratings for doors or door assemblies is defined by a number of standards, as follows:

- *NFPA 252 Standard Method of Fire Tests of Door Assemblies*
- *UL 10B Standard Test for Fire Tests of Door Assemblies*
- *UL 10C Standard for Positive Pressure Fire Tests of Door Assemblies*
- *ASTM E152 Standard Methods of Fire Tests of Door Assemblies*

These test standards prescribe specific fire and hose stream test procedures for fire door assemblies for determining the degree of fire protection provided by such assemblies in retarding the spread of fire (flame, heat, and hot gases) through door openings in a fire resistive wall when exposed to a severe, standard fire exposure [52]. The standard fire exposure simulates severe interior building fire conditions during flashover conditions. It does not represent the wildfire exposures that may also include embers and direct flame impingement. Depending on how the door assembly performs against the performance criteria defined in the standards, the door can achieve anywhere from a 20-min, 1-hour, or up to 3-hours (typically) fire resistance rating.

Fire Test Standards

- *ASTM E119 Standard Test Methods for Fire Tests of Building Construction and Materials:* https://www.astm.org/e2886_e2886m-20.html
- *ASTM E152 Standard Methods of Fire Tests of Door Assemblies.*
- *ASTM E2112 Standard Practice for Installation of Exterior Windows, Doors, Skylights:* https://www.astm.org/e2112-19c.html
- *UL 10B Standard Test for Fire Tests of Door Assemblies:* https://standardscatalog.ul.com/ProductDetail.aspx?UniqueKey=29319
- *UL 10C Standard for Positive Pressure Fire Tests of Door Assemblies:* https://www.shopulstandards.com/ProductDetail.aspx?UniqueKey=31216
- *NFPA 252 Standard Methods of Fire Tests of Door Assemblies:* https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=252

Referenced Codes and Standards

- *2024 International Wildland-Urban Interface (IWUI) Code:* Chapter 5, Sections 504.9, 505.9 Exterior Doors
- *2022 California Building Code (CBC):* Section 708A Exterior Windows, Skylights, and Doors
- *2022 NFPA 1140 Standard for Wildland Fire Protection:* 25.7 Exterior Openings

Other Codes and Standards

Additional local requirements, policies, and programs will vary depending on location and adoption in individual jurisdictions.

- Check local, county, and state amendments for additional wildfire codes and standards.
- Check local general plan, multi-hazard mitigation plan, zoning.
- International Residential Code (if applicable - check for wildfire amendments).

Typical Design, Vulnerability, and Mitigation Considerations

Table 21. Vulnerability, and mitigation considerations for doors.

Door Types	Vulnerability and Mitigation Considerations
Solid Core Wood	Solid core wood doors are still vulnerable due to their combustibility; however, these doors offer greater protection than a hollow core door. These doors should be maintained in good condition with proper weather stripping.
Steel	Steel doors are the most resilient to wildfire as they are noncombustible. These doors may offer a greater capacity for absorbed radiative heat and should be considered a viable option for exterior pedestrian doors.
French Doors	French doors come in a variety of options including multiple doors or sidelite options. These doors typically contain glazing which should be evaluated in accordance with the glazing requirements located in the applicable building codes. The variation in these doors can present vulnerabilities due to the larger surface areas and glass panels. Risk can be reduced by providing rated glazing.
Sliding Glass Doors	Sliding glass doors are the most vulnerable due to the large surface area of the glass panels. To reduce risk these glass panels should be rated glazing.
Dog/Pet Doors	Pet/dog doors could exist both as an opening in an exterior wall, or an opening within the plane of a door. These are both additional areas that are vulnerable if gaps are left within the joint between the door and the plane in which it is penetrating. Any dog/pet doors should not contain gaps around the installation and should be constructed of noncombustible materials. Where the pet door has a removable cover, the cover should be noncombustible and left in the closed position whenever the pet door is not in use.

General Mitigation Strategies

- Provide, where possible, ignition-resistant or noncombustible framing materials (e.g., metal or metal-clad wood).
- Replace old hollow core doors with solid core or steel doors.
- Consider using tempered glass for sliding glass doors or glass panel inserts, which is stronger than annealed glass and will provide additional protection during a wildfire [53].
- Fabricate covers (for example, 1/2” plywood covers), cut to size and marked so that it can easily be installed over a door prior to evacuation. Shutters or other roll-down devices could also be installed [53].
- During a wildfire event, make sure all doors remain closed to avoid ember intrusion into structures.
- Manage vegetation and other types of items that could catch fire in the areas nearest to doors. This includes maintaining the surrounding vegetation and using noncombustible mulch and ignition-resistant materials for yard and garden structures near doors [54].
- The recommended glazing products for homes in wildfire zones are tempered glass, fiberglass-reinforced translucent glazing, and insulated glazing units (IGUs). Glazing products that are not recommended are annealed glass, ceramic glass, and plastic glazing [6].
- Consider installing a self-closing, metal screen door (with openings 1/8” or less) to protect against embers [15]. Note that typical screen doors have 1/16” mesh. However, this should be verified if possible.
- Exposed components (i.e., fixtures) should be made of noncombustible materials [15].
- Provide self-closing doors where possible [15].
- Ensure that any openings within the plane of the door (i.e., windows, dog doors) do not contain gaps and, where possible, are made of noncombustible materials [38].

Training Programs

NFPA - *Assessing Structure Ignition Potential from Wildfire:* https://www.nfpa.org/Training-and-Events/By-topic/Home-Ignition-Zone

Gaps in Knowledge

- Currently, there is no fire test standard to evaluate ember intrusion, direct flame impingement, or thermal transmission of heat via convection or radiation from wildfires for doors.
- Some gels and foams marketed for structure protection during wildfires indicate they will also protect doors, but verification of these claims by an independent source is not currently available [53].
- Glass breaking and/or fall-out is still within the realm of active fire testing and research for all the ranges of glazing types with associated frame types (e.g., wood, vinyl, aluminum, vinyl- and aluminum-clad wood, and fiberglass).
- Most evidence regarding external doors is anecdotal. More research in this area is needed [22].

Other References

- University of California, Agriculture and Natural Resources (UCANR)
  - Wildfire Preparedness, Prepare Your Home, Window - https://ucanr.edu/sites/fire/Prepare/Building/Windows/
- Fire Safe Marin
  - Fire Resistant Windows - https://firesafemarin.org/harden-your-home/fire-resistant-windows/
- Insurance Institute for Business & Home Safety (IBHS)
  - Creating a Fire Adapted Home - http://www.projectwildfire.org/wp-content/uploads/2016/02/IBHS-Guide-to-Creating-Fire-Adapted-Home.pdf
- Fire Safe San Mateo County
  - Windows - https://firesafesanmateo.org/preparedness/home-hardening/windows
- Federal Emergency Management Agency (FEMA)
  - Home Builder's Guide to Construction in Wildfire Zones, Technical Fact Sheet No. 10 - https://www.govinfo.gov/content/pkg/GOVPUB-HS5-PURL-gpo60104/pdf/GOVPUB-HS5-PURL-gpo60104.pdf
  - Mitigation Assessment Team Report: Marshall Fire Building Performance, Observations, Recommendations, and Technical Guidance (FEMA P-2320) - https://www.fema.gov/sites/default/files/documents/fema_p2320-marshall-fire-mAT-report-without-appendices.pdf

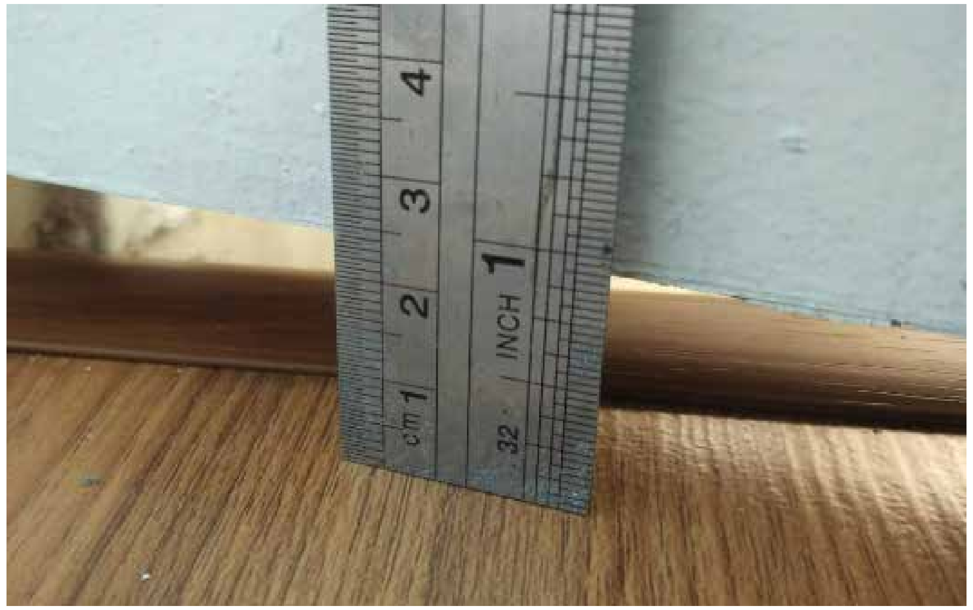


Figure 1.54. Example of gaps in door undercuts. Exterior doors with large gaps at the bottom should be installed with weather strips or replaced.

1.3.3 GARAGE DOORS

Main Concern(s)

Garage doors present vulnerabilities to the structure. These doors are not typically sealed very well due to lack of heating or cooling in these spaces. Gaps around garage doors provide entry point for embers into the garage structure. Homeowners often have large amounts of storage and other types of combustible fuels in garages, which may present higher risks if embers enter the garage space. Garages are not typically finished out with drywall, so the open studs provide exposed combustible material that is vulnerable to ignition. Some garage doors are also provided with small windows. These windows are vulnerable to direct flame impingement. For more information, see Section 1.3.4 *Windows*.

Key Terminology

- **Weather Strip:** A strip of material to cover the joint of a door or window and the sill, casing, frame, or threshold to exclude rain, snow, and cold air [51].

- **Sectional Garage Doors:** Sectional garage doors are made up of panel sections that are connected with hinges. As the door opens and closes, wheels at the edge of each panel roll inside a vertical track on each side of the door opening [55].

Fire Rated Assemblies

Residential roll up garage doors are not fire rated.

Fire Test Standards

- *ASTM E119 Standard Test Methods for Fire Tests of Building Construction and Materials:* https://www.astm.org/e0119-20.html

Referenced Codes and Standards

- *2024 International Wildland-Urban Interface (IWUI) Code:* No explicit requirements
- *2022 California Building Code (CBC):* Section 708A.4 Garage Door Perimeter Gap
- *2022 NFPA 1140 Standard for Wildland Fire Protection:* No explicit requirements

Other Codes and Standards

Additional local requirements, policies, and programs will vary depending on location and adoption in individual jurisdictions.

- Check local, county, and state amendments for additional wildfire codes and standards.
- Check local general plan, multi-hazard mitigation plan, zoning.
- International Residential Code (if applicable - check for wildfire amendments).

Typical Design, Vulnerability, and Mitigation Considerations

Table 22. Vulnerability and mitigation considerations for garage doors.

Garage Door Types	Vulnerability and Mitigation Considerations
Sectional Garage Doors	Sectional garage doors are the most common. These doors, if not sealed well, present openings around the edges for embers to enter the garage.
Slide to the Side Doors	Slide to the side doors are similar to sectional doors, however these doors slide to the side instead of retracting overhead. These doors face the same vulnerabilities as sectional doors.
Tilt-Up Garage Doors	Like side-hinged styles, the tilt-up canopy garage doors don’t have sections. They are made of one solid piece. They have a pivoting hinge mechanism, so they can tilt up into the garage. The canopy-style door sits parallel to the garage ceiling and extends past the front of the house when the door is open. These doors are also vulnerable due to poor seals [55].

General Mitigation Strategies

- Install ignition-resistant or noncombustible framing materials (e.g., metal or metal-clad wood).
- Ensure any weather stripping is in good condition and provides a tight seal.
- Use tempered glass, where glass panels are provided within a garage door. Tempered glass is 3-4 times more resistant to heat compared to annealed glass.
- Manage vegetation and other types of items that could catch fire in the areas nearest to garage doors. This includes maintaining the surrounding vegetation and using noncombustible mulch and ignition-resistant materials for yard and garden structures near garages [54].
- For pedestrian access doors into garages, refer to Section 1.3.2 *Doors*.
- Relocate any combustible or hazardous materials within the garage away from garage door or other openings, or within a protective cabinet to limit ignition, in the event embers enter the garage space.
- Ensure storage of goods and other hazardous materials are properly maintained and in appropriate containers, and that general housekeeping is maintained.
- If the garage door is not metal, install metal flashing at the bottom of the garage door for the first 6 inches from the ground [45].

Training

NFPA - *Assessing Structure Ignition Potential from Wildfire:* https://www.nfpa.org/Training-and-Events/By-topic/Home-Ignition-Zone

Gaps in Knowledge

- Field and/or lab research is limited on the performance of garage doors during wildfire events.
- Fire testing of sealants around garage doors for radiant heat, direct flame impingement, and/or ember exposure is currently unavailable.
- Methods for providing fire protection for concrete surface below the garage door where the concrete has settled.

Other References

- University of California, Agriculture and Natural Resources (UCANR)
  - Garages - https://ucanr.edu/sites/fire/Preparedness/Building/Garage/
- Fire Safe Marin
  - Chimneys, Garages, Driveways, & Address Numbers - https://firesafemarin.org/harden-your-home/chimneys-garages-driveways-address-number/
- Insurance Institute for Business & Home Safety (IBHS)
  - Creating a Fire Adapted Home - http://www.projectwildfire.org/wp-content/uploads/2016/02/IBHS-Guide-to-Creating-Fire-Adapted-Home.pdf
- Federal Emergency Management Agency (FEMA)
  - Home Builder's Guide to Construction in Wildfire Zones, Technical Fact Sheet No. 10 - https://www.govinfo.gov/content/pkg/GOVPUB-HS5-PURL-gpo60104/pdf/GOVPUB-HS5-PURL-gpo60104.pdf
  - Mitigation Assessment Team Report: Marshall Fire Building Performance, Observations, Recommendations, and Technical Guidance (FEMA P-2320) - https://www.fema.gov/sites/default/files/documents/fema_p2320-marshall-fire-mAT-report-without-appendices.pdf
  - Homeowner's Guide to Reducing Risk of Structure Ignition from Wildfire - https://www.fema.gov/sites/default/files/documents/fema_marshall-fire-mat-homeowners-guide-reducing-risk-structure-ignition.pdf

Figure 1.55. Example of gaps around garage door. These gaps can lead to potential ember intrusion or ignition of the frame of the garage door, if combustible. Image courtesy of Jensen Hughes/FEMA.

Figure 1.56. Example of gaps around garage door. These gaps can lead to potential ember intrusion or ignition of the frame of the garage door, if combustible.

1.3.4 WINDOWS (INCLUDING DORMER / ATTIC WINDOWS)

Main Concern(s)

Windows can compromise a home's ability to survive a wildfire when precautions are not taken to prevent them from being an entry point for embers and/or flames. During a wildfire, a window can be compromised due to an extended radiant heat exposure from surrounding vegetation or to flames when embers have ignited vegetation near the window. The glass is the most vulnerable part of the window. If the glass in a window breaks during a wildfire, embers and flame can easily enter a structure. Similarly, combustible window frames can ignite or fail, leading to ember intrusion and ultimately ignition of other material inside of the structure. Therefore, windows must be able to resist the following exposures [53]:

- A radiant exposure severe enough to break the glass in a window or ignite the window frame or the exterior siding directly below it. Burning vegetation in close proximity to a window could also ignite combustible siding [53].

- A flame contact exposure could result from embers igniting vegetation and/or exterior cladding that burns up to the window(s) [53].

- Glass breakage occurs because of thermally induced strains caused by temperature differences between the shielded glass protected by the frame and the exposed glass away from the frame. This non-uniform heating causes the glass to expand at different rates [53]. The presence of a rigid frame also restrains the glass from expanding, leading to cracking of the glass. If the temperature differences are large enough, the cracks grow, potentially leading to failure of glass and fall out.

Key Terminology

- **Double (dual)-Pane Window:** Window provided with two panes of glass to slow the heat transfer across the window. This also provides a security factor should one pane break during a fire event. Dual-pane windows initially became common in construction as a result of more restrictive energy codes as dual-pane windows are more energy efficient. An added benefit is that dual-pane windows are less vulnerable to breakage when exposed to heat.

Fire Rated Assemblies

Windows can comply with several different requirements to resist the effects of fire. Applicable options are as follows:

- Be constructed of multi-pane glazing with a tempered pane [31].
- Be constructed of glass block units [31].
- Have a fire-resistance rating of not less than 20 minutes when tested in accordance with *NFPA 257*.
- Have a fire-resistance rated glazing with performance tested in accordance with *ASTM E119*.

Fire Test Standards

- *ASTM E119 Standard Test Methods for Fire Tests of Building Construction and Materials:* https://www.astm.org/e0119-20.html
- *ASTM E 2112 Standard Practice for Installation of Exterior Windows, Doors, Skylights:* https://www.astm.org/e2112-19c.html
- *UL 263 Fire Tests of Building Construction Materials:* https://global.ihs.com/doc_detail.cfm?document_name=UL%20263&item_s_key=00097028
- *NFPA 257 Standard on Fire Test for Window and Glass Block Assemblies:* https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=257
- *SFM Standard 12-7A-2 Exterior Windows*

Referenced Codes and Standards

- *2021 International Wildland-Urban Interface Code (IWUIC):* Sections 504.8, 505.8 Exterior Glazing
- *2022 California Building Code (CBC):*
  - Chapter 24 Glass and Glazing
  - Section 708A Exterior Windows, Skylights, and Doors
- *2022 NFPA 1140 Standard for Wildland Fire Protection:* Section 25.7 Exterior Openings
- *2017 NFPA 257 Standard on Fire Test for Window and Glass Block Assemblies*
- *2017 NFPA 252 Standard Method of Fire Tests of Door Assemblies*
- *2019 NFPA 80 Standard for Fire Doors and Other Opening Protectives*

Other Codes and Standards

Additional local requirements, policies, and programs will vary depending on location and adoption in individual jurisdictions.

- Check local, county, and state amendments for additional wildfire codes and standards.
- Check local general plan, multi-hazard mitigation plan, zoning.
- International Residential Code (if applicable - check for wildfire amendments).

Typical Design, Vulnerability, and Mitigation Considerations

Table 23. Vulnerability and mitigation considerations for windows.

Window Types	Vulnerability and Mitigation Considerations
General	The wall aspect, as well as whether the window or glazed unit is facing the wildfire or burning structure, will markedly influence its performance. Prioritize mitigations for single-pane or large-bay windows that are facing potential high-fire exposure (e.g., continuous dense vegetation, drainages, ravines, steep aspects, structures within 30 feet).
Single Pane	Testing has shown that single-pane windows are highly vulnerable to breaking when exposed to radiant heat or flames [54].

Double or Triple Paned	Testing has shown that dual-pane and triple-pane windows provide better wildfire protection [54]. Generally, multi-pane windows are more resilient by providing multiple layers of protection [22]. In several fire tests of tempered, double pane windows, the outer pane of glass has been observed to break but not fall out, with the inner panes remaining intact. Both single and multi-pane windows perform better when the panes are tempered (see Table 24). Double pane windows typically withstand about 25 kW/m^2 of thermal exposure [56]. If the window panes are tempered, the resistance increases to about 40 kW/m^2 [57]. In a 1995 study by Cohen [58], where windows were exposed to different heat flux intensities, the outer pane of annealed double-pane windows broke at all heat fluxes tested (9.3 kW/m^2, 13.6 kW/m^2, and 17.7 kW/m^2). The inner pane broke at heat fluxes above 9.3 kW/m^2 in 75% of the tests conducted. However, both single and double pane tempered windows survived these tests. Multi-pane windows also provide added protection to ember strikes or other flying debris during a wildfire that could cause the glass to fail due to impact alone. For these types of windows, the inner panes remain intact, limiting ember intrusion.
Large-Bay Windows	Large-bay windows increase the vulnerability of the structure due to the size and surface of the windows. Additionally, heat can be trapped underneath bay windows [22].
Jalousie (or Louvered) Windows	Jalousie windows are extremely vulnerable to ember intrusion, whether the louvers are closed or in an open condition, as they create large openings directly into the building interior allowing embers, hot gases, and flames to readily ignite combustible materials. Jalousie windows should be replaced with more modern windows, coupled with an alternative method for interior cooling.

Table 24. Vulnerability and mitigation considerations for window construction materials.

Window Construction Material Types	**Vulnerability and Mitigation Considerations**
Wooden & Plastic Frames	Wooden and plastic frames are combustible, and are at high risk of igniting, melting, and failing leading to failure and/or fall out of the glazing. Debris should be kept clear of framing materials. If possible, replace framing with noncombustible materials such as metal or metal-clad wood.
Metal Framing	Metal window framing is noncombustible and therefore would not be susceptible to ignition. However, metals have relatively high thermal conductivity that can transfer heat and high temperature to combustible materials inside a building if not provided with noncombustible insulation to limit thermal transmission. Note that most modern, metal window framing incorporates non-thermally conductive materials in the design. In some cases, metal framing can be more rigid/stiff compared to wooden or plastic frames, which may make the window/glazed unit more susceptible to thermal stresses, cracking, and fallout of the glass pane.
Laminated Glass	Laminated glass provides resistance to windborne firebrands. If a firebrand strikes with enough momentum to break the glass, the plastic film in the core of the glass will keep the glazing in the frame, allowing the broken glass to continue to resist firebrand impacts, embers, and hot gases. The same concept applies for thermal breaking of the glass panes (which are typically made of annealed glass). That is, if exposure is sufficiently hot to break the annealed glass, the plastic film will keep the glass in the frame. If the plastic film in the core gets sufficiently hot, the pane will delaminate whether the glass has been broken or not [6]. If laminated glass is present, it should either be protected by shutters, or combined with tempered glass in an IGU [6].

Tempered Glass	Tempered glass is more resistant to heat and flames than laminated glass or annealed glass. The resistance of tempered glass can be enhanced with proprietary reflective coating. Firebrands with sufficient momentum can break tempered glass [6]. To reduce the vulnerability of glass to breakage, the glass can be protected by a noncombustible shutter [6]. Another alternative is to specify and install an IGU with a laminated glass inner pane, or two layers of tempered glass [6].
Low Emissivity (Low-E) Coated Glass	Low-E coated glass is believed to provide a higher level of resistance to radiant heat than other types of glazing because the coating reflects radiant heat, reducing the probability that the heat will be able to enter the building. Research is currently underway to understand the performance of low emissivity coated glass [6].
Insulated Glazing Unit (IGU)	An IGU consists of two or three panes of glass that are separated by a sealed air space. Double-pane annealed units last about twice as long as single-pane windows in a wildfire [6]. If the first pane fails, the second pane must still be penetrated. Laminated glass, tempered glass, and glass with a low-e coating can be combined in various ways into an IGU [6].
Glass Block Units	Glass blocks are inherently fire-resistive and, while not as visually appealing, are considered a good option for rated windows [59].

General Mitigation Strategies

- Install ignition-resistant or noncombustible framing materials (e.g., metal or metal-clad wood).
- Replace old single-pane windows with dual-pane windows.
- Close all windows during a wildfire or before evacuating.
- Consider using tempered glass, which is stronger than annealed glass and will provide additional protection during a wildfire [53].
- Consider using insect screens. Screens fabricated from corrosion-resistant, noncombustible materials are preferred. Plastic clad fiberglass screens will fail as a result of a flame contact exposure.
- Fabricate covers (for example, 1/2” plywood covers), cut to size and marked so that it can easily be installed over a window prior to evacuation. Shutters or other roll-down devices could also be installed [53].
- Install noncombustible window screens of at least 1/16”.
- Manage vegetation and other types of items that could catch fire in the areas nearest to windows. This includes maintaining the surrounding vegetation and using noncombustible mulch and ignition-resistant materials for yard and garden structures near windows [32].
- Exterior shutters can provide protection in a wildfire. Solid metal shutters are recommended over wooden or plastic shutters. A wood covering (e.g., plywood) will protect the window from embers and radiant heat until the covering fails. If the building is located in a windborne debris region within a hurricane-prone region, the shutter should meet the windborne debris criteria in *ASCE 7-05*. Note that temporary shutters are only effective if the homeowner has sufficient time to put the shutters into place [6].
- The recommended glazing products for homes in wildfire zones are laminated glass, tempered glass, and insulated glazing units (IGUs). See Table 24 for more information. Glazing products that are not recommended are single pane annealed glass and plastic glazing [6].

Training

NFPA - *Assessing Structure Ignition Potential from Wildfire:* https://www.nfpa.org/Training-and-Events/By-topic/Home-Ignition-Zone

Gaps in Knowledge

- Glass breaking and/or fall-out is still within the realm of active fire testing and research for all the ranges of glazing types with associated frame types (e.g., wood, vinyl, aluminum, vinyl- and aluminum-clad wood, and fiberglass).
- Theoretically it would be possible to polish the edges of the glass for windows, thereby minimizing the number of edge flaws present, making the glass less vulnerable to breakage. Whether this could be a long-term solution in terms of maintaining the polished edge during the processing in making the window has not been determined [50].

Other References

- University of California, Agriculture and Natural Resources (UCANR)
  - Wildfire Preparedness, Prepare Your Home, Window - https://ucanr.edu/sites/fire/Prepare/Building/Windows/
- Fire Safe Marin
  - Fire Resistant Windows - https://firesafemarin.org/harden-your-home/fire-resistant-windows/
- Insurance Institute for Business & Home Safety (IBHS)
  - Creating a Fire Adapted Home - http://www.projectwildfire.org/wp-content/uploads/2016/02/IBHS-Guide-to-Creating-Fire-Adapted-Home.pdf
- Fire Safe San Mateo County
  - Windows - https://firesafesanmateo.org/preparedness/home-hardening/windows
- Federal Emergency Management Agency (FEMA)
  - Home Builder's Guide to Construction in Wildfire Zones, Technical Fact Sheet No. 10 - https://www.govinfo.gov/content/pkg/GOVPUB-HS5-PURL-gpo60104/pdf/GOVPUB-HS5-PURL-gpo60104.pdf
  - Mitigation Assessment Team Report: Marshall Fire Building Performance, Observations, Recommendations, and Technical Guidance (FEMA P-2320) - https://www.fema.gov/sites/default/files/documents/fema_p2320-marshall-fire-mAT-report-without-appendices.pdf
  - Decreasing Risk of Structure-to-Structure Fire Spread in a Wildfire (Marshall Fire MAT) - https://www.fema.gov/sites/default/files/documents/fema_marshall-fire-mat-decreasing-structure-fire-spread.pdf
  - Homeowner's Guide to Reducing Risk of Structure Ignition from Wildfire - https://www.fema.gov/sites/default/files/documents/fema_marshall-fire-mat-homeowners-guide-reducing-risk-structure-ignition.pdf

Figure 1.57a. An example of louvered windows with vegetation directly adjacent to the window. Image courtesy of Jensen Hughes/FEMA.

Figure 1.57b. Four examples of window vulnerabilities. Image adapted from Wildland Fire Embers and Flames: Home Mitigations That Matter, IBHS, 2023. https://ibhs.org/risk-research/wildfire/

1.3.5 JOINTS (AROUND WINDOWS, DOORS, BOTTOM-OF-WALL TO FOUNDATION, & WALL-TO-WALL INTERSECTIONS)

Main Concern(s)

In general, joints create gaps in the continuity of a fire rated or ignition-resistant wall assembly, presenting a potential pathway for hot gases, flames, or embers to penetrate the wall assembly and into the building interior or the outer membrane of the cladding system, leading to ignition of combustible interstitial spaces. A fire in combustible interstitial spaces can go unnoticed for long periods, allowing the fire to grow to uncontrollable levels before being detected. Joints can also create places for the accumulation of combustible debris that can be easily ignited by embers, hot gases, or direct flaming. Embers can accumulate at windowsills, door framing and at wall-to-wall intersections (such as an interior corner), creating a concentrated source of heat that may compromise the integrity of the wall, window, or door. In addition, there is currently no fire test for joints in wall assemblies to wildfire exposures - embers, direct flaming, or hot gases. This can create a short-circuit of a fire resistance rated (e.g., 1-hour, 2-hour), ignition-resistant, or fire resistive exterior wall.

Key Terminology

- **Joint:** The opening in or between adjacent assemblies that is created due to building tolerances or is designed to allow independent movement of the building in any plane caused by thermal, seismic, wind or any other loading [9].

- **Fire-Resistant Joint System:** An assemblage of specific materials or products that are designed, tested and fire-resistance rated in accordance with a standard fire test to resist for a prescribed period of time the passage of fire through joints made in or between fire-resistance rated assemblies [9]. (Note: There are currently no fire-resistant joint system tests for wildfire exposures.)

- **Flashing:** A section of thin sheet metal that is installed at joints to protect against intrusion of unwanted elements such as water and embers. In the wildfire context, the flashing is primarily to protect an underlying combustible material. In the case of a drip edge, there would be a second function of minimizing ember accumulation or entry in gap between sheathing and fascia.

- **Expansion Joint:** A physical discontinuity that spans the entire breadth of an element in a building, creating two separate sections of the element instead of one bigger one. They are designed and configured to allow the different sections or elements to move independently of each other, so the elements don’t become overstressed, crack or break [37] under various loads (e.g., thermal expansion/contraction, seismic movement).

Fire Classification and Ratings

Currently, there is no fire test standard to evaluate ember intrusion, direct flame impingement, or thermal transmission of heat via convection or radiation from wildfires for joints in wall assemblies. Fire rated joints are necessary to maintain a wall assembly's fire rating, integrity, and continuity to wildfire exposure. While a variety of fire tests exist for joints in interior building fire exposures (e.g., *ASTM E1966* or *UL 2079*), none are explicitly designed for the fire conditions presented by wildfires. A range of joint systems (e.g., static joints, movement joints) and joint conditions (e.g., window-to-wall, door-to-wall, wall-to-wall, expansion joints) for exterior wildfire exposures are still needed.

Fire Test Standards

Currently, there is no fire test standard to evaluate ember intrusion, direct flame impingement, or thermal transmission of heat via convection or radiation from wildfires for joint systems (wall joints or otherwise). Note: While there are no specific fire tests for exterior joints to wildfire exposure, many of the existing test methods (e.g., *ASTM E119*, *ASTM E84*) can be used to evaluate the impact of joints on performance.

Referenced Codes and Standards

- *2024 International Wildland-Urban Interface (IWUI) Code:* No explicit requirements
- *2022 California Building Code (CBC):* No explicit requirements
- *2022 NFPA 1140 Standard for Wildland Fire Protection:* No explicit requirements

Other Codes and Standards

Additional local requirements, policies and programs will vary depending on location and adoption in individual jurisdictions.

- Check local, county, and state amendments for additional wildfire codes and standards.
- Check local general plan, multi-hazard mitigation plan, zoning.
- IRC (if applicable - check for wildfire amendments).

Typical Design, Vulnerability, and Mitigation Considerations

Table 25. Design, vulnerability, and mitigation considerations for exterior wall joints.

Joint Types at Exterior Walls	Design, Vulnerability, and Mitigation Considerations
Wall-to-Wall Joints	Static wall joints between different wall systems or panels can create construction gaps providing an avenue for embers, hot gases, and/or flame to enter the building. Embers can accumulate at these gaps, and if ignition occurs, the resulting hot gases and flames can ultimately enter the stud cavity and building. To increase the resistance of these joints to wildfires, various systems are available depending on the wall construction type and location in the wall (e.g., mid wall or corner). For example, for typical wood stud wall construction with composite panel siding, metal flashing with an underlying mineral surfaced cap sheet can be incorporated into the assembly [12]. For concrete-to-concrete wall construction, 1" and 1.5" polyethylene backer rod compressed into the joint and recessed 1/2", followed by a minimum 1/2" fire sealant flush to the exterior wall surfaces (same to the interior side of the walls). Combustible materials are often used to fill wall joints, and thus it's important to confirm that fire rated firestopping products (e.g., sealants, caulking) are used to limit ignition of combustible fillers and provide a proper seal on the exterior surface of the joint.
Window-to-Wall Joint	Windows can have gaps around the interface of the window frame and the wall assembly. These gaps can create an avenue for embers, hot gases, and/or flame to enter the building, even if the window is fire rated. Because windowsills and frame can also provide a location for debris and/or embers to collect, maintaining a proper joint protection system is key. Window construction should typically incorporate the use of rigid cap flashing at the bottom-of-wall-top-of-window between the underlayment and wall siding. However, this may not always be the case. Depending on the size of the gaps and type of weather seals around the edges of the window joint, a range of firestopping and/or through penetration materials/products may be needed. This may include the use of firestopping products (e.g., sealants, caulking) to limit ignition of combustible fillers and provide a proper seal on the exterior surface of the joint. Ensure there is no vegetation or other combustible materials within 5-feet of windows.
Doors-to-Wall	Doors, due to their functional need for opening and closing, present numerous gaps around the interface of the door frame and the wall assembly. These gaps can create an avenue for embers, hot gases, and/or flame to enter the building, even if the door itself is fire rated. Door construction should incorporate the use of rigid cap flashing around the joint of the wall-to-door frame interface, between the underlayment and wall siding. However, this may not always be the case. Depending on the size of the gaps and type of weather seals around the edges of the door frame-to-wall joint, a range of firestopping and/or through penetration materials/products may be needed. This may include the use of firestopping products (e.g., sealants, caulking) to limit ignition of combustible fillers and provide a proper seal on the exterior surface of the joint. Similar considerations should be given to garage doors and large/specialty doors/openings - see Section 1.3.3 *Garage Doors*. In addition, to accommodate the functional movement of doors, gaps around the top, side and undercut of the door can range from 1/8" (around top and sides) up to 3/4" (bottom of door). These gaps should be provided with weather stripping or gaskets to limit the intrusion of embers. All combustible materials should be cleared away from doors both interior and exterior spaces. Ensure there is no vegetation or other combustible materials within 5' of doors.
Expansion Joint	Exterior wall expansion joints are not very common in residential homes but can be found in commercial buildings. The joint allows the wall assembly to expand and contract in sync with the building, without compromising the wall. Wall expansion joints accommodate a range of building movements, such as thermal movement (most common), wind sway (more common for tall buildings), seismic activity (common in high seismic regions), building settlement (common where new construction connects to an existing building). There are numerous types of details and systems to accommodate these movements. Expansion joints typically consist of a joint cover to protect the joint from weather elements (e.g., water, dirt, dust). The materials used at the expansion joint can consist of a range of combustible and noncombustible materials (e.g., foam, neoprene, sealant, metal). If the materials are combustible or have metal flashing without sufficient, noncombustible thermal insulation, they can present a vulnerability in the wall assembly to embers, hot gases, or flames. Surface mounted covers require a square, clean joint.

Bottom-of-Wall to Foundation	The joints between the wall footer and façade cladding may create small gaps or corners. These gaps are intentional to allow moisture to ventilate from behind the siding. However, these gaps encourage dry leaves, pine needles, and other combustible litter or debris to gather. Debris ignition from wind-blown embers would present a source of flame exposure to the façade and structure. • Clapboard (also known as bevel siding, lap siding, and weatherboard) is a type of siding of a building that comes in long, narrow overlapping planks installed horizontally. This is a common design that creates gaps between the cladding and foundation. These gaps should be blocked with firestopping materials (e.g., mineral wool, fire caulking, or sealants). • Horizontal siding with more complicated lap joints (e.g., tongue and groove and ship lap) are more resistant to flame penetration into the stud cavity [6].

General Mitigation Strategies

- All combustible materials should be cleared away from doors both on the interior and exterior sides.
- Ensure there is no vegetation or other combustible materials within 5' of windows and glass doors.
- Clear debris from windowsills, wall-to-wall joints, and other surfaces where combustible debris collects near wall joints.
- Seal any gaps at wall joints with firestopping (i.e. mineral wool, fire caulking, and fire-rated sealants [38]) and through-penetration systems as needed to maintain the continuity of the exterior wall assembly.
- Repair damage to foundation wall and cladding to reduce the accumulation of embers and fire brands between damaged materials.
- Where possible, use or replace existing expansion joints with noncombustible materials [38].
- Install a minimum 6" noncombustible vertical separation where horizontal surfaces meet the wall [20].

Training

NFPA - *Assessing Structure Ignition Potential from Wildfire:* https://www.nfpa.org/Training-and-Events/By-topic/Home-Ignition-Zone

Gaps in Knowledge

- Currently, there is no fire test standard to evaluate ember intrusion, direct flame impingement, or thermal transmission of heat via convection or radiation from wildfires for joint systems.
- No set of catalogs of "listed" fire resistive joint systems, products, and fire-rated assemblies at the national level exists for exterior building components and associated joints, detailing or interfaces exposed to wildfires in combination with weathering pre-tests. (California has state-approved WUI products, but there are limited joint and other interface detailing products specific to WUI [38].)
- It is unclear how susceptible various wall joints or functional gaps around doors are to wildfire exposures.

Other References

- Insurance Institute for Business & Home Safety (IBHS)
  - Preparedness - https://disastersafety.org/wp-content/uploads/2021/08/WFR-Home-Preparedness-Guide.pdf
- National Fire Protection Association (NFPA)
  - Roofing Materials - https://www.nfpa.org/-/media/Files/Firewise/Fact-sheets/FirewiseFactSheetsRoofingMaterials.ashx
- Federal Emergency Management Agency (FEMA)
  - Mitigation Assessment Team Report: Marshall Fire Building Performance, Observations, Recommendations, and Technical Guidance (FEMA P-2320) - https://www.fema.gov/sites/default/files/documents/fema_p2320-marshall-fire-mAT-report-without-appendices.pdf
  - Homeowner's Guide to Reducing Risk of Structure Ignition from Wildfire - https://www.fema.gov/sites/default/files/documents/fema_marshall-fire-mat-homeowners-guide-reducing-risk-structure-ignition.pdf
  - Wildfire Resilient Detailing, Joint Systems, and Interfaces of Residential Building Components - https://www.fema.gov/sites/default/files/documents/fema_marshall-fire-mat-detailing-joints.pdf
  - Home Builder's Guide to Construction in Wildfire Zones - https://www.govinfo.gov/content/pkg/GOVPUB-HS5-PURL-gpo60104/pdf/GOVPUB-HS5-PURL-gpo60104.pdf

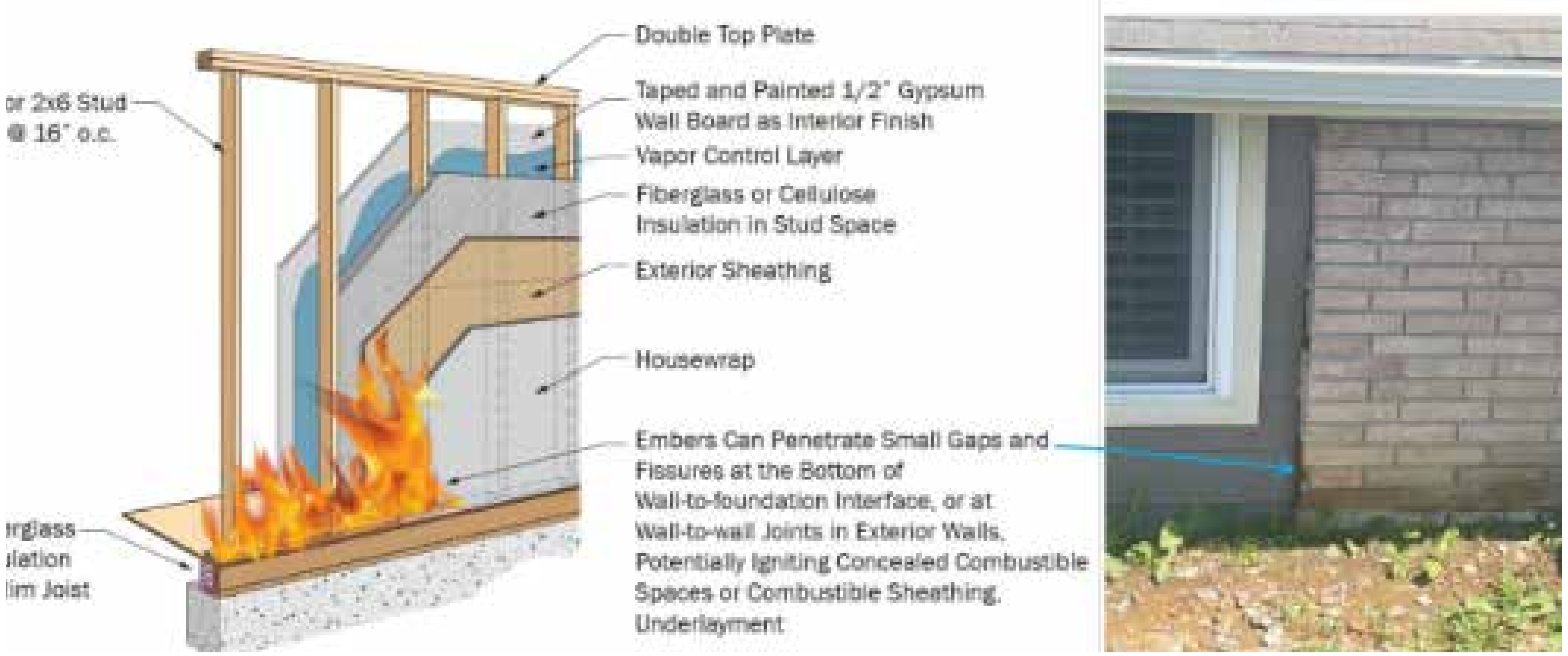


Figure 1.57c. Example of gaps in common exterior wall construction (e.g., interfaces of wall systems, butt joints between siding, bottom-of-wall to foundation details) that can create pathways for hot gases, flames and embers to ignite combustible interstitial spaces. Image adapted from FEMA Marshall Fire MAT, Wildfire Resilient Detailing, Joint Systems, and Interfaces of Residential Building Components, FEMA, 2023. https://www.fema.gov/

Figure 1.58a. Applying fire caulking around window-to-wall joints.

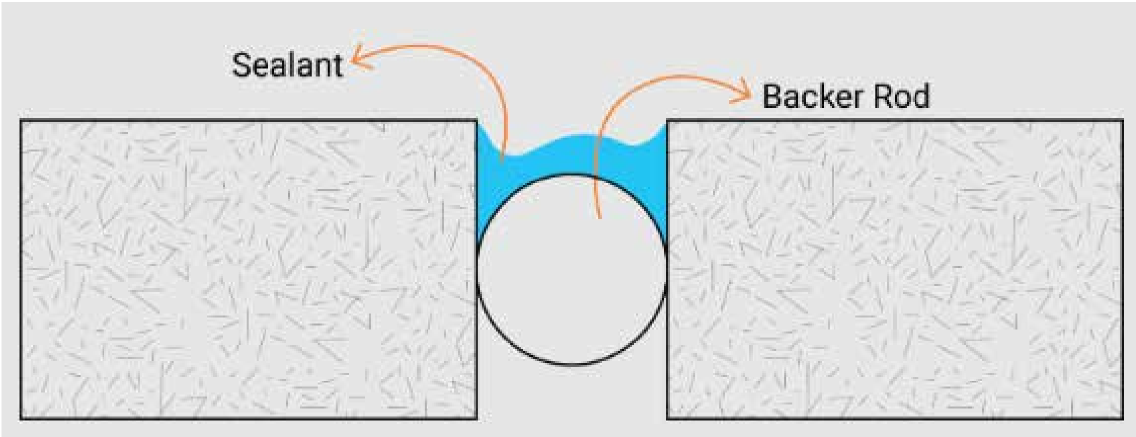


Figure 1.58b. Example cross-section of exterior wall joints in plan view, where a backer rod is placed to fill a joint and covered with sealant.

1.3.6 ARCHITECTURAL EMBELLISHMENTS & ORNAMENTS

Main Concern(s)

Architectural embellishments are decorative in nature and not part of the engineered structure. In this sense these attachments do not add to the structure stability but can significantly compromise the structure by providing locations for ember accumulation or transfer of heat through connecting methods to the structure itself. In some cases, the architectural features can present a fuel load itself, if comprised of combustible, unprotected materials. Some balconies on buildings are solely architectural embellishments, where they are purely for aesthetics and not load-bearing. (***Note:*** Refer to Section 1.3.7 *Balconies, Decks, and Porches Construction & Surfaces* for additional information where decorative balconies are provided.)

Key Terminology

- **Architectural Embellishment:** A decorative detail or feature added to the exterior of the building to enhance the aesthetics.

- **Ornament:** An applied embellishment in various styles that is a distinguishing characteristic of buildings. Ornamentation often occurs on entablatures, columns, and the tops of buildings and around entryways and windows, especially in the form of moldings [60].

Fire Classification and Ratings

There are currently no fire classifications or ratings for architectural embellishments and ornaments.

Fire Test Standards

Currently, there is no fire test standard to evaluate the performance of architectural embellishments during wildfires. There are also no fire tests to assess the contribution of these architectural features to the vulnerability of buildings in wildfire incidents (e.g., if they significantly contribute to building ignition, heat transfer to interior spaces, lead to ignition of exterior walls).

Referenced Codes and Standards

- *2024 International Wildland-Urban Interface (IWUI) Code:* No explicit requirements
- *2022 California Building Code (CBC):* Section 710A Accessory structures
- *2022 NFPA 1140 Standard for Wildland Fire Protection:* Section 25.4 Overhanging Projections

Other Codes and Standards

Additional local requirements, policies, and programs will vary depending on location and adoption in individual jurisdictions.

- Check local, county, and state amendments for additional wildfire codes and standards.
- Check local general plan, multi-hazard mitigation plan, zoning.
- International Residential Code (if applicable - check for wildfire amendments).

Typical Design, Vulnerability, and Mitigation Considerations

Table 26. Design, vulnerability, and mitigation considerations for architectural embellishments.

Architectural Embellishments	Design, Vulnerability, and Mitigation Considerations
Decorative Overhang/ Balconies	Decorative overhangs and balconies can be constructed of a range of combustible and noncombustible materials. The combustible materials could present sources of fuel, particularly as these types of features collect debris, pine needles, and other fuels over time. Decorative overhangs/balconies can also provide locations where embers can accumulate and potentially create hot spots where heat can transfer to the exterior wall causing ignition. Furthermore, the attachments where the overhang connects to the structure may present a gap or breach in the continuity of the exterior wall envelope and fire rated wall assembly (where applicable). Where possible, architectural embellishments should be comprised of noncombustible materials or fire-retardant treated wood. Debris and other vegetative materials should be regularly cleared off these elements. Firestopping should also be provided for any gaps around connection points to the exterior wall systems or building structure.
Decorative Shutters, Wall Panels, and Artwork	Decorative shutters, wall attachments, and artwork can be constructed of a range of combustible and noncombustible materials. The combustible materials could present sources of fuel, particularly as these types of features collect debris, pine needles, and other fuels over time. These decorative features can also provide locations where embers can accumulate and potentially create hot spots where heat can transfer to the exterior wall causing ignition. Decorative, combustible wall attachments (such as wood lattice panels) may be placed in between the ground and the exterior covering of the home, overtop of a noncombustible material. This condition should be removed where present, as they provide an avenue for a fire to spread to the exterior of the home.
Other Decorative Trims, Moldings and Treatments	These features can collect vegetative debris and other fuels over time. Regular clearing of these materials and general housekeeping can minimize the risk of ignition.

General Mitigation Strategies

- Remove combustibles (e.g., furniture, firewood, BBQs, mulch, vegetation, ornamental landscaping) from areas under decorative overhangs that could create a localized fire that ignites these decorative features.
- Seal any openings that may allow passage of embers or flame into a structure with firestopping and fire caulking.
- Upgrade attachment points of artwork and other decorative panels such that they fixed further away from the exterior wall where embers could collect.
- Consider replacing combustible architectural embellishments with noncombustible materials.

Training

NFPA - *Assessing Structure Ignition Potential from Wildfire:* https://www.nfpa.org/Training-and-Events/By-topic/Home-Ignition-Zone

Gaps in Knowledge

- There is no fire test standard to evaluate the performance of architectural embellishments during wildfires.
- There are no fire tests to assess the contribution of these architectural features to the vulnerability of buildings in wildfire incidents (e.g., if they significantly contribute to building ignition, heat transfer to interior spaces, lead to ignition of exterior walls).
- There are limited codes and standards on the resiliency of these elements to wildfires.

Other References

- Federal Emergency Management Agency (FEMA)
  - Mitigation Assessment Team Report: Marshall Fire Building Performance, Observations, Recommendations, and Technical Guidance (FEMA P-2320) - https://www.fema.gov/sites/default/files/documents/fema_p2320-marshall-fire-mAT-report-without-appendices.pdf

Figure 1.59. Architectural embellishments such as coverings on columns and decorative detailing on exterior wall create additional combustible surfaces where embers and debris collect. Image courtesy of Jensen Hughes/FEMA.

Figure 1.60. Decorative balconies and overhangs. These types of architectural embellishments are prone to combustible debris accumulation. Image courtesy of Jensen Hughes/FEMA.

Figure 1.61. This photo shows an example of where adequate bottom-of-wall clearance is provided, but with obstructions. The wooden latticework can provide a path for fire spread. Image adapted from FEMA P-2320, Mitigation Assessment Team Report: Marshall Fire Building Performance, Observations, Recommendations, and Technical Guidance. FEMA, 2023. https://www.fema.gov/

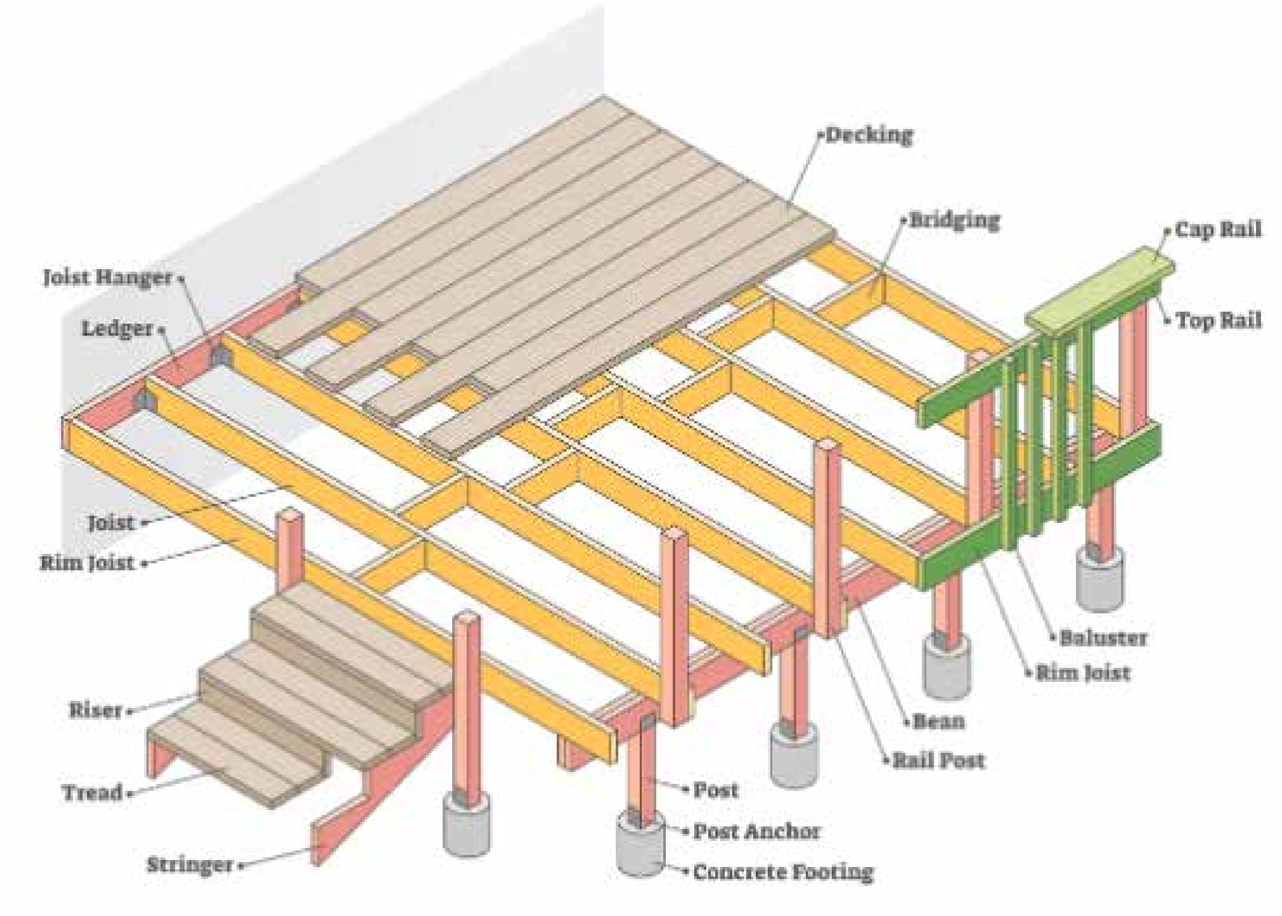


Figure 1.62a. Diagram of parts of a deck. Many of the parts highlighted on this figure can be constructed of combustible materials and are therefore susceptible to ignition.

1.3.7 BALCONIES, DECKS, AND PORCHES CONSTRUCTION & SURFACES

Main Concern(s)

Balconies and decks can pose a significant hazard in the event of a wildfire. One of the main concerns associated with balconies and decks is the large surface area they present for collecting embers, leading to ignition of materials located on the balcony/deck or the balcony/deck itself. Similar to eave overhangs, unique fire induced flows can lead to the accumulation of embers and hot gases in the underside of balconies or elevated decks, potentially leading to ignition of the balcony/deck, particularly where the framing elements are exposed and of combustible construction. In a 2022 study, Hedayati et al. found that once combustible deck joists are ignited during a wildfire, the joists can burn for extended periods of time, exposing the bottom side of the deck boards to flames, ultimately leading to ignition of the entire deck [22]. In addition, most homeowners tend to store various types of combustible fuel loads below and on balconies/decks, such as combustible furniture, BBQs, wood piles etc. Balconies/decks can also introduce additional interfaces with the main structure, presenting numerous joints and potential gaps in the continuity of the exterior wall envelope, which may or may not be fire rated.

For combustible decks and other similar features (e.g., combustible stairs) that are at or near grade, these building components are also susceptible to direct flame impingement from surface fuels and other proximate vegetation. Many existing commercial or residential decks are constructed with less expensive combustible materials such as untreated wood, plastics, and wood-plastic composite products, which are vulnerable to ember and heat exposure in a wildfire event. Higher density deck boards (ipe-like hardwoods and plastic composites) are far less vulnerable to ember ignition than lower density decking (redwood and western red cedar). In addition, decks can oftentimes be built on a slope with hazardous vegetation below, where, if ignited, would result in increased exposure severity to the deck [6]. To limit storage of combustible goods, vegetative debris collection, and other fuel loads from accumulating below a combustible deck, a noncombustible enclosure or skirt around the underside of the deck should be provided. Note, the under-deck enclosure should also be designed to accommodate any flood mitigation measures particularly for decks on slopes greater than 10% (e.g., stop under-deck enclosure 6” from the ground) [25]. In addition, to vertical enclosure around the underside of deck structures, a fire-resistance rated horizontal surface may be needed, but only in the cases where combustible decks have solid walking surfaces. Material selection, orientation, design, storage, and landscaping practices around the deck are all critical to reducing the risk of ignition of the deck and the home.

Key Terminology

- **Balcony:** A platform enclosed by a wall or balustrade on the outside of a building, with access from an upper-floor window or door [61].
- **Deck:** A flat surface capable of supporting weight, similar to a floor, but typically constructed outdoors, often elevated from the ground, and usually connected to a building [62].
- **Flashing:** A sheet of thin, impervious material used to prevent water penetration or seepage into a building and to direct the flow of moisture in walls [63].

Fire Classification and Ratings

Balconies, decks, and other similar projections of combustible construction are treated similar to floors in building codes and therefore are required to be fire-resistance rated, if the code requires floors in the building to achieve a fire resistance rating (e.g., per Table 601 of the *International Building Code*.) That said, building codes oftentimes allow exceptions for balconies and decks (e.g., balconies/decks in Types III, IV, and V construction are permitted to be of any material where sprinkler protection is extended to these areas). This means, balconies and decks in most residential homes are not required to be fire rated.

The *IWUI Code* provides a range of options for appendages and projections such as decks and balconies, including 1-hour fire resistance rating per *ASTM E119*.

The State of California has its own set of *State Fire Marshal Standards (SFM)* which also tests decking materials, and has been adapted into *ASTM E2632* with some modification. Decking materials need to meet the performance requirements of these standards. Chapter 7A of the *California Building Code* provides a complete list of assembly options for the walking surface material of decks, porches, balconies, and stairs in relation to the fire test standards listed below.

Fire Test Standards

- *ASTM E119 Standard Test Methods for Fire Tests of Building Construction and Materials:* https://www.doi.org/10.1520/E0119-22
- *ASTM D2898 Standard Practice for Accelerated Weathering of Fire-Retardant-Treated Wood for Fire Testing:* https://www.astm.org/d2898-10r17.html
- *ASTM D7032 Standard Specification for Establishing Performance Rating for Wood-Plastic Composite and Plastic Lumber Deck Boards, Stair Treads, Guards, and Handrails:* https://www.astm.org/d7032-21.html
- *ASTM D6662 Standard Specification for Polyolefin-Based Plastic Lumber Decking Boards:* https://www.astm.org/d6662-17.html
- *ASTM E84 Standard Test Method for Surface Burning Characteristics of Building Materials:* https://www.astm.org/e0084-21a.html
- *ASTM E2726 Standard Test Method for Evaluating the Fire Test Response of Deck Structures to Burning Brands*
- *ASTM E2632 Standard Test Method for Evaluating the Under-Deck Fire Test Response of Deck Materials*
- *ASTM E2768 Standard Test Method for Extended Duration Surface Burning Characteristics of Building Materials:* https://www.astm.org/e2768-11r18.html
- *UL 723* Standard for Test for Surface Burning Characteristics of Building Materials: https://standardscatalog.ul.com/ProductDetail.aspx?productId=UL723
- *SFM Standard 12-7A-4, Decking:* A two-part test consisting of a heat release rate (Part A) deck assembly combustion test with an under-deck exposure of 80 kW intensity direct flame for a 3-minute duration, and a (Part B) sustained deck assembly combustion test consisting of a deck upper surface burning ember exposure with a 12 mph wind for 40 minutes.
- *SFM Standard 12-7A-4A Decking Alternate Method A:* A heat release rate deck assembly combustion test with an under-deck exposure of 80 kW intensity direct flame for a 3-minute duration.
- *SFM Standard 12-7A-5 Ignition-resistant Material:* A generic building material surface burning flame spread test standard consisting of an extended 30-minute *ASTM E84* or *UL 723* test method as issued for fire-retardant-treated wood.

Referenced Codes and Standards

- 2024 International Wildland-Urban Interface (IWUI) Code:
  - 504.6, 505.6, 506.3 Underfloor Enclosure
  - 504.7 & 505.7 Appendages and Projections
- 2022 California Building Code (CBC):
  - Section 707A.7 Exterior Porch Ceilings
  - 707A.8 Floor Projections
  - 707A.9 Underfloor Protection
  - 707A.10 Underside of Appendages
  - 709A Decking
- 2022 *NFPA 1140* Standard for Wildland Fire Protection:
  - Section 25.4 Overhanging Projections
  - A structural assessment rating form and guide included in Appendix A material associated with Chapter 24 provides an assessment of siding and deck building construction material.

Other Codes and Standards

Additional local requirements, policies, and programs will vary depending on location and adoption in individual jurisdictions.

- Check local, county, and state amendments for additional wildfire codes and standards.
- Check local general plan, multi-hazard mitigation plan, zoning.
- International Residential Code (if applicable - check for wildfire amendments).

Typical Design, Vulnerability, and Mitigation Considerations

Table 27. Design, vulnerability, and mitigation considerations for balconies and decks.

Types of Balconies and Decks	Design, Vulnerability, and Mitigation Considerations
Balconies or Decks with Solid Surface Decking	Constructed using a continuous, solid surface (e.g., tiles, concrete, or brick) on top of a substrate. A solid surface deck can be applied over a substrate, that has a polymer-based waterproofing membrane topping surface. The exposed walking surface can be a combustible or noncombustible material. Balconies with solid surface decking can be susceptible to ember exposure to the top of the deck, particularly at the deck-to-wall interface or joint. Additionally, embers and hot gases can become lodged or trapped under balconies. Consider using noncombustible or ignition-resistant materials for decking surfaces, railings, and siding [6].
Balconies or Decks with Gapped Board Decking	Constructed using spaced deck boards (e.g., wood, plastic, or wood-plastic composite products). Most commercially available deck boards are combustible (including redwood, cedar, and plastic composite lumber decking products). Similar to solid surface decking, balconies with gapped board decking are also susceptible to ember exposure to the top of the deck at the deck-to-wall interface. Consider using noncombustible or ignition-resistant materials for decking surfaces, railings, and siding [6].

General Mitigation Strategies

- For balconies and decks of combustible construction, consider providing the following:
  - Enclosing the underside of the balcony or deck with a noncombustible, vertical enclosure around the outer perimeter of the balcony/deck from the underside of the deck or balcony to grade.
    - If the deck or balcony is over a 10% slope or greater, the enclosure should stop within 6 inches above the ground surface to allow for drainage [64].
    - Where a solid, fire-resistant or ignition-resistant enclosure is provided, ensure appropriate venting is provided and appropriately protected to limit ember intrusion.
  - Replacing any combustible structural supports with noncombustible or ignition-resistant construction materials. Note: Heavy timber supporting elements do not need to be replaced or require protection [14].
  - Where the walking surface is solid, provide one layer of 5/8" Type X gypsum sheathing applied behind the exterior covering on the underside of the balcony or deck.
  - Where possible, access to the underside of the balcony and/or deck should be provided so that regular cleaning of debris can be undertaken prior to core fire season [7].
  - Create a noncombustible zone under the deck or balcony, including a 5' zone around the perimeter. Lay weed barrier and a top level of gravel under and around the deck to minimize the opportunity for vegetation to grow under or near the deck or balcony.

- Replace combustible furniture and cushions/coverings with noncombustible materials, where kept on or under balconies or decks.

- At the connection point of decks and balconies to the main structure, consider:
  - Install metal flashing on ledger boards without any gaps to limit embers and prevent water from accumulating and igniting the main structure or home.
  - Seal any gaps and joints with appropriate firestopping and fire caulking to prevent ember or flame intrusion [6]. The flashing should extend at least 18" (6" for retrofits) up the wall and be tucked in behind the lap joint [65].
  - Alternatively, if the exterior building siding is combustible, remove the bottom two to three courses of siding and replace them with noncombustible siding [65].

- Repair damage to deck or balcony walking surface.

- Keep the deck clear of debris, vegetation, and combustible materials (e.g., seat cushions, straw mats, rugs, pine needles, firewood, etc.). Remove needles and leaf litter from deck board gaps and the deck-to-house connection where embers may easily accumulate.

- Retrofitting the deck is also an option:
  - If the existing deck frame is structurally sufficient, remove the existing deck boards and install new ignition-resistant decking such as those comprised of aluminum, steel, autoclaved aerated concrete, noncombustible tile, or fire-retardant treated wood.
  - Do not use plastic composite deck boards unless the manufacturer has provided documentation that they are noncombustible. Plastic composite and non-FRT wood deck boards are combustible and should not be used.
  - For new construction, apply foil-faced self-adhering bitumen along the length and tops of the joists supporting the deck, and position the tape on each side of the joist near the top where the deck boards are attached [65].
  - If fully replacing a combustible deck surface is not feasible, ensure that under-deck exposure hazards have been addressed (remove combustibles under the deck), and replace the boards closest that are parallel and within one foot of the adjacent exterior wall of the house with a noncombustible material of the same thickness as the rest of the deck [65].
  - Replace dimensional timber railings with railings constructed of fire-resistant materials such as metal, tempered glass, cables, or 4-inch nominal thickness fire-retardant-treated wood [6].
  - When the deck, balcony, stairs, or ramp can accommodate or be reinforced to accommodate additional load, install brick or concrete pavers and a suitable drainage mat over the existing decking [6].

- Install metal flashing on ledger boards that are attached without gaps (Figure 1.65) [38].

- Where possible, replace any stairs and associated handrails that are connected to decks with noncombustible materials. Where this is not achievable, the following actions are recommended [66]:
  - Where stairs are 4 feet or less in width and open underneath, replace the first 6 vertical inches of the bottom of the stairs with noncombustible material. Stair treads should be replaced with noncombustible, solid material.
  - Where stairs are over 4 feet in width and open underneath, clear the underneath of the stair and enclose with solid fire-resistant materials or 1/16" non-corrosive metal screening. Replace the first 6 vertical inches of the bottom of the stairs with noncombustible material. Stair treads should be replaced with noncombustible, solid material. Where the bottom of the stair is enclosed, ensure that it is properly ventilated and provide appropriate vent protection for embers.

Training

NFPA - *Assessing Structure Ignition Potential from Wildfire:* https://www.nfpa.org/Training-and-Events/By-topic/Home-Ignition-Zone

Gaps in Knowledge

- Wildfire building codes and standards do not provide a clear definition or distinction for balconies and decks. It is unclear which provisions are applicable.
- There is no prioritized list of retrofit ideas which include the most effective methods to improve the fire resistance of existing decking.

Other References

- Insurance Institute for Business & Home Safety (IBHS)
  - Preparedeness - https://disastersafety.org/wp-content/uploads/2021/08/WFR-Home-Preparedness-Guide.pdf
- National Fire Protection Association (NFPA)
  - Firewise Toolkit - https://www.nfpa.org/-/media/Files/Firewise/Toolkit/FirewiseToolkit.ashx?la=en
- National Fire Protection Association (NFPA) Firewise
  - Safer from the Start - https://www.nfpa.org/-/media/Files/Training/certification/CWMS/SaferFromtheStart.ashx
- University of California, Agriculture and Natural Resources (UCANR)
  - Wildfire Home Retrofit Guide - http://www.readyforwildfire.org/wp-content/uploads/Wildfire_Home_Retrfit_Guide-1.26.21.pdf
  - Deck - https://ucanr.edu/sites/fire/Prepare/Building/Deck/
- Fine Home Building - https://www.finehomebuilding.com/membership/pdf/9390/021s41055.pdf
- Insurance Institute for Business & Home Safety (IBHS)
  - Wildfire Retrofit Guide - https://disastersafety.org/wp-content/uploads/2019/03/Wildfire-Retrofit-Guide-California_IBHS.pdf
- Federal Emergency Management Agency (FEMA)
  - Mitigation Assessment Team Report: Marshall Fire Building Performance, Observations, Recommendations, and Technical Guidance (FEMA P-2320) - https://www.fema.gov/sites/default/files/documents/fema_p2320-marshall-fire-mAT-report-without-appendices.pdf

- Decreasing Risk of Structure-to-Structure Fire Spread in a Wildfire (Marshall Fire MAT) - https://www.fema.gov/sites/default/files/documents/fema_marshall-fire-mat-decreasing-structure-fire-spread.pdf
- Homeowner's Guide to Reducing Risk of Structure Ignition from Wildfire - https://www.fema.gov/sites/default/files/documents/fema_marshall-fire-mat-homeowners-guide-reducing-risk-structure-ignition.pdf
- Home Builder's Guide to Construction in Wildfire Zones - https://www.govinfo.gov/content/pkg/GOVPUB-HS5-PURL-gpo60104/pdf/GOVPUB-HS5-PURL-gpo60104.pdf

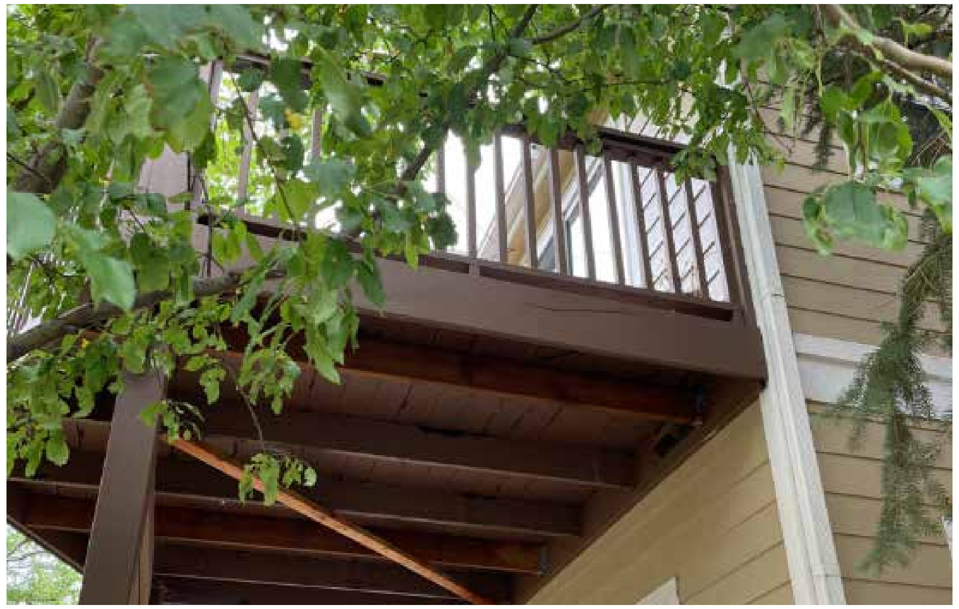


Figure 1.62b. Example of residential balcony comprised of combustible wood construction and decking. This balcony is vulnerable to ignition due to combustible construction, and proximate vegetation. Image courtesy of Jensen Hughes/FEMA.

Figure 1.63. Example of single-family residential home with elevated combustible deck. Decks are commonly constructed without an enclosure to limit the placement of combustible goods or vegetation that can provide receptive fuel bed for embers or surface fire. Image courtesy of Jensen Hughes/FEMA.

Figure 1.64. Example of deck over sloped ground. Some decks are constructed on sloped ground with unmanaged vegetation near and/or below the deck, exposing the deck and associated home to more severe fire exposure. Image courtesy of Jensen Hughes/FEMA.

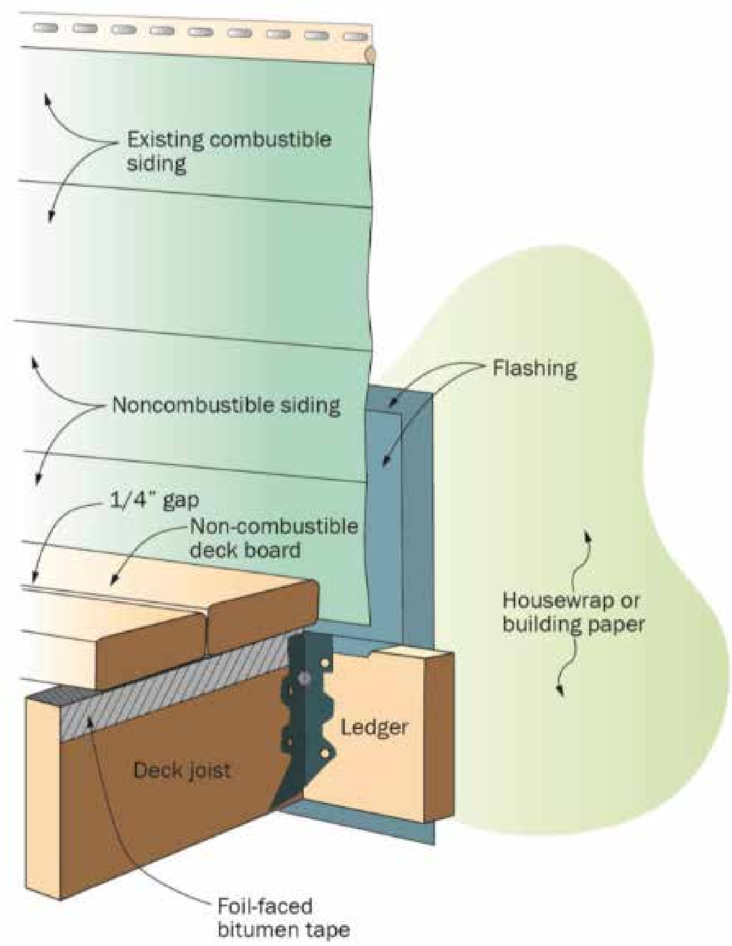
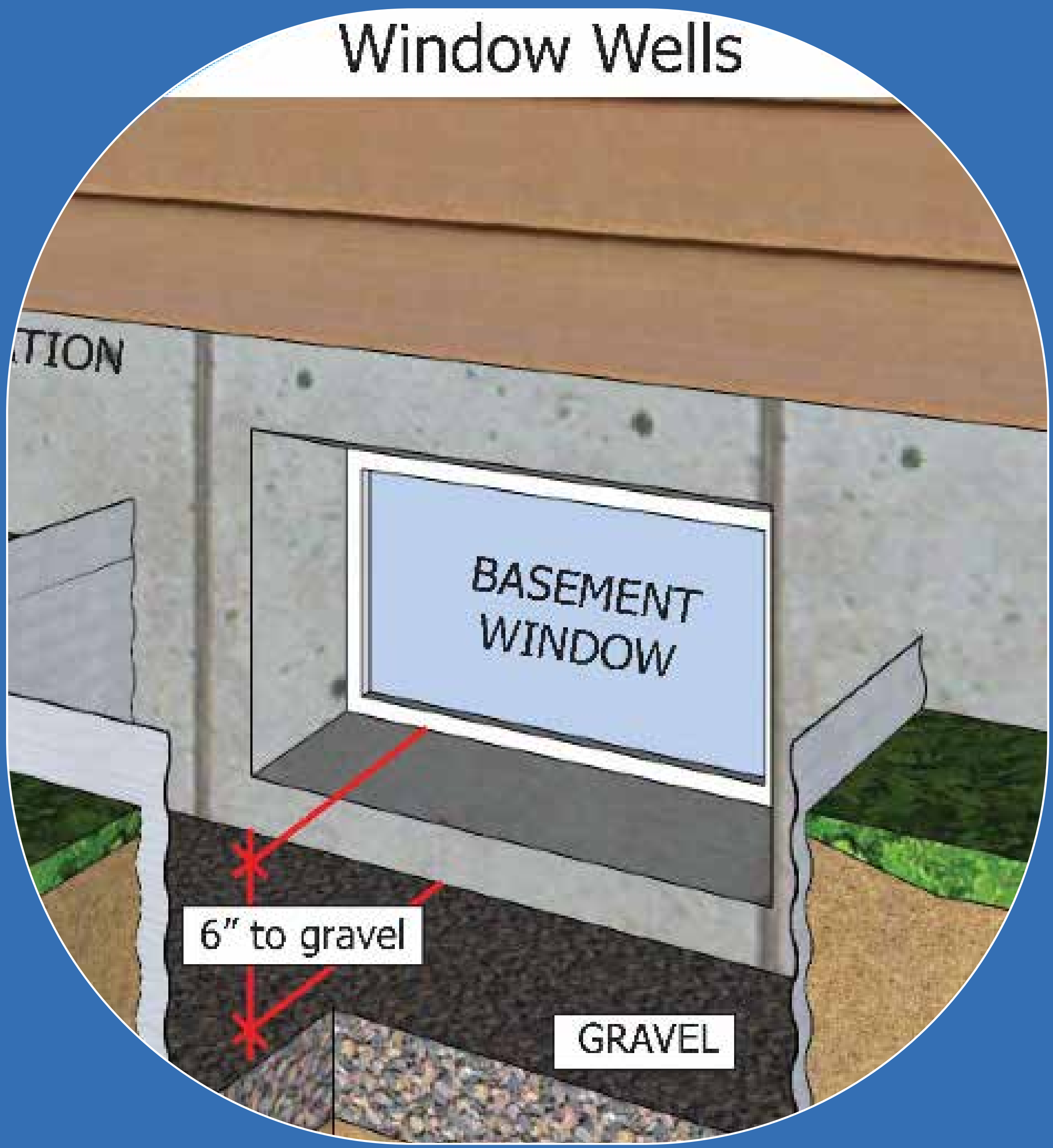


Figure 1.65. Example exterior wall to exterior balcony interface detail. Replacing some portions of the exterior siding with non-combustible material can help protect the home from fire spread. Image adapted from FEMA Marshall Fire MAT, Homeowner's Guide to Reducing Risk of Structure Ignition from Wildfire, FEMA, 2023. https://www.fema.gov/

BOTTOM OF WALL-TO-FOUNDATION

STRUCTURAL HARDENING



1.4.1 CRAWL SPACE / BASEMENT VENT

Main Concern(s)

The intrusion of embers through crawl space or basement vents is a vulnerability that can lead to structure ignition during wildfires. The main concern with crawl space/basement vents is that they can provide several openings where windborne embers, convective heat, and flames from wildfires (particularly surface fuels) can enter the structure and potentially cause ignition of interior building contents and other building components. Both vent inlets and outlets are sources of vulnerability. Debris can also accumulate at crawl space/basement vent openings, providing a source of combustible fuels for ignition.

Key Terminology

- **Crawl Space:** An unoccupied, unfinished, narrow space within a building, between the ground and the first (or ground) floor. The area is called a crawl space because there is typically only enough room to crawl rather than stand (about 3' to 5') [67].

- **Crawl Space Vents:** Active or passive openings or vents through foundation walls or exterior walls providing aeration of the under-floor space between the bottom of the floor joists and the earth under a building (except space occupied by a basement) [68].

- **Ember:** Small burning or glowing pieces of vegetation or other cellulosic-based material.

- **Vent:** A device or assembly placed in an exterior opening of a building that allows for aeration.

Fire Classification and Ratings

The ember and direct flame impingement resistance of vents mounted on vertical walls is defined by *ASTM E2886 Standard Test Method for Evaluating the Ability of Exterior Vents to Resist the Entry of Embers and Direct Flame Impingement*. This test standard prescribes two individual methods to evaluate the ability of the vent opening to resist embers and flame. The ability of such vents to completely exclude entry of flames or embers is not evaluated. Acceptance criteria are not provided in this standard [16]. However, performance criteria are specified in the *California Building Code (CBC)* Section 706A.2 and *NFPA 1144* Section 5.3.3.

Table 28. Vent fire tests for crawl space and basement vents.

Vent Fire Test	Technical Description
Ember Penetration Test (ASTM E2886)	This test method evaluates the impact of ember exposure on vertically or horizontally mounted vents as described in *ASTM E2886* (e.g., gable-end, crawl space, under eave vents). The fire test apparatus allows embers to fall vertically and impinge on the vent mounted horizontally on ledges within the test chamber. An induction fan located at the bottom of the apparatus pulls the air stream through the vent, allowing any embers that pass through the vent to impinge on a combustible target material of cotton. Ember intrusion is evaluated based on observation of occurrence of combustion of a cotton pad on the unexposed side of the vent, given a 3-min exposure to tumbled Class C brands. Performance criteria for the 10-min flame intrusion test, as well as integrity test, are specified in *ASTM E2912*. Visual observations are made for the presence and duration of any flame penetration through the vent. *[CBC and NFPA 1144 acceptance criteria - No flaming ignition of the cotton material on the unexposed side of the vent.]*
Direct Flame Impingement Test and Integrity Test (ASTM E2886)	This test method evaluates the impact of direct flame impingement on vertically or horizontally mounted vents in a test assembly as described in ASTM E2886. Note that ASTM E2886 references ASTM E2912 as the test procedure to be used for the direct flame impingement test (or flame intrusion test) and integrity test. The flame source is directed into the test assembly and directly impinges the vent that is mounted in either a vertical or horizontal position for a 10-min period. Visual observations are made for the presence and duration of any flame penetration through the vent flame. Note, the integrity test is also specified in ASTM E2912 for thermal transmission concerns. *[CBC and NFPA 1144 requirements - No flaming ignition and maximum temperature of the unexposed side of the vent shall not exceed 662°F or 350°C [69].]*
Non-Mechanical Fire Dampers Used in Vented Construction (ASTM E2912)	This fire test response standard assesses the ability of non-mechanical fire dampers used in vented construction in the open state to limit passage of hot gases, radiation, and flames during a prescribed fire test exposure. The fire exposure condition in this test method is sudden direct flame impingement, which produces hot gases, radiation, and flames [23]. This test method does not circumvent or eliminate the fire-resistance rating requirements for construction [23].

Fire Test Standards

- *ASTM E2886/E2886M-14 Standard Test Method for Evaluating the ability of Exterior Vents to Resist the Entry of Embers and Direct Flame Impingement:* https://www.astm.org/e2886_e2886m-20.html
- *ASTM E2912 Standard Test Method for Fire Test of Non-Mechanical Fire Dampers Used in Vented Construction:* https://www.astm.org/e2912-17.html

Referenced Codes and Standards

- *2024 International Wildland-Urban Interface (IWUI) Code:* 504.10, 505.10 Vents
- *2022 California Building Code (CBC):* 706A Vents
- *2022 NFPA 1140 Standard for Wildland Fire Protection:* 25.3.3 Vent Assemblies

Other Codes and Standards

Additional local requirements, policies, and programs will vary depending on location and adoption in individual jurisdictions.

- Check local, county, and state amendments for additional wildfire codes and standards.
- Check local general plan, multi-hazard mitigation plan, zoning.
- International Residential Code (if applicable - check for wildfire amendments).

Typical Design, Vulnerability, and Mitigation Considerations

Table 29. Design, vulnerability, and mitigation considerations for crawl space vents.

Crawl Space Vent Type	Design, Vulnerability, and Mitigation Considerations
Active Venting	In some cases, homes will be provided with mechanically circulated air for the crawl space or basement. In this case, the foundation walls are provided with insulation of an appropriate R-value for the regional climate and a vapor retarder. Active systems may not require perimeter vent inlets in the crawl space (because they are provided with mechanically circulated air), and therefore are not vulnerable to ember, hot gas, or flame intrusion.
Passive Venting	Individual vents are the most widely used crawl space or basement vent type. The ventilation openings are typically 1 ft2 for each 150 ft2 of under-floor area unless the ground surface is covered by a Class 1 vapor retarder (then 1:1500). Passive crawl space vents are typically comprised of expanded sheet metal plates not less than 0.047”, perforated sheet metal plates not less than 0.07”, cast iron grill or grating, extruded load-bearing brick vents, hardware cloth of 0.035”, and/or corrosion-resistant wire mesh of 0.125” [68]. As the vents are typically of metal, they are noncombustible and therefore will not ignite in a wildfire. However, most crawl space vents will only have metal screens of 1/4” to keep out rodents. These screens are not small enough to limit the passage of embers. The noncombustible mesh should be no more than 1/8”, preferably 1/16”. Research has shown that 1/8” mesh screening can still lead to embers with sufficient energy to ignite fine fuels in the attics. With finer mesh screening additional vents may be needed to satisfy building officials. In addition, crawl space/basement vents are of particular concern as they are near the grade level where vegetative debris and other combustible fuel loads accumulate or are stored. This presents high potential for embers, direct flame impingement, and hot gases to directly enter the building and ignite a range of fuels that are often stored in basements. It’s critical to keep the 0-5’ zone around the perimeter of the building clear of any combustible fuel, as well as frequently cleared of vegetative debris, particularly near the crawl space vents.

General Mitigation Strategies

- Common 1/4” screens are ineffective and should be replaced.
- Install vents that are listed to *ASTM E2886* or those listed by the California Office of the State Fire Marshal’s Building Materials Listing Program [70].

- Cover existing vents with wire mesh screen having openings with a maximum of 1/8”, preferably 1/16”. Research has shown that 1/8” mesh screening can still lead to embers with sufficient energy to ignite fine fuels in the attics.
- Replace screens that have painted over or detached from the substrate.
- Vent and covering materials used shall be noncombustible, and corrosion resistant. Do not use fiberglass or plastic mesh because they will melt when exposed to flames [24].
- Use fire-rated caulking around penetrations to seal openings.
- Inspect and maintain vegetation in the vicinity of crawl space vents [71]. Remove combustible fuel loads including vegetation within 0-5’ of building perimeter [24], [49].
- Clean vents on a regular basis to minimize buildup of debris in the mesh [24].
- Consider making vent covers that can be installed prior to the approach of a wildfire (and removed after the wildfire has passed) [24].

Training Programs

Certified Wildfire Mitigation Specialist (CWMS) Certification: https://catalog.nfpa.org/Certified-Wildfire-Mitigation-Specialist-CWMS-Certification-P18148.aspx

Gaps in Knowledge

- Fire testing does not account for weathering of materials prior to fire exposure or the impact of general wildfire environmental conditions (e.g., high winds, flying debris, impact from objects).
- *ASTM E2886* does not evaluate the ability of vents to completely exclude entry of flames or embers [16].
- In most instances, it’s challenging to verify in-the-field if a vent has been fire-tested. (Professional judgement and discussion with the homeowner are required.)
- Air flow calculations may need to be reconsidered or redesign where fire rated vents are installed in existing structures, to ensure sufficient airflow is still satisfied for non-fire purposes.

Other References

- National Fire Protection Association (NFPA)
  - Wildfire Research Fact Sheet - https://www.nfpa.org/-/media/Files/Firewise/Fact-sheets/FirewiseFactSheetsAtticsCrawlSpaces.ashx
  - Firewise How to Prepare Your Home for Wildfire - https://www.nfpa.org//-/media/Files/Firewise/Fact-sheets/FirewiseHowToPrepareYourHomeForWildfires.pdf
- Federal Emergency Management Agency (FEMA)
  - Home Builder’s Guide to Construction in Wildfire Zones - https://www.govinfo.gov/content/pkg/GOVPUB-HS5-PURL-gpo60104/pdf/GOVPUB-HS5-PURL-gpo60104.pdf
  - Mitigation Assessment Team Report: Marshall Fire Building Performance, Observations, Recommendations, and Technical Guidance (FEMA P-2320) - https://www.fema.gov/sites/default/files/documents/fema_p2320-marshall-fire-mAT-report-without-appendices.pdf
  - Decreasing Risk of Structure-to-Structure Fire Spread in a Wildfire (Marshall Fire MAT) - https://www.fema.gov/sites/default/files/documents/fema_marshall-fire-mat-decreasing-structure-fire-spread.pdf
  - Homeowner’s Guide to Reducing Risk of Structure Ignition from Wildfire - https://www.fema.gov/sites/default/files/documents/fema_marshall-fire-mat-homeowners-guide-reducing-risk-structure-ignition.pdf

Figure 1.66. Example of crawl space vent. Crawl space vents are a vulnerability in wildfires if unprotected, as they are oftentimes located proximate to dry grasses, vegetative debris, mulch or other ornamental landscaping. Image courtesy of Jensen Hughes/FEMA.

Figure 1.67. Example of dryer vent and other mechanical vents. When left unprotected, these can provide an entry point for embers into the home. Image courtesy of Jensen Hughes/FEMA.

1.4.2 WINDOW / LIGHTWELL

Main Concern(s)

Window/light wells, while serving several uses to the home, present multiple wildfire vulnerabilities. The design of the well creates deep corners along the exterior wall which encourages dry leaves, pine needles, and other combustible litter or debris to gather. Debris ignition can present a source of flame exposure to the structure, particularly at the window opening it surrounds. The configuration of these wells creates a hazardous condition where combustible materials that have collected in the light/window well over time will be directly adjacent to the window and frame, which already experience their own vulnerabilities.

Key Terminology

- **Window/lightwell:** U-shaped, ribbed metal or plastic product designed to fit around basement windows, providing a space between the window and the surrounding earth to allow light into sub-grade structures. More notably, a window well can prevent water damage to a basement while also providing a route for an emergency escape and rescue opening with a finished sill height below the adjacent ground level during an emergency [68], [72].

- **Window/lightwell covers:** A physical barrier between the well and the ground elements to prevent debris build-up in the well. The covering can be constructed of mesh, plastic bubble covers, grill-type, etc. Covers are also provided to prevent injuries from falls and to discourage children and animals from entering the wells and becoming injured or trapped [72].

- **Defensible space:** The selection, location, grouping, and maintenance of vegetation on the property in such a manner that the opportunity for a fire to burn directly to a structure is minimized [73].

Fire Rated Assemblies

No standard or tested assemblies exist for lightwells installed in the WUI.

Fire Test Standards

None identified at time of publication.

Referenced Codes and Standards

There are currently no requirements in adopted codes and standards that address window/lightwells.

Other Codes and Standards

Additional local requirements, policies, and programs will vary depending on location and adoption in individual jurisdictions.

- Check local, county, and state amendments for additional wildfire codes and standards.
- Check local general plan, multi-hazard mitigation plan, zoning.
- International Residential Code (if applicable - check for wildfire amendments).

Typical Design, Vulnerability, and Mitigation Considerations

Table 30. Design and construction considerations for lightwells.

Lightwell Types	Design and Construction Considerations
Window Wells	Sizing for window wells needs to account for fully equipped firefighters conducting emergency rescue operations. Window wells may be designed to provide an emergency point of egress in conjunction with emergency escape and rescue openings from windows below grade. Window wells may be designed to drain excess rainwater away from the building's foundation. Replace combustible lightwells and associated combustible covers (e.g., polycarbonate plastic or fiber glass) with noncombustible materials. Maintain areas in and around lightwells to be clear of debris, and combustible materials. Do not store combustible items, such as firewood, in a lightwell.
Window Well Covers	Window well covers are generally custom fitted. Covers are generally constructed of mesh, plastic bubble covers, and grill-type metal. Bars, grilles, covers, and screens for window wells need to comply with minimum required opening sizes. These devices are required to be releasable or removeable from the inside without the use of a key, tool, or force greater than that which is required for normal operation of any emergency escape and rescue opening that is being served [68]. Window wells and their covers are often constructed with combustible materials such as plastic and bubble covers. It is recommended that covers be provided to keep debris out of the well. Recommend using noncombustible covers. Metal window well covers are referred to as grates and are generally implemented to protect the building from intrusion. Where a mesh cover is provided, clean vents on a regular basis to minimize buildup of debris in the mesh.

General Mitigation Strategies

- Replace combustible lightwells and associated combustible covers (e.g., polycarbonate plastic or fiber glass) with noncombustible materials or minimum 1/8" noncombustible, non-corrosive screening.
- Maintain areas in and around lightwells to be clear of debris and combustible materials.
- Do not store combustible items, such as firewood, in a lightwell.
- Provide a lightwell cover, constructed of noncombustible material to limit build-up of debris in the lightwell. This may not be advisable if the window well is provided for egress purposes.
- Where a mesh/screen cover is provided, clean vents on a regular basis to minimize buildup of debris in the mesh.
- Provide a minimum of 6" noncombustible vertical separation between the bottom of the lightwell and the siding/exterior wall.

Training Programs

- Certified Wildfire Mitigation Specialist (CWMS) Certification: https://catalog.nfpa.org/Certified-Wildfire-Mitigation-Specialist-CWMS-Certification-P18148.aspx
- NFPA - *Assessing Structure Ignition Potential from Wildfire*: https://www.nfpa.org/Training-and-Events/By-topic/Home-Ignition-Zone

Gaps in Knowledge

- No codes or standards related to the appropriate design, installation, and material selection of lightwells in the Wildland-Urban Interface.
- Wildfire home hardening guidance does not mention material selection or design of lightwells.
- Manufacturers do not have specific guidance for homeowners installing lightwells on their property in the Wildland-Urban Interface.
- No research has been conducted related to lightwell performance and impact in a wildfire.

Other References

- National Fire Protection Association (NFPA)
  - 1144 Standard for Reducing Structure Ignition Hazards from Wildland Fire: 5.6.4. Exterior vertical walls
- Federal Emergency Management Agency (FEMA)
  - Home Builder's Guide to Construction in Wildfire Zones - https://www.govinfo.gov/content/pkg/GOVPUB-HS5-PURL-gpo60104/pdf/GOVPUB-HS5-PURL-gpo60104.pdf

Figure 1.68. Example of light well that is hardened. Noncombustible grates are one way to prevent combustible debris from collecting in the window well. Image courtesy of Jensen Hughes/FEMA.

Figure 1.69. Example of unmitigated window well (debris collected at bottom, plants growing into and out of window well).

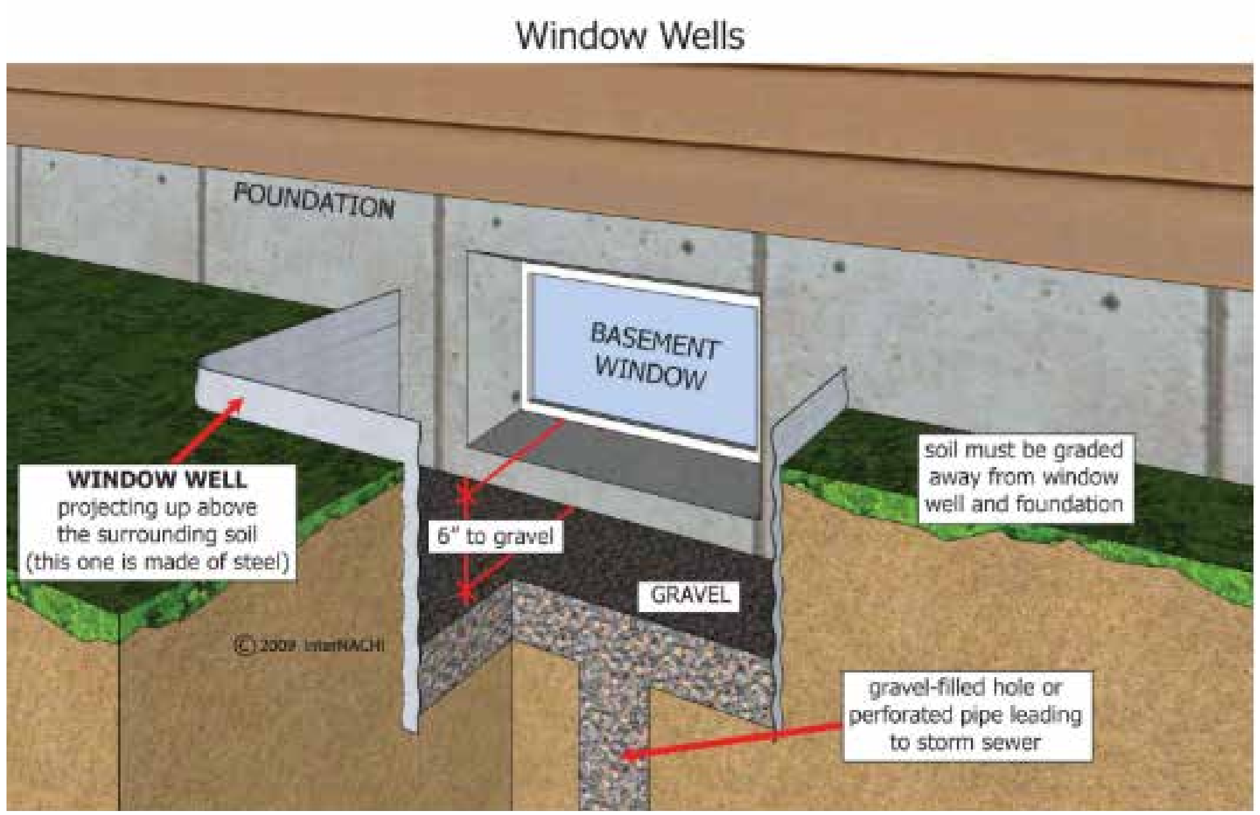


Figure 1.70. Example of window well components including drainage. Many components of this image can be constructed of combustible materials and are susceptible to ignition. Image courtesy of InterNACHI.

1.4.3 FOUNDATION

Main Concern(s)

The foundation of a building is often the first area to meet a spreading wildfire, as it the closest part of the structure to the ground. Debris can easily accumulate at the base of the foundation, which can be ignited by embers and surface fuels fires. These embers can ignite combustible foundation and siding, penetrate crawlspace vents, and breach basement windows [6]. Where the underside of the first floor is supported by pile or piers of combustible construction (i.e., timber), direct flaming impingement and/or embers could ignite the structure and lead to structural instability and damage.

Key Terminology

- **Basement Foundation:** Full basement foundations cover the building's perimeter and are typically constructed of poured concreted walls and footing approximately 6-8' below ground level. Full basements can either be finished or unfinished. Finished basements are insulated and installed with drywall and flooring, providing living and storage space. Unfinished basements are usually not insulated, and their walls and floors are left bare [74].

- **Crawl Space Foundation:** Crawl space foundations are elevated several feet off footings, leaving a small, protected space (usually 3' or 4') between the ground and base of the building. The foundation walls are built partially underground and shorter than basement foundation walls [74]. They are shallower than full basements.

- **Open Foundations (e.g., pier & pilings, post, caissons, or stilts foundation):** A foundation that includes openings beneath the structure, such as an open crawl space or similar open areas below the ground floor construction. They typically stand several feet above the ground.

- **Shallow Foundation:** An enlarged base (in the plan area) for the support of the columns or walls of the superstructure in order to spread the stresses of the columns or walls onto a wider founding stratum without failure [75]. Shallow foundations can further be categorized as raft, mat, or slab-on-grade foundations and are useful in controlling differential settlement over low-bearing capacity soil.

- **Wall Footing:** A wall footing is a continuous strip of concrete that serves to spread the weight of a load-bearing wall across an area of soil [76].

Fire Rated Assemblies

The fire resistance rating of foundation structural elements is determined by the construction type of the building.

The fire resistance of structural elements and systems is defined by *ASTM E119* or *UL 263 Standard Test Methods for Fire Tests of Building Construction and Materials*. This test standard is applicable to assemblies of masonry units and to composite assemblies of structural materials for buildings, including loadbearing walls and partitions, columns, girders, beams, slabs, and composite slab and beam assemblies for floors and roofs (inclusive of foundations) [48].

The standard is used to measure and describe the response of materials, products, or assemblies to heat and flame under controlled conditions, but does not by itself incorporate all factors required for fire hazard or fire risk assessment of the materials, products, or assemblies under actual fire conditions [48]. This is due to limitations of the size of the specimens tested, size of the furnace, standard fire exposure, etc. However, the test standard is one of the most widely adopted methods for comparing the performance of building construction materials, elements, and assemblies to a standard fire exposure.

The test method includes measurements of exposed and unexposed surface temperature, as well as the ability of an element or assembly to maintain structural stability, integrity, and insulation when exposed to a severe, standard fire exposure. The standard fire exposure simulates severe interior building fire conditions during flashover conditions. Depending on how the floor assembly performs against the performance criteria for stability, integrity, and insulation, the structural element can achieve anywhere from a 1-hour up to a 4-hour fire resistance rating.

Table 31. Performance categories for foundations in *ASTM E119* and *UL 263*.

Performance Category	Technical Description [48]
Stability	The ability of the structural element or assembly to sustain the applied load during the fire-resistance test.
Integrity	The ability of a structural element or assembly to limit the passage of flame or gases hot enough to ignite cotton waste.
Insulation	The ability of a structural element or assembly to limit transmission of heat to the unexposed side such that the temperature on the unexposed surface does not exceed more than 250°F (139°C) above the initial temperature. ***Note:*** This is primarily for floor/roof assemblies.

Fire Test Standards

- *ASTM E119 Standard Test Methods for Fire Tests of Building Construction and Materials:* https://www.astm.org/e0119-20.html
- *UL 263 Fire Tests of Building Construction and Materials:* https://global.ihs.com/doc_detail.cfm?document_name=UL%20263&item_s_key=00097028

Referenced Codes and Standards

- *2024 International Wildland-Urban Interface (IWUI) Code:* No explicit requirements
- *2022 California Building Code (CBC):*
  - Section 707A.3.1 Extent of exterior wall covering shall extend from the top of the foundation to the roof
  - Section 602 Construction Classification
  - Section 703 Fire Resistance Ratings and Fire Tests
- *2022 NFPA 1140 Standard for Wildland Fire Protection:* 25.6.4 Exterior vertical walls

Typical Design, Vulnerability, and Mitigation Considerations

Table 32. Design, vulnerability, and mitigation considerations for foundations.

Foundation Types	Design, Vulnerability, and Mitigation Considerations
Slab-on-Grade Foundation	Slab-on-grade foundations are shallow foundations typically constructed of approximately 6" of reinforced concrete (i.e., noncombustible) and footings 2' into the ground. As the foundation directly rests on the ground below at a shallow depth, it is less vulnerable to exposure to embers, direct flame impingement, or hot gases from wildfire threats. This foundation type does not have crawl space vents, which are vulnerable to ember intrusion. However, the portion of the foundation that is above grade has been shown in past fire incidents to experience high temperatures, leading to spalling and damage [77].
Crawl Space Foundation	Crawl space foundations are an elevated foundation with footings for support, typically raised 18" to 4' above ground. Concrete or cinder blocks extend past the footings and close off unvented areas [78]. As these foundations are primarily constructed of noncombustible materials, they are not vulnerable to ignition. Crawl space foundations are common in warm, moist climates where it is advantageous to raise the structure slightly off the ground to avoid moisture [79]. To minimize moisture build-up in crawl spaces, crawl spaces require several vents around the perimeter of the foundation. As described in the crawl space vents section, these vents are highly vulnerable to ember intrusion, hot gases, and/or direct flame breaching the interior crawl space. Refer to Section 1.4.1 *Crawl Space/Basement Vents* for mitigations. Combustible items stored in basements or crawlspaces (such as household goods in cardboard boxes) can become fuel in a fire [6].
Basement Foundation	Full basement foundations consist of structural foundation walls that bear on foundation footings running along the perimeter [80]. Basement foundations are typically constructed of concrete, cement block, brick, or stone. All these materials are noncombustible, and therefore less vulnerable to wildfire threats. That said, high intensity wildfires have been observed to cause spalling or other damage to the top of basement foundations that are above grade. Similar to crawl space foundations, full basements require some form of ventilation. Direct flame, embers, or hot gases can enter through crawlspace vents or breached basement windows. Refer to Section 1.4.1 *Crawl Space/Basement Vents* for vulnerabilities and mitigations. Combustible items stored in basements or crawlspaces (such as household goods in cardboard boxes) can become fuel in a fire [6].
Open Foundation	Pier & beam style foundations are considered "open foundations" and can be comprised of a range of combustible (e.g., wooden piers) and noncombustible (e.g., concrete, CMU, brick) construction. As this style of foundation is raised and open around the perimeter, it is highly vulnerable to ember intrusion and ignition of debris or other combustible materials below the foundation (or even the foundation itself). Wood lattice screens can be ignited by direct flame, embers, or hot gases. Lattice screens often trap combustible debris such as leaves and paper, increasing the potential for ignition. Ignition of a lattice screen can lead to ignition of the underside of the first floor. Combustible debris or storage items (such as firewood or gas in a container) in an open foundation can be ignited, leading to ignition of the underside of the first floor [6]. To mitigate potential ember intrusion or direct flame impingement from a surface fuels fire, a fire-resistive or ignition-resistant enclosure could be provided around the perimeter of the foundation. However, ventilation would need to be provided with appropriate ember protection. Alternatively, the structural elements could be provided with a 1-hour rated jacket around the piers, along with an ignition-resistant or fire-resistant enclosure for the underside of the substructure floor. (Attach 5/8" thick exterior Type X gypsum board to the underside of the joists. Attach fire-retardant-treated plywood, fiber-cement panels, or metal siding panels over the gypsum board [6]). An ember resistant zone (0-5') should also be maintained around the perimeter of the foundation, and below the foundation.

General Mitigation Strategies

- Where possible, provide at least 6” of vertical clearance of noncombustible materials along the exterior wall from the ground to the siding. Note that this minimum assumes a 5’ ember resistant zone around the building.
- Maintain a 5’ ember resistant zone around the building by clearing debris, dead vegetation, and any combustible items within this zone.
- Repair damage to foundation and fill in any gaps at joints with firestopping to minimize embers intrusion.
- Where an existing building has an open foundation:
  - Where possible, open foundations should be enclosed to remove the opportunity for debris, vegetation, and combustible items from accumulating under the building.
  - Remove any combustible items under the structure, and keep it clear of debris, vegetation, and storage.
  - Protect the underside of the floor structure and supporting structure with fire-rated, noncombustible, or fire-resistant materials.
  - Provide noncombustible skirting to help reduce the accumulation of debris under the building (1/16” wire mesh).

Training

None identified at time of publication.

Gaps in Knowledge

- Minimal guidance related to the design, material selection and maintenance of foundation walls in the Wildland-Urban Interface.
- Minimal guidance related to mitigation options for open foundation configurations in the Wildland-Urban Interface.

Other References

- Federal Emergency Management Agency (FEMA)
  - Home Builder’s Guide to Construction in Wildfire Zones - https://www.govinfo.gov/content/pkg/GOVPUB-HS5-PURL-gpo60104/pdf/GOVPUB-HS5-PURL-gpo60104.pdf
    - Fact Sheet #7, Exterior Walls, for guidance on walls and wall coverings
    - Fact Sheet #8, Vents, for guidance on crawlspace vents
    - Fact Sheet #10, Windows and Skylights, for guidance on windows
  - Mitigation Assessment Team Report: Marshall Fire Building Performance, Observations, Recommendations, and Technical Guidance (FEMA P-2320) - https://www.fema.gov/sites/default/files/documents/fema_p2320-marshall-fire-mAT-report-without-appendices.pdf
  - Homeowner’s Guide to Reducing Risk of Structure Ignition from Wildfire - https://www.fema.gov/sites/default/files/documents/fema_marshall-fire-mat-homeowners-guide-reducing-risk-structure-ignition.pdf
- UC Extension, Agriculture, Biotechnology & Natural Resources - http://www.readyforwildfire.org/wp-content/uploads/Wildfire_Home_Retrfit_Guide-1.26.21.pdf

Figure 1.71. Mat foundation. Mat foundations are less susceptible to ember intrusion, however can be damaged in a fire event.

Figure 1.72. Example of an open pier and stilts foundation. This photo shows combustible covering around the open foundation, which presents a hazard to the home. Image by RBerteig on Flickr., CC BY 2.0.

Figure 1.73. Example of a crawl space foundation. Crawl space foundations typically contain vents that are susceptible to ember intrusion.

Figure 1.74. Example of wall footing. Footings can shift over time and create gaps along the interface of the foundation to the superstructure.

Figure 1.75. Example of brick foundation below siding. While brick is a non-combustible material and there is less of a concern of a surface fire breaching the home via the foundation, it is important to note that the foundation shown still contains vents that must be protected.

ATTACHMENTS

STRUCTURAL HARDENING

ATTACHMENTS 1.5

1.5.1 FENCING

Main Concern(s)

Fences can become hazardous in the event of a wildfire, particularly if they connect directly to a structure. Typical wooden post-and-board fences can provide a "wick" leading directly to the structure. These fences also have ledges or spaces between components that can allow embers to collect [65]. The bottom of fences also collect debris that, when combined with combustible fencing, can become a fuel source to carry fire directly to the structure and ignite the building through radiant heat, convective heat, or direct flame contact [6]. This is further supported by a recent NIST study that found that when combustible objects burn in close proximity to fences, fire hazards are disproportionately higher [2]. There are also several case studies performed by NIST that have identified fences and mulch as common contributors to fire spread within communities [17], [81], [82]. Since fences are often just below the eaves of a house, there is the potential to carry the fire up to the eaves and thus to the roof. Additionally, fences can also create access problems for fire crews trying to enter a yard during an emergency.

Key Terminology

- **Non-combustible:** In building construction material, noncombustible means one of the following:
  - Material of which no part will ignite and burn when subjected to fire. Any material passing *ASTM E136* will be considered noncombustible [83].
  - Material having a structural base of noncombustible material as defined above, with a surfacing material not over 1/8" thick which has a flame-spread index of 50 or less [83].

Fire Rated Assemblies

None identified at time of publication.

Fire Test Standards

There are no test standards for fencing assemblies.

Referenced Codes and Standards

- *2024 International Wildland-Urban Interface (IWUI) Code:* No explicit requirements
- *2022 California Building Code (CBC):* No explicit requirements
- *2022 NFPA 1140 Standard for Wildland Fire Protection:* Section 25.6.3 Appendages and Projections

Other Codes and Standards

Additional local requirements, policies, and programs will vary depending on location and adoption in individual jurisdictions.

- Check local, county, and state amendments for additional wildfire codes and standards.
- Check local general plan, multi-hazard mitigation plan, zoning.
- International Residential Code (if applicable - check for wildfire amendments).

Typical Design, Vulnerability, and Mitigation Considerations

Table 33. Vulnerability and mitigation considerations for fencing.

Fencing Types	Vulnerability and Mitigation Considerations
Wooden Post-and-Board Fences	Can become fuel for a wildfire, especially when weather-beaten. Fences can collect embers and firebrands in a wildfire and act as a horizontal ladder fuel by allowing the fire to travel along the fence toward the main building. Wooden fences typically have no resistance to ignition or flame spread. Dense hardwoods such as red oak, white oak, hickory/pecan, and walnut are more fire resistant than pines and other softwoods [6].
Vinyl Fences	Although less vulnerable to embers, can ignite through direct flame exposure if vegetative debris has accumulated at its base. The vinyl will deform and melt when exposed to radiant heat [6].
Metal Fences	Metal fences are more fire-resistant than plastic fences. Wire fences such as barbed wire, hog wire, and chain link have little or no effect on fire passage. It should be noted that if combustible materials have accumulated in or around the fence or the fence contains combustible materials such as wooden posts, the fence can act as a ladder fuel [6].
Concrete, Stone, or Masonry	Noncombustible and can act as a barrier to a wildfire by deflecting flames away from a building, but the passage of airborne embers (also called firebrands) will not be significantly altered. These materials are the most effective at minimizing the potential for damage to a building from a wildfire [6].

General Mitigation Strategies

- If practical, replace combustible fences using noncombustible or ignition-resistant materials (e.g., fire retardant treated lumber for exterior exposure). Stone, decorative block, brick, precast concrete, and steel are all noncombustible materials that can be used to construct visually pleasing fences [65].
- If existing wood fences cannot be fully replaced, replace the portion of the fence within 5' from the building with noncombustible materials (e.g., a metal gate that is attached to the fence on one side and to the exterior siding on the other side). Fences parallel to the home should also be constructed of noncombustible materials if a single fence is within 10' of exterior walls [65]
- Remove combustible materials such as trash bins, firewood, mulch, or other combustible materials against the fence. Ensure that all combustible components are at least 5' from the building to prevent heat and flames from igniting the building [6].
- Remove combustible mulch near fences and replace with noncombustible mulch, gravel, or other similar material.
- Remove debris and dead vegetation at the bottom of fences.
- Remove plants where the fence is being used as a trellis as it creates and traps ignitable vegetative debris. Any grass along the fence line should be regularly trimmed.
- Ensure the fence or gate is not an access problem for fire crews.
- Maintain physical condition of fence and replace any damaged, deteriorated components.
- Back-to-back fencing along either side of a property line should not be used [65].

Training Programs

Certified Wildfire Mitigation Specialist (CWMS) Certification: https://catalog.nfpa.org/Certified-Wildfire-Mitigation-Specialist-CWMS-Certification-P18148.aspx

Gaps in Knowledge

- Fire testing and standards do not exist for fencing installed in the Wildland-Urban Interface.
- Design and installation guidelines do not exist for fencing in the Wildland-Urban Interface.

Other References

- Federal Emergency Management Agency (FEMA)
  - Home Builder's Guide to Construction in Wildfire Zones, Technical Fact Sheet No. 14 - https://www.govinfo.gov/content/pkg/GOVPUB-HS5-PURL-gpo60104/pdf/GOVPUB-HS5-PURL-gpo60104.pdf
  - Mitigation Assessment Team Report: Marshall Fire Building Performance, Observations, Recommendations, and Technical Guidance (FEMA P-2320) - https://www.fema.gov/sites/default/files/documents/fema_p2320-marshall-fire-mAT-report-without-appendices.pdf
  - Decreasing Risk of Structure-to-Structure Fire Spread in a Wildfire (Marshall Fire MAT) - https://www.fema.gov/sites/default/files/documents/fema_marshall-fire-mat-decreasing-structure-fire-spread.pdf
  - Homeowner's Guide to Reducing Risk of Structure Ignition from Wildfire - https://www.fema.gov/sites/default/files/documents/fema_marshall-fire-mat-homeowners-guide-reducing-risk-structure-ignition.pdf
- National Institute of Standards and Technology (NIST)
  - Knocking Down Fences for Fire Research - https://www.nist.gov/blogs/taking-measure/knocking-down-fences-fire-research
  - Structure Vulnerability to Firebrands from Fences and Mulch - https://www.nist.gov/publications/structure-vulnerability-firebrands-fences-and-mulch
  - Effects of Wind Speed and Angle on Fire Spread along Privacy Fences - https://www.nist.gov/publications/effects-wind-speed-and-angle-fire-spread-along-privacy-fences

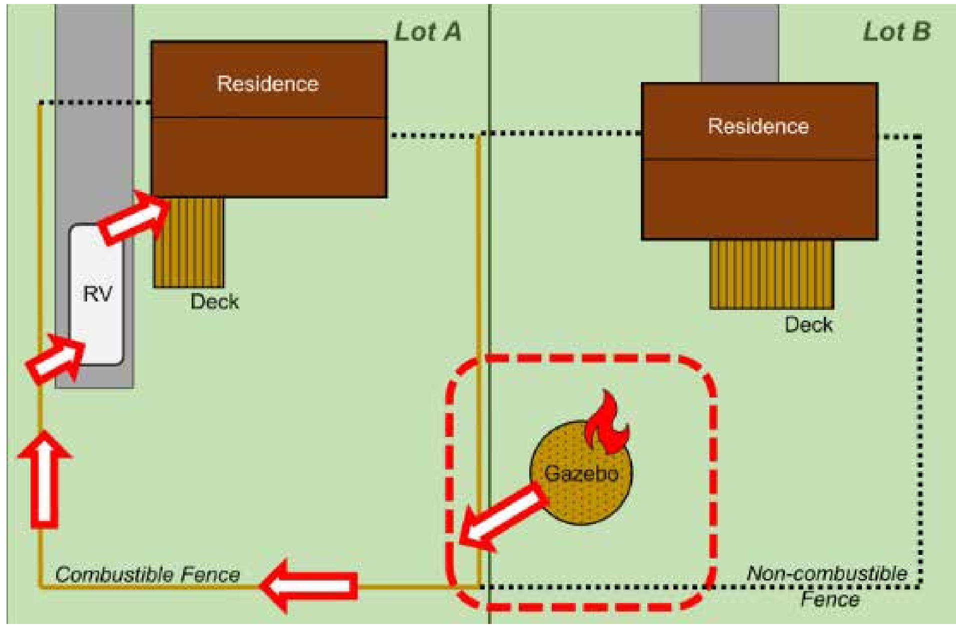


Figure 1.76. Fuel on Lot B is adequately spaced from Residence B; however, fuel is agglomerated at the fence, which opens the pathway to Residence A. Ignition on Lot B may still result in pathway shown, Gazebo -> Fence -> RV-> Residence A, despite noncombustible fence attachments on both residences. Image adapted from NIST Technical Note No. 2205, NIST, 2022. https://doi.org/10.6028/NIST.TN.2205

Figure 1.78. Example of metal fence. Where fences are located within 5' of the structure, they should be of noncombustible material such as metal. Image courtesy of Jensen Hughes/FEMA.

Figure 1.77. Example of cedar privacy fence attached to house. Any fencing that directly connects to the home should be replaced with noncombustible material for at a minimum 5' within the vicinity of the home. Image courtesy of Jensen Hughes/FEMA.

Figure 1.79. Example of cedar split rail fence. Wooden fences present a greater hazard than those of noncombustible materials. Image courtesy of Jensen Hughes/FEMA.

Figure 1.80. Example of stone privacy fence. Stone privacy fences are non-combustible and are considered inherently fire-resistant. Image courtesy of Jensen Hughes/FEMA.

1.5.2 COVERINGS (CANOPIES, AWNINGS, SHADES)

Main Concern(s)

Attachments directly protruding from the façade of the building, such as window awnings, shades, patio covers, and canopies can pose a hazard in the event of a wildfire. These components are susceptible to both direct flame exposure and firebrand accumulation and, if combustible, can become a fuel source to carry fire directly to the structure. Awnings are often composed of fabric or other lightweight material that can be readily ignited, providing a direct flame impingement on the structure. Material selection, design, and debris clearance of these attachments are critical to mitigating the impact of wildfire.

Key Terminology

- **Awnings:** A sheet of canvas or other material stretched on a frame and used to keep the sun or rain off a storefront, window, doorway, or deck [84].

- **Canopy:** A structure or architectural projection of rigid construction over which a covering is attached that provides weather protection, identity or decoration, and may be structurally independent or supported by attachment to a building on one end and by not less than one stanchion on the outer end [14].

Fire Classification and Ratings

- *The International Building Code (IBC)* provides several requirements for the fire-resistant design and construction of awnings and canopies in Section 3105.
- The frames supporting awnings can be rated to achieve a 1-hour fire resistance rating per *ASTM E119*.
- The materials of awnings and canopies can be classified based on their performance to *NFPA 701*, or their flame spread index per *ASTM E84* or *UL 723* or performance to *NFPA 286*.

Note: There is no wildfire specific fire classification or rating.

Fire Test Standards

Currently, there are no wildfire specific fire test standards to assess the performance of awnings, covers, or shades to embers. The following fire test standards are based on standard interior building fire exposures.

- *ASTM E119 Standard Test Methods for Fire Tests of Building Construction and Materials:* https://www.astm.org/e0119-20.html
- *UL 263 Fire Tests of Building Construction and Materials:* https://global.ihs.com/doc_detail.cfm?document_name=UL%20263&item_s_key=00097028
- *ASTM E84 Standard Test Methods for Surface Burning Characteristics of Building Materials*
- *UL 723 Test for Surface Burning Characteristics of Building Materials*

- *NFPA 268 Standard Test Method for Determining Ignitability of Exterior Wall Assemblies Using a Radiant Heat Energy Source:* https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=268
- *NFPA 701 Standard Methods of Fire Tests for Flame Propagation of Textiles and Films:* https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=701

Referenced Codes and Standards

- *2024 International Building Code (IBC):* Section 3105 Awnings and Canopies
- *2024 International Wildland-Urban Interface (IWUI) Code:* No explicit requirements
- *2022 California Building Code (CBC):* Section 3105 Awnings and Canopies (not strictly for WUI)
- *2022 NFPA 1140 Standard for Wildland Fire Protection:* Section 25.4 Overhanging Projections

Typical Design, Vulnerability, and Mitigation Considerations

- Attached canopies/awnings can either be attached to a building or can also be mounted on the ground by the support of posts. Retractable canopies are popular as a space-saving solution.
- Freestanding, portable, umbrella shades may also be used.
- Material selection: Awnings or canopies are typically constructed of fabric, wood, polycarbonate, or metal.
- Combustible materials: Fabrics, including canvas, vinyl, and acrylic are typically the cheaper option, with easier installation. In addition, wood or polycarbonate materials may be used. These materials are combustible and should be avoided in the WUI.
- Noncombustible or ignition-resistant materials: Metals including aluminum, steel, and copper provide a more durable option. Due to the weight of the components, it is typically more costly, and requires professional installation. Metal coverings are suggested in the WUI.

General Mitigation Strategies

- Ensure awnings and canopy materials consist of Class A flame spread per *ASTM E84* or satisfy other alternative specified in Section 3105 of the *IBC*.
- Keep all awnings and canopies clear of debris and vegetation. Remove needles and leaf litter accumulation on or around the covering or retractable mechanism.
- Do not place or store combustible materials under coverings [11].
- Repair damage to awnings and canopies to reduce the accumulation of embers and firebrands between damaged materials.
- Where any gaps or holes are presented at the attachment points to the structure, provide with appropriate firestopping and fire caulking.

Training

Certified Wildfire Mitigation Specialist (CWMS) Certification: https://catalog.nfpa.org/Certified-Wildfire-Mitigation-Specialist-CWMS-Certification-P18148.aspx

Gaps in Knowledge

- Currently, there are no wildfire specific fire test standards to assess the performance of awnings, covers, or shades to embers.
- The contribution of awnings and canopies to the vulnerability of homes to wildfire threats is uncertain.
- Relative benefit of removing or retracting awnings and canopies during preparations for a wildfire is unknown.

Other References

None identified at time of publication.

Figure 1.81. Example of patio covering that provides a potential source for debris and ember collection. The covering should be of ignition-resistant materials. Image courtesy of Jensen Hughes/FEMA.

Figure 1.82. Example of canopy. If the canopy material is made of combustible material, the canopy can potentially act as a wick to ignite the home. Additionally, combustible debris can accumulate on canopies configured this way.

Figure 1.83. Example of retractable pergola cover. If the cover is made of combustible material, this cover can ignite and pose an exposure hazard to the home. Image by European Rolling Shutters, CC BY 2.0.

SPRINKLER SYSTEMS

STRUCTURAL HARDENING - SUPPRESSION SYSTEMS

1.6.1 SPRINKLER SYSTEMS

Main Concern(s)

Interior building fire sprinkler systems are not effective under significant exterior exposure and typically do not provide protection to exterior construction elements. Potential functions of exterior sprinkler systems that may be intended include the control of embers landing adjacent to the protected structure and/or reduction of radiant energy from adjacent wildland or building fire exposure. The latter function would require a higher level of water delivery than control of embers.

There is no widely accepted design standard for exterior sprinklers with respect to wildland fire exposure or guidance for extension of interior residential fire sprinkler systems to protect exterior portions of a structure. Available exterior exposure protection sprinkler system information and criteria is based on building-to-building exposures and is not relevant to residential wildfire exposure. Other main concerns with exterior sprinkler protection in wildland fire applications include:

- Lack of widely accepted fire test standards, design criteria, and performance specifications for the sprinkler system (e.g., design area, flow rates, duration), water supplies (e.g., robustness of water supply, duration, source), activation method (e.g., manual, detection device), etc., for the range of scenarios that may occur during a wildfire incident.

- Due to the lack of testing, the effectiveness of an exterior sprinkler system is uncertain for the range of potential exposure types (e.g., radiation, convection, hot gases, embers) from the wildfire or adjacent structures on fire with a range of exposure durations and extended intensities.

- A municipal water source may not provide sufficient water flow and pressure during a wildfire, particularly as first responders will likely be drawing from the same system. Water supplies dependent on pumps may also be rendered ineffective during wildfire incidents when power can typically be lost due to the wildfire incident. Additionally, extensive adoption of automatic exterior exposure sprinklers for residences could present a concern for overall water supply in affected areas for firefighting operations if widely adopted by homeowners.

- The most threatening wildfires occur during high-wind events. Exterior sprinkler systems in high-wind conditions may not be effective at protecting the desired asset due to the uncertain distribution/transport of water droplets as well as evaporative losses.

- Reliable system activation is also questionable in terms of the appropriate approach, technology, and associated needs for independent and reliable power supply.

Key Terminology

- **Exterior Sprinkler:** A sprinkler, either deployable or fixed, on the structure that operates independent of human interaction to douse the structure, portions of the structure, and/or surrounding vegetation with water. They can be placed on top of the roof, in the under eave area, or on the property with spray towards the building.

- **Non-Residential Fire Sprinkler System:** An in-building sprinkler system that meets the requirements of *NFPA 13*.

- **Residential Fire Sprinkler System:** An in-home sprinkler system that meets the requirements of *NFPA 13D* or *13R*.

- **Sprinkler, Automatic:** A water spray device that is designed to provide fire protection automatically, based on either heat-activated operation or separate detection, releasing, and/or control.

- **Sprinkler, Manual:** A water spray device that is intended to provide fire protection when manually deployed and supplied with water under pressure.

Fire Rated Assemblies

None identified at time of publication.

Fire Test Standards

None that are specific to wildland fire applications. *NFPA 13, 13D, 13R* provide general automatic sprinkler design requirements.

Referenced Codes and Standards

- *International Wildland-Urban Interface (IWUI) Code:* No explicit requirements
- *2022 California Building Code (CBC):* No explicit requirements
- *NFPA 1144 Standard for Reducing Structure Ignition Hazards from Wildland Fire: No explicit requirements*

Other Codes and Standards

Additional local requirements, policies, and programs will vary depending on location and adoption in individual jurisdictions.

- Check local, county, and state amendments for additional wildfire codes and standards.
- Check local general plan, multi-hazard mitigation plan, zoning.
- International Residential Code (if applicable - check for wildfire amendments).

Typical Design, Vulnerability, and Mitigation Considerations

Table 34. Design and construction considerations for sprinkler systems.

Sprinkler System Types	Design and Construction Considerations
Interior Sprinklers (per NFPA 13)	Interior sprinkler systems designed to *NFPA 13* requirements must meet higher demand and density/area application requirements. Where the design water supply is maintained during fire exposure, these types of systems are more likely to sustain effectiveness during a larger fire exposure to the structure. Non-residential sprinkler systems typically do not provide any features to address exterior/wildland fire exposure. Use of sprinkler systems to address building fire exposures is also uncommon.
Interior Sprinklers (per NFPA 13R, 13D)	Interior sprinklers systems design to *NFPA 13R* and *13D* are only intended to provide occupant protection during an interior fire exposure. They are specifically not designed to provide protection to the building. Residential sprinkler systems typically do not provide features to address exterior/wildland fire exposure.
Building Exposure Sprinklers (per NFPA 80A)	The only technical requirements that are provided for exterior exposure sprinklers on buildings is within *NFPA 80A Recommended Practice for Protection of Buildings from Exterior Fire Exposures*. This building exposure sprinkler criteria is primarily oriented toward urban exposures and commercial buildings and is not readily applicable to residential buildings and wildland fire exposure.
Exterior Sprinklers, Automatic	The installation of wildfire sprinkler systems is not common, regulated, or well-documented. There are limited examples of successful performance in wildfire incidents. Successful systems generally rely on protection of the home and adjacent vegetation, some degree of pre-wetting, and the formation of a humid microclimate adjacent to the structure. One concern with even successful performance is that the protected area must be maintained after the incident to avoid ignition from surrounding hotspots that remain.
Exterior Sprinklers, Manual	These sprinklers must be manually positioned in advance of wildfire threat but are otherwise like automatic exterior sprinklers. Attachments to ground, vegetation, and structure must be reliable enough to keep the sprinklers in place during exposure after occupants have vacated.

General Mitigation Strategies

- Where an existing exposure sprinkler is provided, consult with a licensed fire protection professional or wildfire professional to assess the existing installation and provide recommendations.
- Where exposure sprinkler protection is considered, several factors must be addressed including system detection/activation methods, potential pumping systems for water pressure, potential water storage for reliability. Maximizing reliability could potentially involve providing on-site water supply/storage, pump equipment, and backup power supply for the on-site water supply equipment. A licensed fire protection professional should be involved with the design and installation of wildfire exposure sprinkler protection.
- Utilize sprinkler kits provided by agencies or use home sprinklers systems. This should NOT be considered the main line of defense, as exterior sprinklers systems have no standard fire test, design criteria, or performance specifications to have any certainty of its reliability and performance in a wildfire event.
- Given the potential issues regarding performance, it's recommended that sprinkler use be a supplement to, and not a replacement for, already proven mitigation strategies, such as the reduction of potential fuels throughout the home ignition zones, along with removal of roof and gutter debris, and use of noncombustible and fire/ember ignition-resistant building materials and installation design details [49]. Sprinkler protection of any type does not allow for reduction or relaxation of other recommendations.

Training

None identified at time of publication.

Gaps in Knowledge

- There is little information on how well these systems actually perform under wildfire exposure or what system features can improve their performance.
- There is no design standard or performance criteria.

Other References

- Federal Emergency Management Agency (FEMA)
    - Home Builder's Guide to Construction in Wildfire Zones, Technical Fact Sheet No. 15 - https://www.govinfo.gov/content/pkg/GOVPUB-HS5-PURL-gpo60104/pdf/GOVPUB-HS5-PURL-gpo60104.pdf
- National Fire Protection Association (NFPA)
    - Firewise Fact Sheet - https://www.nfpa.org/-/media/Files/Firewise/Fact-sheets/FirewiseFactSheetsExteriorSprinklers.ashx
- University of Wollongong
    - Research Report - Sprinkler Systems for the Protection of Buildings from Wildfire - https://ro.uow.edu.au/theses1/617/

Figure 1.84. Upright sprinkler and piping provided on roof.

Figure 1.85. Roof provided with sprinkler system.

INTRODUCTION 2

PART II - DEFENSIBLE SPACE

Chapter Organization

VEGETATION MANAGEMENT

DEFENSIBLE SPACE

2.1.1 PLANT AND TREE TYPES AND SELECTION

Main Concern(s)

Plants and trees located in the wildlands, man-made landscaping, or other open spaces directly surrounding a home, building, or structure[1] are all potential ignition locations and fuel sources for wildland or wildland-urban interface fires. Once ignited, vegetative fuels can burn with great intensity over a range of burn times, producing radiative and convective heat, and embers that can potentially lead to home or structure ignition. Landscape vegetation can be as combustible as wildland vegetation, and can easily spread fire from wildland vegetation to a home or structure, both horizontally via surface fuels or vertically as ladder fuels, from grasses and shrubs to low branches of trees. Presence of vegetation and man-made fuels proximate to a structure can also reduce the available space for firefighters to safely conduct operations.

Understanding and identifying the potential fire hazards that proximate vegetation can impose on the fire safety of homes or structures depends on a variety of factors. Vegetation type (e.g., woodland, shrubland, herbaceous, hardwood, conifer, agriculture), biological classification, plant characteristics, plant arrangements, purpose or use of the vegetation, local climate and fire regime, and quality of ongoing maintenance are key factors that influence expected fire performance of plants and trees (i.e., ignitability, combustibility, duration of combustion, and ember production). Due to the range and complexity of these factors, identifying and selecting a universal list of "fire-resistant" plants and trees, or "hazardous" vegetation, is challenging, generally requires local knowledge, understanding, and expertise, and is generally not recommended. *See further detailed discussion below.*

Note: This section focuses on inherent characteristics of plants and trees that affect flammability, while the next section covers defensible space zoning, spatial layout, and landscaping design.

Below are some practical challenges with managing vegetation at the parcel-scale:

- **Factors Affecting Fire Performance:** Wildland and landscaped vegetation immediately around a home, structure, or building can consist of a wide range of typologies (e.g., trees, shrubs, grasses), biological classifications (e.g., genius, species, native vs. invasive, fire-adaptive), plant characteristics (e.g., height, growth type and extent, phenology, chemical volatility), spatial arrangements, purposes (e.g., food, shade, recreation), and quality of ongoing maintenance (hydration, dead material) - all of which impact flammability or combustibility. In addition, local weather, climatic conditions, and natural fire regime also play a key role in understanding potential performance of plants and trees to wildfires. Fire regime describes "the spatial, or place-related, relationship between plants and fire, the intensity and severity of a fire, and the temporal, or timing-related, relationships between vegetation and fire: what time of year, and how often, does fire naturally occur? [85]" Understanding the local fire regime provides insight into the seasonality, severity, and nature (e.g., wind-driven) of wildfire threat, which can be used to bolster home protection (e.g., irrigating landscaping plants during the fire season fire season).

- **Native vs. Non-Native:** The relationship between non-native species and fire is complex. Evidence suggests that in some regions, non-native species are more hazardous compared to native species, and that post-fire invasions by non-native species can displace native vegetation and greatly reduce the amount and quality of habitat for native wildlife. This can be critical, as non-native species may not be well adapted to the local biome potentially disturbing soils, natural processes and ecological health. That said, in other regions even native species can be highly hazardous for fire. Non-native species invasions can also impact the overall fire regime of the landscape. Some non-natives have been documented to create feedbacks that amplify local fire regimes, increasing frequency or severity. However, the effects of non-native species are dependent on the plant community and can vary with site and climatic factors. Site-specific knowledge is instrumental [85], [86].

- **Fire-Adaptive vs. Fire-Resistant:** The terms fire-adaptive and fire-resistant are often ill-defined and can lead to misunderstandings about the plants in question. "Fire-adaptive" plants are those that have adapted to survive and live in environments with fire. They are typically classified into five different categories based on their adaptations [87], [88]:
  - Resisters, i.e., minimally damaged or consumed during moderate to low-intensity fires.
  - Sprouters, i.e., are partially or wholly consumed by fire and regrow.
  - Seeders, i.e., shed lots of seeds that sprout after a fire.
  - Invaders, i.e., take over recently burned areas.
  - Avoiders, i.e., grow in areas where fire does not normally occur.

Fire adaptations are not mutually exclusive and do not guarantee that the plant is fire resistant or fire hazardous. "Fire-resistant" plants are those that do not readily burn or ignite from flame or other ignition sources. Common characteristics of fire-resistant plants include [89]:

- Low amounts of volatile sap or resin materials.
- Low chemical volatility.
- High moisture content.
- Succulent leaves.
- A tendency to not accumulate dead material.

The terms "fire-adaptive" and "fire-resistant" are not interchangeable. Fire-adaptive is an ecological term while fire resistance refers to a plant's flammability directly. Possessing certain fire adaptations does not make a plant inherently more fire resistant than a plant with different fire adaptations. Fire resistance should be evaluated through scientific testing or firsthand observations of the plant's fire performance if test data is lacking.

- **Fire-resistant ("approved") and hazardous ("prohibited") plant lists:** Many jurisdictions have compiled lists of both "fire resistant / approved / recommended" and "hazardous / prohibited" plants to guide homeowners, design professionals and others in landscaping design. There are fewer recommendations for fire-resistant plants because low plant flammability is difficult to confirm without standardized testing, and plant flammability can change dramatically for some species as the plant moves from hydrated, to drought stressed, to droughted.

  The ability or inability to resist ignition is based on the physical features of the plant. While these lists are beneficial to the general public, they can be incomplete or misleading. Plant and tree performance during a fire is highly dependent on a variety of local factors that may not be relevant to other locations or biomes. Numerous factors as mentioned earlier - e.g., plant species, genus, structure, hydration, placement, location, setting, chemical composition, surface mass (i.e., how much biomass a plant produces within 6' of ground level), branching patterns, surface to volume ratio, foliage size, density, litter production and retention, maintenance practices (i.e., irrigation and trimming), weather, and weather history, influence whether a plant or tree should be considered "hazardous" or "fire resistant." These characteristics should be verified to confirm the hazard level of a plant or tree. Due to the large variation and detailed nuances of plant flammability, combustibility and burn intensity, evaluation of plant "safety" should be conducted by an expert from a holistic and scientific perspective [90].

  Even "approved" plants can burn. Plants/trees on hazardous or prohibited lists are often invasive, contain volatile oils or resins, have waxy leaves, and accumulate litter around the plant or tree. Fire-resistant or "approved" plants are often native species, low-flammability, maintain live/healthy structure under drought, slow growing, and wind resistant. If no local recommendations are available, or if uncertainties remain, it is recommended to refer to both local ecologists and fire departments. Local ecologists or botanic gardens can generally provide detailed information about the fire relevant traits of different plants, including their response to drought and seasonal weather and how much maintenance is required to keep the plant in a state that minimizes fire hazard. Fire department personnel can often provide valuable insight on what plants present high fire hazard from their observations of field plant combustion.

- **Other fuels in the built environment:** There is a wide range of other types of combustible fuels that landowners or homeowners may have stored near the primary structure. This can include wood piles, propane tanks for outdoor grills, outdoor furnishings, gasoline tanks for lawnmowers, the handles of many yard tools, trash bins, vehicles, and decorative landscaping (e.g., artificial grass). The type, quantity, and characteristics of these other fuel loads range dramatically, which presents challenges in understanding the additional fire hazard, burning characteristics, and other contributions they may have during a wildfire. Refer to Section 2.1.2 Zones, Spatial Layout, and Landscape Design for details.

1 The guidance in Parts I and II of this handbook primarily targets "homes" such as single-family homes, duplexes and townhomes. However, majority of the concepts and recommendations are relevant to other types of "buildings" such as multi-family apartment and condo buildings, commercial buildings, industrial buildings, and "structures" such as accessory structures (e.g., sheds, gazebos, ADUs) and infrastructure (e.g., communication tower, utility infrastructure, road infrastructure). The use of the various terms - "home", "building" and "structure" - are used interchangeably, but the intention is that the concepts hereinafter are relevant to all home, building and structure typologies.

Key Terminology

- **Biome:** A large community of vegetation and wildlife adapted to a specific climate [91].

- **Embers (firebrands):** Burning or smoldering particles of vegetation from tree branches, parts of shrubs or chaparral, or other combustible materials (e.g., building materials) that ignite and burn during a wildfire and are carried by winds in front of the wildfire at varying distances (e.g., 1/2 to 2 miles) [13]. This creates a wind-driven fire hazard that is unique to wildfire incidents.

- **Fire Regime:** The concept of fire regime is used to capture the expected patterns of wildfire for a given ecosystem during a given period. This can include fire frequency, intensity, seasonality, extent (final size) and other metrics, as well as observed feedbacks or dependencies between vegetation and fire [92].

- **Fire-Resistant Plants:** Fire-resistant plants are those that do not readily ignite from a flame or other ignition source or do not readily sustain combustion [89]. These plants can be damaged or killed by fire; however, their foliage and stems do not significantly contribute to the fuel load and, therefore, the fire's intensity. There are several other factors that influence the fire characteristics of plants, including plant moisture content, age, total volume, dead material, and chemical content.

- **Hazardous Plants:** Hazardous plants are generally based on characteristics that increase ignitability, burn with high intensity, and introduce fire hazards in the landscape [1].

- **Native Species:** A species that is a part of the balance of nature that has developed over hundreds or thousands of years in a particular region or ecosystem. The term "Native" should always be used with a geographic qualifier [93].

- **Non-Native Species:** Non-native species are those that do not occur naturally in an area and are introduced as the result of deliberate or accidental human activities [94].

- **Phenology:** The study of the timing and cyclical patterns of events in the natural world, particularly those related to the annual life cycles of plants, animals, and other living things. These events include the budding of leaves in spring, the arrival of migratory birds, the flowering of plants, and the onset of fruit ripening. Phenology is a vital field of ecological research that helps us understand how living organisms respond to environmental cues such as day length, temperature, and rainfall, and how climate change can impact these seasonal changes [95].

- **Plant Flammability:** A description of how a plant burns, including how easily it ignites, how intensely it burns, and how well it sustains combustion [96]. Plants with high flammability generally ignite easily, burn with high intensity and sustain flaming combustion; however, aspects of flammability are not necessarily related - plants that ignite easily (like grass) do not typically burn with high intensity, although some do. Flammability is dependent on several characteristics of the plant, including type of leaves, moisture content, etc.

Fire Classification and Ratings

None identified at time of publication.

Fire Test Standards

Currently, there are no standardized methods for determining plant flammability, ignitability, and combustibility (i.e., heat release rate), or criteria for plant and tree selection. See Section 2.1.1 *Other References* for available information.

Referenced Codes and Standards

- *2024 International Wildland-Urban Interface (IWUI) Code:* n/a
- *2022 California Building Code (CBC):* Chapter 49
    - Section 4906 Hazardous Vegetation and Fuel Management
- *NFPA 1140 Standard for Wildland Fire Protection:* n/a

Other Codes and Standards

Regulations vary depending on location and adoption in individual jurisdictions.

- Check local, county, and state amendments for any additional requirements.
- Check local general plan, multi-hazard mitigation plan, and zoning documents for any additional requirements.
- Consult the local or state fire agency, or a qualified fire management specialist about codes, requirements, and standards related to defensible space [6].
- International Residential Code (if applicable - check for wildfire amendments).

Table 35. Characteristics, vulnerability, and mitigations for plants.

Typical Designations	Characteristics, Vulnerability, and Mitigations
Prohibited Plant List	Plant species geometry has a significant influence on flammability. This includes the structure of the plant itself, as well as location and setting of the plant within the managed landscape. Surface mass of a plant is a key influence on its flammability. Plant features to consider include branching pattern, foliage size and density, litter production and retention, and evergreen versus deciduous [97]. Many wildfire prone areas will have a list of common plants that are prohibited or considered hazardous. These lists can be anecdotal and so should be evaluated for local relevance and from a holistic and scientific perspective. (See Section 2.1.1 *Other References* for a sample of these prohibited plant lists). Some common characteristics of prohibited plants include [6], [89], [96], [97]: • Volatile resins and oils, generally aromatic when crushed (e.g., eucalyptus). • Narrow leaves or long thin needles such as conifer needles. • Waxy or fuzzy leaves. • Accumulates dead leaves and twigs on and/or under the outer portions of the plant (e.g., Italian cypress, juniper). • Loose or papery bark. • Invasive species. If the areas around a home or structure include prohibited plants with characteristics that are especially prone to wildfire and/or have an active fire history, greater clearance and separation between plants and plant groupings are recommended and removal may be required [98]. While plants on the prohibited list may present increased hazard, they do not necessarily require removal. A key component of wildfire hazard mitigation is the proper placement and maintenance of plants around the home.

<table>
<tr>
<td>“Approved” or “Fire-Resistant” Plant List</td>
<td>Approved plant lists are developed to meet local residents’ requests for plant selection guidance and/or regulatory agencies’ permitting and enforcement needs. However, it can be more difficult to locate approved plant lists than prohibited or hazardous plant lists. Even though most fire-resistant or plant flammability lists include some type of warning statement that “all plants can burn,” these lists/guidance documents can be misleading if they [97]:

• Lack definitions.
• Do not clarify criteria or methods used.
• Do not provide sources or include mechanisms for an owner to request the use of non-listed plants.
• Do not provide industry standards (e.g., some based on flammability or how easily a plant ignites, while others are based on combustibility or on how intensely a plant burns).
• Use inconsistent plant names (e.g., common names, genus/species, sub-species). Species in the same genus may not have the same flammability characteristics or similar growth forms.
• Do not provide guidance on seasonal influences or location/geographic area of application.

Where necessary, refer to local lists of “approved” or “fire-resistant” plants. Some general characteristics* of typical plants in this category include [6], [89]:

• Maintains healthy structure/foliage under drought.
• Pest-resistant.
• Non-invasive.
• Slow growing.
• Wind-resistant.
• Sustainable without supplemental fertilization.
• Is well maintained to remove dead material, fallen debris at the base of the plant.

An example of a list of native, fire-resistant plants is this one compiled for California: http://firesafesdcounty.org/wp-content/uploads/2017/05/Comprehensive-Fire-Resistant-Plant-List.pdf. Refer to local guidance to achieve best results.

Note that native plants should generally not be considered synonymous with “fire-resistant.” Consult with local plant ecologists and fire departments for guidance on use of specific native plants for fire-resistant landscapes.

*It is not recommended to predict low plant flammability from single plant traits or environmental responses. Consult local plant ecologists and fire departments for guidance on specific plants.</td>
</tr>
</table>

General Mitigation Strategies

- Plant and Tree Selection
  - Use the right plants in the right places, keeping fire, climate, and irrigation needs in mind.
  - Create separated plant islands that have similar sun, nutrient, and water needs to limit fuels continuity and maximize plant health.
- Maintenance
  - Keep landscaping free of dry and dead wood, dry grasses and leaf litter, especially near any structures.
  - Prune plants to provide horizontal and vertical space throughout and to eliminate ladder fuel conditions. A grass fire can move up into shrubs and then into trees.
  - Hydrate plants with a water-wise irrigation system. All plants will burn if not well maintained or hydrated.
  - Refer to Part III for vegetation management practices for various critical infrastructure.

Training Programs

- NFPA - Assessing Structure Ignition Potential from Wildfire: https://www.nfpa.org/Training-and-Events/By-topic/Home-Ignition-Zone.
- Fire Adapted Communities Learning Network: https://fireadaptednetwork.org/resource/webinar-recording-learning-exchanges-trex/.
- University of Idaho - Fire Ecology and Management
  - REM 144 - Wildland Fire Management
  - FOR 326 - Fire Ecology and Management
  - FOR 433 - Fire and Fuel Modelling
  - FOR 450 - Fire Behavior
  - REM 429 - Landscape Ecology
  - GEOG 313 - Global Climate Change

Gaps in Knowledge

- Currently, there are no standardized methods for determining plant flammability, other plant fire behavior characteristics, or criteria for landscaping plant recommendations.
- Understanding of fire ecology, fire hazards, and risks of all vegetation types is still developing.
- Comprehensive lists of fire-resistant vegetation and hazardous plant lists do not currently exist for all biomes, regions, and weather conditions. Most information is developed at the local level and can be anecdotal and possibly misleading.
- Best management practices, even for the same species of plant, can vary depending on the topography and local weather/climate conditions. Strategies used by residents and landscapers to alter influences on flammability (e.g., pruning and plant establishment methods), impacts to plant vigor versus flammability, and other landscaping objectives still need development and industry standardization [97].
- Widely used terms such as “low flammability vegetation,” “irrigated vegetation,” and others used in existing literature and guidance have no consistent definition [22].

Other References

- University of California, Agriculture and Natural Resources
    - Preparing Home Landscaping: https://ucanr.edu/sites/fire/Prepare/Landscaping/
    - Invasive Plants and Wildfires: https://anrcatalog.ucanr.edu/pdf/8397.pdf
    - Vegetation and Landscaping: https://anrcatalog.ucanr.edu/pdf/8695.pdf
    - Home Landscaping for Fire: https://anrcatalog.ucanr.edu/pdf/8695.pdf
- UCCE
    - Research Literature Review of Plant Flammability Testing, Fire-Resistant Plant Lists and Relevance of a Plant Flammability Key for Ornamental Landscape Plants in the Western States: https://ucanr.edu/sites/SaratogaHort/files/235710.pdf
- NFPA: https://www.nfpa.org/Public-Education/Fire-causes-and-risks/Wildfire/Preparing-homes-for-wildfire
- FEMA Fact Sheets: https://www.govinfo.gov/content/pkg/GOVPUB-HS5-PURL-gpo60104/pdf/GOVPUB-HS5-PURL-gpo60104.pdf
- IBHS: https://disastersafety.org/wp-content/uploads/2021/08/Fire-Resistant-Landscaping-for-Your-Home.pdf
- CALFIRE, Prepare for Wildfire: https://www.readyforwildfire.org/prepare-for-wildfire/get-ready/defensible-space/
- DisasterSafety.org: https://disastersafety.org/wildfire/d-space/
- Sample Fire Resistance Plant List, CA: http://firesafesdcounty.org/wp-content/uploads/2017/05/Comprehensive-Fire-Resistant-Plant-List.pdf
- Be Ember Prepared (Video): https://www.youtube.com/watch?v=gAuhNDb963Y
- Drill, Sabrina L., Stephen L. Quarles, Valerie T. Borel, Drew Ready, Jason Casanova, John Todd, and Bill Nash. S.A.F.E Landscapes Southern California Guidebook: Sustainable and Fire-Safe Landscapes in the Wildland Urban Interface. UC Cooperative Extension, 2009. https://ucanr.edu/sites/safelandscapes/files/93415.pdf
- Etlinger, Matthew G. and Frank C. Beall . "Development of a Laboratory Protocol for Fire Performance of Landscape Plants," International Journal of Wildland Fire 13, no. 4 (2004): 479-488. https://doi.org/10.1071/wf04039
- SelectTree: A Tree Selection Guide. https://selectree.calpoly.edu/
- Tree Care Information from International Society of Arboriculture. https://www.treesaregood.org/
- California Invasive Plant Council Landscaping Guidelines. https://www.cal-ipc.org/solutions/prevention/landscaping/dpp/
- Zouhar, K. Smith, J.K., Sutherland, S. "Chapter 2: Effects of Fire of Nonnative Invasive Plants and Invasibility of Wildland Ecosystems." USDA Forest Service Gen. Tech. Rep. RMRS-GTR-42-vol. 6. https://www.fs.usda.gov/rm/pubs/rmrs_gtr042_6/rmrs_gtr042_6_007_032.pdf

Figure 2.1. Variety of wildland and landscape vegetative fuels proximate to a home or structure that can be sources of ignition, provide a fireflow path from the wildlands to the structure and/or when burning can ignite the structure.

Figure 2.2. Common "hazardous" plants and trees for wildfires. (first) Italian cypress, (second) Cedars, (third): Eucalyptus, (fourth): Acacia, (fifth): scrub oak, (sixth): foundation grass, (seventh): cheat grass, (eighth): juniper bush, (ninth) palms. Image courtesy of Fire Safe Marin. https://firesafemarin.org/create-a-fire-smart-yard/plants/fire-hazardous-plants/

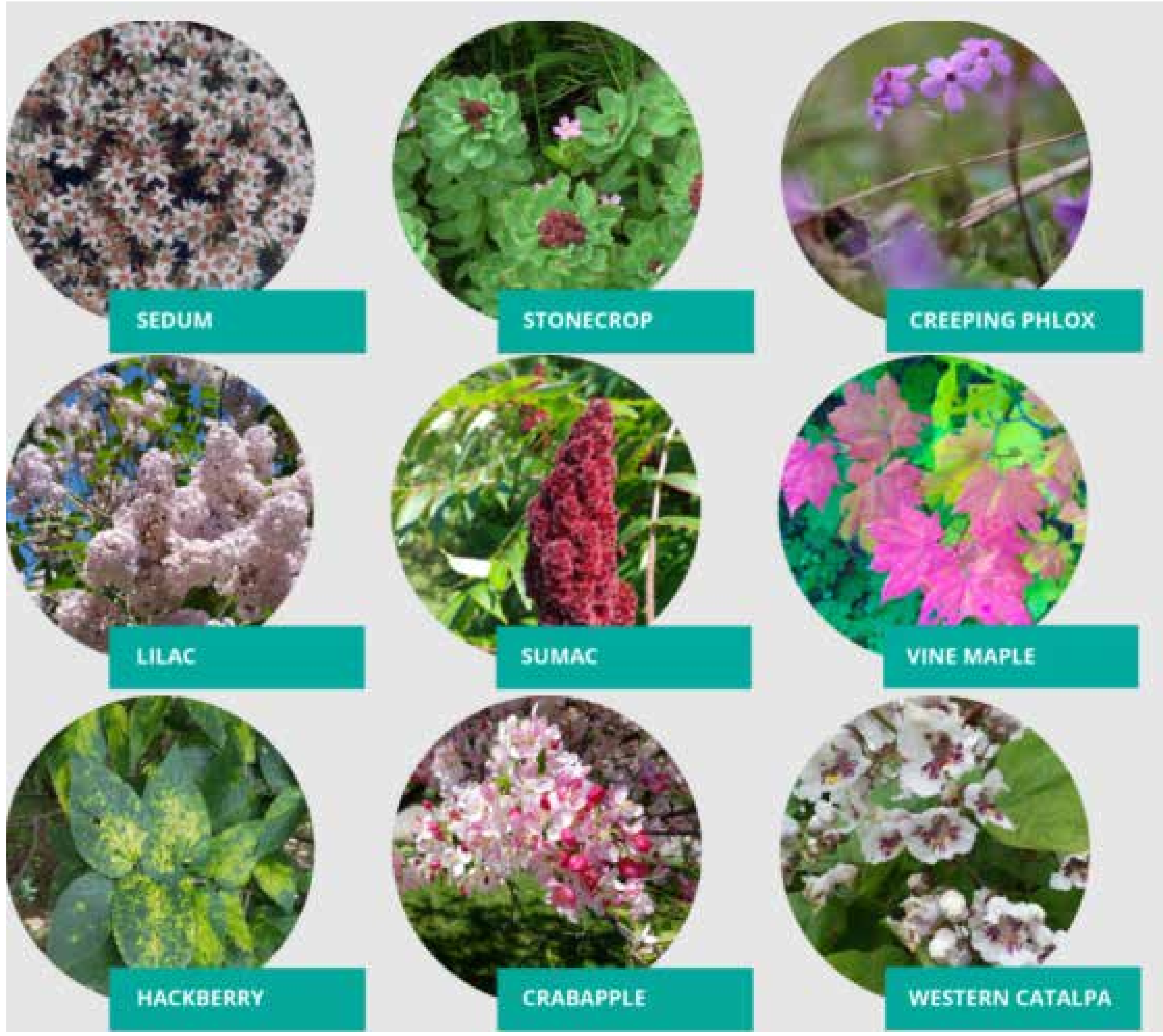


Figure 2.3. Common "fire-resistant" plants and trees. Image courtesy of Western Fire Chiefs Association. https://wfca.com/wildfire-articles/fire-resistant-plants/

2.1.2 ZONES, SPACING, AND LANDSCAPING DESIGN

Main Concern(s)

Arguably more important than the type(s) of plants and trees is the spatial arrangement (e.g., proximity of vegetative and non-vegetative fuels to buildings, other fuels, and hazardous topographies; density and continuity of fuels), design, and maintenance of the vegetative fuels and other combustible man-made fuels immediately surrounding a home, building, or structure.[2] These aspects of the landscaping and use of the spaces immediately around a home or structure significantly contribute to the potential ignition of a structure whether by providing potential pathways for fire to travel directly to the home or provide receptive fuel beds for spot fires and additional sources of embers. While radiation and direct flaming from fire are important heat transfer mechanisms that can spread fire to the built environment, windborne embers are estimated to be responsible for more than 2/3 of home ignitions in the wildland-urban interface (WUI) [17]. Once burning, the structure, landscaping vegetation, or other combustible materials on the property act as both sources of heat and embers that can ignite nearby property and structures. Additionally, the presence of vegetation and man-made fuels proximate to a building can also reduce the available space for firefighters to safely conduct operations.

Understanding and identifying the potential hazards that spatial arrangement, design and maintenance of proximate vegetation and man-made fuels can impose on the fire safety of homes or structures, depends on a variety of factors. Some of the key concerns immediately surrounding a structure (0-100’) include:

- **Wildland vegetation (e.g., grass, brush, timber):** These fuels can burn with great intensity over a range of burn times, producing radiative and convective heat, hot gases, and embers.
- **Landscape/ornamental vegetation:** Landscaping can consist of a wide range of managed vegetation typologies (e.g., trees, shrubs, grasses), plant characteristics (e.g., height, growth type, and extent), fire ecologies, native/non-native species, arrangements, practices, purposes (e.g., food, shade, recreation) and quality of ongoing maintenance. These plants can be as combustible as wildland vegetation and can easily spread fire from wildland vegetation to the structure, both horizontally via surface fuels and vertically, as ladder fuels from grasses and other surface fuels spread to low branches of trees.
- **Fire-resistant and hazardous plant lists:** See Section 2.1.1 *Plant and Tree Types and Selection*.
- **Other fuels in the built environment:** There is a wide range of other types of combustible fuel loads that landowners or homeowners may have stored near the primary structure. This can include wood piles, portable and stationary propane tanks, outdoor furnishings including cushions, lawnmowers and yard tools, trash bins, vehicles, and decorative landscaping (e.g., artificial grass and wood/bark mulch). The type, quantity, and characteristics of these other fuel loads range dramatically, which presents challenges in understanding the additional fire hazard, burning characteristics, and other contributions they may have during a wildfire.
- **Outbuildings (e.g., sheds, gazebos, pergolas):** Outbuildings are often composed of combustible materials, and once ignited, can contribute to structure-to-structure fire spread.
- **Site Constraints (e.g., limited setbacks, less than 30’ to nearby structures, less than 100’ of defensible space):** Most urban and suburban homes cannot achieve 100’ of defensible space, let alone 30’ to other structures on all yards without reaching their property line first. Current wildfire safety codes on defensible space do not provide guidance on how to achieve defensible space when various site constraints exist. These constraints can oftentimes introduce additional hazards (e.g., adjacent unmanaged vegetation, vacant lots, structure-to-structure fire spread)

that are mostly outside of the control of the landowner. Some industry guidance does exist that recommends adopting "communal defensible space" concepts, enhancing defensible space requirements and/or structural hardening measures on the aspects of the buildings with limited setbacks [1]. However, this guidance is limited and does not necessarily address all forms of site constraints, construction typologies, vegetation conditions, and other practical limitations. Alternative methods, such as communal defensible space with neighbors and other structural hardening measures, are needed to address these increased risks.

2 The guidance in Parts I and II of this handbook primarily targets "homes" such as single-family homes, duplexes and townhomes. However, majority of the concepts and recommendations are relevant to other types of "buildings" such as multi-family apartment and condo buildings, commercial buildings, industrial buildings, and "structures" such as accessory structures (e.g., sheds, gazebos, ADUs) and infrastructure (e.g., communication tower, utility infrastructure, road infrastructure). The use of the various terms - "home", "building" and "structure" - are used interchangeably, but the intention is that the concepts hereinafter are relevant to all home, building and structure typologies.

Key Terminology

- **Defensible Space:** Defensible space is the area or space around homes and buildings where vegetation and other factors are managed for a specific distance to keep fire at a distance where it is less likely to ignite the structure. This managed area or space literally provides a "defense" against the fire to reduce the structure's exposure to flame radiation (heat), flame impingement, and ignition from firebrands (burning embers), which are considered the three principal factors in igniting a fire [99].

- **Embers (Firebrands):** Burning or smoldering particles of vegetation from tree branches, parts of shrubs or chaparral, or other combustible materials (e.g., building materials) that ignite and burn during a wildfire and are carried by high winds in front of the wildfire at varying distances (e.g., 1/2 to 2 miles) [13]. This creates a wind-driven fire hazard that is unique to wildfire incidents.

- **Ember-Resistant Zone:** The ember-resistant zone, as defined by the state of CA, is the space from 0 to 5' around the base of the structure and any decking where limited combustible fuels are permitted. In practical terms, this means to use primarily hardscaping; remove dead plant material (including on roofs, in gutters, and underneath structures); limit or relocate combustible furniture or other items; replace combustible fences, gates and other combustible non-structural attachments with non-combustible materials; relocate garbage containers, boats, RVs, and other vehicles.

- **Fire-Resistant Plants:** Fire-resistant plants are those that do not readily ignite from a flame or other ignition source. These plants can be damaged or killed by fire; however, their foliage and stems do not significantly contribute to the fuel load and, therefore, the fire's intensity. There are several other significant factors that influence the fire characteristics of plants, including plant moisture content, age, total volume, dead material, and chemical content. See also Section 2.1.1 *Plant and Tree Types and Selection*.

- **Hardscape:** Any non-living structures (such as fountains, benches, or gazebos) that are incorporated into a landscape [100]. For the purposes of this handbook this term also includes hard paths, paving, driveways, retaining walls, stairs, and any other landscape elements constructed of sturdy materials such as stone and concrete.

- **Home Ignition Zone (HIZ):** The concept of the home ignition zone was developed by retired USDA Forest Service fire scientist Jack Cohen in the late 1990s, following breakthrough experimental research into how homes ignite via radiant heat. The original definition of the HIZ included no zone divisions. California defensible space regulations, beginning in the 1960's, further developed the concept of the HIZ to include first, one (0-30'), then two (0-30' and 30-100') zones. An additional zone, the noncombustible zone (0-5'), first grew out of meetings in the early 1990's that were organized by University of Nevada CE Specialist Ed Smith and included Tahoe Basin fire officials. Living with Fire publications officially termed the zone the "noncombustible" zone. In the 2000's, the UC Cooperative Extension started advocating for use of the zone. IBHS also began advocating for the zone in the early 2010's. NFPA Firewise renamed zones when they adopted the concept in the mid 2010's [101]. CAL FIRE began to consider the convention around the year 2020. Presently, the HIZ is divided into three zones described as: the immediate zone (0-5'), intermediate zone (5-30'), and extended zone (30-100') [102]. Although variations on this concept may also be found, the HIZ generally accounts for the 0 - 100' space around a structure.

- **Ladder Fuels:** Surface vegetation or other fuels that allow fire to climb up from the landscape or forest floor to the tree canopy above. Common ladder fuels include tall grasses, shrubs, and tree branches, both living and dead. Non-vegetative ladder fuels include woodpiles, fenceposts, etc. The removal of ladder fuels is part of defensible space 'fire scaping' practices [103].

- **Noncombustible Zone:** A noncombustible zone is the space immediately around and under a structure (typically 0 - 5'), where no form of fuel load or combustible material is located. The intent is to keep fire and embers from igniting all combustible materials, including any form of vegetation, that can spread to the structure and cause ignition.

Fire Classification and Ratings

None identified at time of publication.

Fire Test Standards

Currently, there are no standardized methods for determining plant flammability, other plant fire behavior characteristics, or criteria for landscaping plant recommendations. See Section 2.1.2 *Other References* for available information.

Referenced Codes and Standards

- International Wildland-Urban Interface (IWUI) Code: Section 603, A105.4.1 (woodpiles)
- California Building Code (CBC): Chapter 49
  - Section 4906 Hazardous Vegetation and Fuel Management
  - Section 4907 Defensible Space
- California Code of Regulations (CCR): Title 14, Section 1299
- California Assembly Bill (AB) 3074: Fire prevention: wildfire risk: defensible space: ember-resistant zones. https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201920200AB3074
- California, Public Resources Code, 4291: Defensible space requirements
- *NFPA 1140* Standard for Wildland Fire Protection: Sections:
  - A.25.9 (outbuildings)
  - 25.12.5 (woodpiles)
  - 25.11 (vehicle parking areas)
  - Chapter 26 (fuel modification area)

Other Codes and Standards

Codes and standards vary depending on location and adoption in individual jurisdictions.

- Check local, county, and state amendments for any additional requirements.
- Check local general plan, multi-hazard mitigation plan, and zoning documents for any additional requirements.
- Consult the local or state fire agency or a qualified fire management specialist about codes, requirements, and standards related to defensible space [16].
- International Residential Code (if applicable - check for wildfire amendments).

Typical Design, Vulnerability, and Mitigation Considerations

Defensible space is designed to provide a buffer between the building and the wildland, or other fuels, that surround it. It protects a structure from direct flame impingement, reduces exposure to radiant heat and ember cast, and is essential for structure survivability during wildfires. Defensible space also allows room for firefighting operations. Defensible space requirements and recommendations are typically subdivided into three zones, whereby the highest priority mitigations and most restrictive measures occur in the area closest to the structure or home [98]. The most common zones are as follows:

- Zone 0 (0 - 5') = "Ember-resistant zone" or "Immediate Zone"*
- Zone 1 (5 - 30') = "Intermediate Zone" or "Lean, Clean, and Green Zone"
- Zone 2 (30 - 100') = "Extended Zone" or "Reduced Fuel Zone"

****Note:*** *California is currently in the process of developing and adopting local regulations to implement an "ember-resistant" zone within 5' of a structure or occupied dwelling located in high fire prone areas (i.e., as defined by CAL FIRE and local jurisdictions) adjoining a mountainous area, forest-covered land, brush-covered land, grass-covered land, or land that is covered with flammable materials [104].*

Table 36. Design, vulnerability, and mitigations for the home ignition zone.

Typical Conditions or Typologies	Design, Vulnerability, and Mitigations
Zone 0 ***0 - 5’***	This is considered the most important defensible space zone and includes areas immediately surrounding a structure/building, as well as areas under any attached decks or overhangs. Establishing a 5’ ember-resistant zone around a structure to eliminate materials that will likely be ignited by embers provides important protection measures that enhance a home’s chance of surviving a wildfire [104]. This in combination with an accompanying 0-6” of noncombustible construction at the base of the exterior wall is critical. These protection measures include: • Remove anything combustible including vegetative and “urban” type fuels (e.g., woody plants, mulch, woodpiles, combustible trellises, trash bins, vehicles, woodpiles, and other stored combustible items). This is particularly important for homes or structures with combustible siding such as wood or vinyl. Combustible fences with mulch at their base have been demonstrated to transport fire to structures and provide a major source of embers [2]. • Move any trash, recycling, or compost bins further than 5’ from any structures (in Zones 1 or 2), or store them within a hardened garage or outbuilding. • Remove or prune flammable plants and shrubs near windows to maintain 5’ of clearance [105]. • Relocate woodpiles to Zone 2 (> 30’ from structures) with a minimum of 10’ separation from other fuels, or 40’ if adjacent to multiple woodpiles. Or place them within a well-sealed, protected structure (e.g., hardened garage or shed). • Remove any dead/dying vegetative debris (e.g., leaves, pine needles). • Consider replacing existing landscaping in Zone 0 with hardscaping such as pavers, concrete, rock mulch, pea gravel, or noncombustible mulch. • Consider replacing the bottom 6” of the exterior wall with noncombustible materials (e.g., brick, stone veneer, exposed concrete, stucco) from the foundation to the exterior siding. • Trim back all trees, shrubs, and any other vegetation so that it’s not within this zone, particularly around chimney and stovepipe outlets. • Limit combustible items (e.g., outdoor furniture, grills) on top of decks and balconies [98]. Potted plants should be limited in number and size and planted in noncombustible planters [66]. • Replace combustible fencing, gates, and arbors attached to the structure with non-combustible materials for at least the first 5’ [98]. If the home/structure consists of noncombustible siding such as fiber cement, and plants in this zone are still desirable, limit the selection to varieties that grow no more than 12” in height. Avoid planting below windows or near other openings (e.g., vents, crawl space openings). Ensure that the plants are well watered and cared for because a**ny plant can become highly flammable if it is dead, dried out, or not well maintained**.

Zone 1 ***5 - 30'***	This zone is considered critical to creating defensible space and limiting structure-to-structure fire spread. ***Note:*** *This designation also applies to the area within 10' of driveways, access roads, or public roads adjacent to the property.* • Minimize fuel in this zone - plants should be low growing, low-volume, nonwoody, and properly watered. ***Note:*** *Research shows that plant moisture is one of the most influential characteristics of plant flammability.* • Cut or mow grass to 4" or less in height. • Remove all dead or dying vegetation (e.g., grass, weeds, pine needles). • Trim trees to maintain a minimum of 10' distance between trees (including branches). • Remove all tree branches that are within 6' of the ground to limit fire ladders [98]. • Trim and prune vegetation per horizontal and vertical separation requirements (as indicated in associated diagrams, NFPA Firewise, or other local guidance). Additional separations may be needed for steep slopes. See section below. • Separate all vegetation from each other and from other items which could ignite - create "islands" of vegetation surrounded by non-flammable materials such as gravel walkways or noncombustible patios. • Remove any branches/tree limbs which extend over the roof or are within 10' of chimney or stovepipe outlets. • Relocate woodpiles to Zone 2 (> 30' from structures) and ensure a minimum of 10' separation from other fuels; 40' if adjacent to multiple woodpiles. Alternatively, place woodpile within an enclosed, non-combustible structure (e.g., non-combustible shed). • Alternatively, as a more practical consideration for reducing risk of ignition, woodpiles can be provided with a securely fastened fire-resistant material (tarp that complies with, at a minimum, *NFPA 701 Method 2* standard). • For many landowners/homeowners, property lines may restrict achieving 30' of defensible space. At the discretion of the fire department, property owners may elect to increase hardscaping to offset the reduced width of Zone 1. Some jurisdictions propose hardscaping or provide a noncombustible property line wall, to minimize ember transmission and/or production close to the home.

Zone 2 ***30 - 100'***	This zone is intended to interrupt the path of a wildfire, minimize flame length, and keep fires on the ground. • Cut or mow grass to 4" or less height. • Remove all tree branches that are within 6' of the ground to limit fire ladders [98]. • Create vertical and horizontal space between shrubs and trees (see images) - property on steeper slopes requires greater spacing. See Section 2.1.2 *General Mitigation Strategies*. • Remove heavy accumulation of ground debris/litter. • Incorporate landscape designs which can act as fuel breaks (e.g., driveways, walkways, orchards). If possible, tie these fuel breaks in with existing firebreaks on adjoining properties (e.g., bodies of water, roads, trails, orchards, golf courses) [106]. • Separate auxiliary structures such as a detached garage, pump house, pergola, and utility shed from the home anywhere from 40-50' away. Increase the distance if the structure is used for the storage of highly flammable or combustible materials [6]. Also see NIST Technical Note 2235 for more specific information on structure separation from auxiliary structures (sheds) [107]. • Store combustible patio furniture in a location where it is protected from wildfire ignition [6]. • For many landowners/homeowners, property lines may restrict achieving 100' of defensible space. At the discretion of the fire department, property owners may elect to increase hardscaping to offset the reduced width. In some jurisdictions, the full 100' is achieved through community defensible space, where neighbors on adjacent properties maintain the portion of the 100' HIZ that falls within their land. ***Note:*** Research shows that plant moisture is one of the most influential characteristics that influence plant flammability.
Zone 3 ***> 100 ft***	Where possible and within the control of the landowner, reduce fuels that are farther than 100' from a building, particularly where the property sits on or adjacent to a steep slope. This can include thinning and pruning vegetation, horizontally and vertically, similar to the approach in Zone 2, but more limited [6].
Prohibited Plant List	See Section 2.1.1 *Plant and Tree Types and Selection*.
"Approved" or "Fire-Resistant" Plant List	See Section 2.1.1 *Plant and Tree Types and Selection*.

Outbuildings (e.g., Sheds, Gazebos, Pergolas) and other Decorative Features (e.g., fences)	Outbuildings and other decorative features are common within the landscaping around homes. As with other fuels, these are combustible materials that are an added source of heat and embers during wildfires. Use appropriate clearance or modify positioning for these features to reduce the threat from burning embers [98]. • Any sheds should be "hardened" with sealed doors, screened vents, and surrounded by defensible space. • Sheds should be removed from the immediate zone of 0-5' from the structure and restricted to those constructed of metal or non-combustible materials in the 5-30' intermediate zone. Increase distance of sheds beyond 50' from the structure when constructed of—or containing—combustible fuels. • Non-metal sheds in Zones 1 and 2 should have 10' of clearance consisting of bare mineral soil or similar non-combustible materials (e.g., rock mulch), and an additional 10' with no flammable vegetation. • If sheds cannot be moved or retrofitted to be "hardened," remove them entirely if possible. • Remove combustible materials (e.g., outdoor furniture) from, adjacent to, or below any unenclosed outbuildings.
Vehicles	Vehicles, including cars, RVs, and boats, are often stored near structures and pose a risk of spreading fire to adjacent structures. Any vehicles in the home ignition zone should be stored outside of Zone 0, at a minimum. Vehicles should not be parked in a way that obstructs access to defensible space by firefighting personnel.
Steep Slopes and Winds	If the home is located on a steeper slope, in a drainage area, in a windy area, or in an area surrounded by unusually dense, tall, or combustible vegetation, thinning recommendations increase [98]. As fire and heat rise, structures or homes at the top of a slope will experience more intense fire exposure and effects. In these cases, greater effort is needed for the area downslope of the home as well as within Zones 0 and 1. Recommendations based on the judgement of fire professionals are given below [105]. • **Under 20% slope:** Space shrubs at 2 times their height. • **20-40% slope:** Space shrubs at 4 times their height. • **Greater than 40%:** Space shrubs at 6 times their height. Additional structural hardening measures on the aspects of the structure or home fronting steep slopes (if not the entire home or structure) may also be warranted to offset the increased fire severity adjacent to steep slopes. Refer to Table 38 in Section 3.2.1 of the handbook for structural hardening recommended options.

Site Constraints Condition #1: < 30 feet to property line or another structure	Where 30' of setback to the property line or another building is not feasible (e.g., parcel geometry, topographic limitations, or other easements), the following guidance should be considered to reduce the likelihood of structure-to-structure fire spread: • Install a 6', solid, noncombustible property line wall or fence (e.g., brick, masonry, or concrete masonry unit walls) to minimize ember transmission, radiation, and other forms of heat transfer from adjacent properties. Note that this is more effective for grass and shrubland landscapes. In forested landscapes, it is possible that a crown fire could extend over the top of a 6' wall [1]. • Install 5-10' of noncombustible material (e.g., pavers, gravel) horizontally around the home. Where there is significant hardscaping around the home, additional measures may be needed to limit potential drainage or flooding issues [1]. • Prioritize localized structural-hardening measures on the side of the structure with less than 30' of setback (e.g., replace combustible siding with noncombustible siding) [1]. • Provide additional structure hardening such as installing or upgrading exterior walls, windows, vents, and under-eaves areas of the home to be fire-resistance rated (e.g., 1-hour rated) [1].
Site Constraints Condition #2: More than 30 feet, but less than 100 feet to property line	Where 30-100' of defensible space next to wildlands, open space, or adjacent properties is not available, the following strategies can be implemented: • Work with adjacent property owners to ensure that common defensible space considerations are implemented between, and adjacent to, structures on both properties within Zone 2 shared between properties. • Alternatively, consider enhancing structural hardening measures on the sides of the building with insufficient defensible space in zone 2 (30-100'). Refer to Site Constraint #1 for guidance.

General Mitigation Strategies

- **Design and implement defensible space.**
  - Create fuel breaks surrounding the house and within the HIZ.
  - Create space vertically and horizontally via plant placement and pruning.
  - Use noncombustible mulch near the house.
  - Use hardscape and noncombustible materials around structures and to separate individual plants and groups of plants.
  - Use the right plants in the right places, keeping fire, climate, and irrigation needs in mind.
  - Create plant islands that have similar sun, nutrient, and water needs.

- **Maintain landscaping.**
  - Keep landscaping free of dry and dead wood, dry grasses, and leaf litter, especially near any structures.
  - Prune plants to provide horizontal and vertical space throughout and to eliminate ladder fuel conditions. A grass fire can move up into shrubs and then into trees.
  - Hydrate plants with a water-wise irrigation system. All plants will burn if not well maintained or hydrated.
  - Refer to Part III for vegetation management practices for various critical infrastructure.

Training Programs

- NFPA - Assessing Structure Ignition Potential from Wildfire: https://www.nfpa.org/Training-and-Events/By-topic/Home-Ignition-Zone.
- Fire Adapted Communities Learning Network: https://fireadaptednetwork.org/resource/webinar-recording-learning-exchanges-trex/.
- National Wildfire Coordinating Group
  - S-190 - Introduction to Wildland Fire Behavior
  - S-290 - Intermediate Wildland Fire Behavior
  - S-390 - Introduction to Wildland Fire Behavior Calculations
    S-490 - Advanced Fire Behavior Calculations
- University of Idaho - Fire Ecology and Management
  - REM 144 - Wildland Fire Management
  - FOR 326 - Fire Ecology and Management
  - FOR 433 - Fire and Fuel Modelling
  - FOR 450 - Fire Behavior
  - REM 429 - Landscape Ecology
  - GEOG 313 - Global Climate Change

Gaps in Knowledge

- Currently, there are no standardized methods for determining plant flammability, or criteria for landscaping plant recommendations.
- Fire-resistant plant lists broadly lack scientific backing and are frequently based on anecdotal reports. When they do include scientific information, it is often a narrow representation of the plants' flammability. Caution should be used with existing plant lists because they are generally published and distributed without verification by local officials [108].
- Defensible space requirements and guidance are based primarily on studies of structure survivability in standardized conditions, and not necessarily across the full range of vegetative fuel types, topologies, and weather conditions. Additional separations and distance are likely needed where there will be severe weather conditions (e.g., high winds) and fire behavior (e.g., steep slopes, structure density, other urban fuels).
- Communal defensible space requirements do not currently exist and are often difficult to enforce if property owners do not have agreements or other easements that compel them to perform vegetation management/fuel treatments on adjacent properties that are within the 100' home ignition zone.
- Understanding of fire ecology, fire hazards, and risks of all vegetation types is still developing.
- Comprehensive lists of fire-resistant vegetation and hazardous plant lists do not currently exist for all biomes, regions, and weather conditions. Most information is developed at the local level and can be anecdotal and possibly misleading.
- Best management practices, even for the same species of plant, can vary depending on the topography and local weather/climate conditions. Strategies used by residents and landscapers to alter influences on flammability (e.g., pruning and plant establishment methods), impacts to plant vigor versus flammability and other landscaping objectives still need development and industry standardization [97].
- More detailed guidance and alternatives are needed to allow for variations in topography, siting of structure(s), ornamental landscaping, and exemplar fire-adapted landscape appropriate for local conditions/context.
- Site specific defensible space requirements need to be developed at the local level to account for local topography, vegetative typology, local construction practices, local weather/climate conditions, local environmental sensitive habitat requirements, etc.
- Expanded options and guidance are not readily available for how building/homeowners can offset defensible space requirements due to site restrictions (e.g., small parcel sizes, limited set-

backs), no control over vegetation management practices of neighboring properties within the defensible space zones, building/housing density, etc.
- Understanding structure-to-structure fire spread and influence of building density, neighborhood layout and configuration on wildfire vulnerability, and associated mitigation measures is a current topic of research.
- Verifying the utility of fuel separation distance requirements in current building codes for wildfire applications is still developing.
- Parcel level versus neighborhood levels of defensible space are areas of further research.
- Common space or shared open space defensible space requirements.
- There are limited codes, standards, and guidance on vehicles in the home ignition zone. There is overlap between guidance related to vehicles and other flammable items such as liquid propane tanks.
- Widely used terms such as "low flammability vegetation," "irrigated vegetation," and others used in existing literature and guidance have no consistent definition [22].

Other References

- University of California, Agriculture and Natural Resources
  - Preparing Home Landscaping: https://ucanr.edu/sites/fire/Prepare/Landscaping/
  - Invasive Plants and Wildfires: https://anrcatalog.ucanr.edu/pdf/8397.pdf
  - Vegetation and Landscaping: https://anrcatalog.ucanr.edu/pdf/8695.pdf
  - Defending Your Home in Wildfire: https://ucanr.edu/sites/postfire/files/255137.pdf; https://anrcatalog.ucanr.edu/pdf/8322.pdf
  - Home Landscaping for Fire: https://anrcatalog.ucanr.edu/pdf/8695.pdf
- UCCE
  - Research Literature Review of Plant Flammability Testing, Fire-Resistant Plant Lists and Relevance of a Plant Flammability Key for Ornamental Landscape Plants in the Western States: https://ucanr.edu/sites/SaratogaHort/files/235710.pdf
- NFPA: https://www.nfpa.org/Public-Education/Fire-causes-and-risks/Wildfire/Preparing-homes-for-wildfire
- FEMA Fact Sheets: https://www.govinfo.gov/content/pkg/GOVPUB-HS5-PURL-gpo60104/pdf/GOVPUB-HS5-PURL-gpo60104.pdf
- IBHS: https://disastersafety.org/wp-content/uploads/2021/08/Fire-Resistant-Landscaping-for-Your-Home.pdf
- CALFIRE, Prepare for Wildfire: https://www.readyforwildfire.org/prepare-for-wildfire/get-ready/defensible-space/
- DisasterSafety.org: https://disastersafety.org/wildfire/d-space/
- Sample Fire Resistance Plant List, CA: http://firesafesdcounty.org/wp-content/uploads/2017/05/Comprehensive-Fire-Resistant-Plant-List.pdf
- Be Ember Prepared (Video): https://www.youtube.com/watch?v=gAuhNDb963Y
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- Quarles, Stephen and Ed Smith. The Combustibility of Landscape Mulches. Reno: University of Nevada Cooperative Extension, 2011. http://firesafesdcounty.org/wp-content/uploads/2017/05/The-Combustibility-of-Landscape-Mulches.pdf
- Beyler, Craig, Josh Dinaburg, and Chris Mealy. "Development of Test Methods for Assessing the Fire Hazards of Landscaping Mulch," Fire Technology 50, no. 1 (2014): 39-60. https://doi.org/10.1007/s10694-012-0264-y

Figure 2.4. Variety of vegetative and man-made fuels surrounding a structure that are considered part of defensible space. Please note the furniture and pergola are combustible. Also note, the propane tanks and hazardous vegetation are within the closest zone and therefore too close to the structure. Credit: Image annotated by SFPE Foundation. Original diagram from FEMA Marshall Fire MAT, FEMA, 2023. https://www.fema.gov/

Figure 2.5. Example of effective defensible space protecting a home from wildfire.

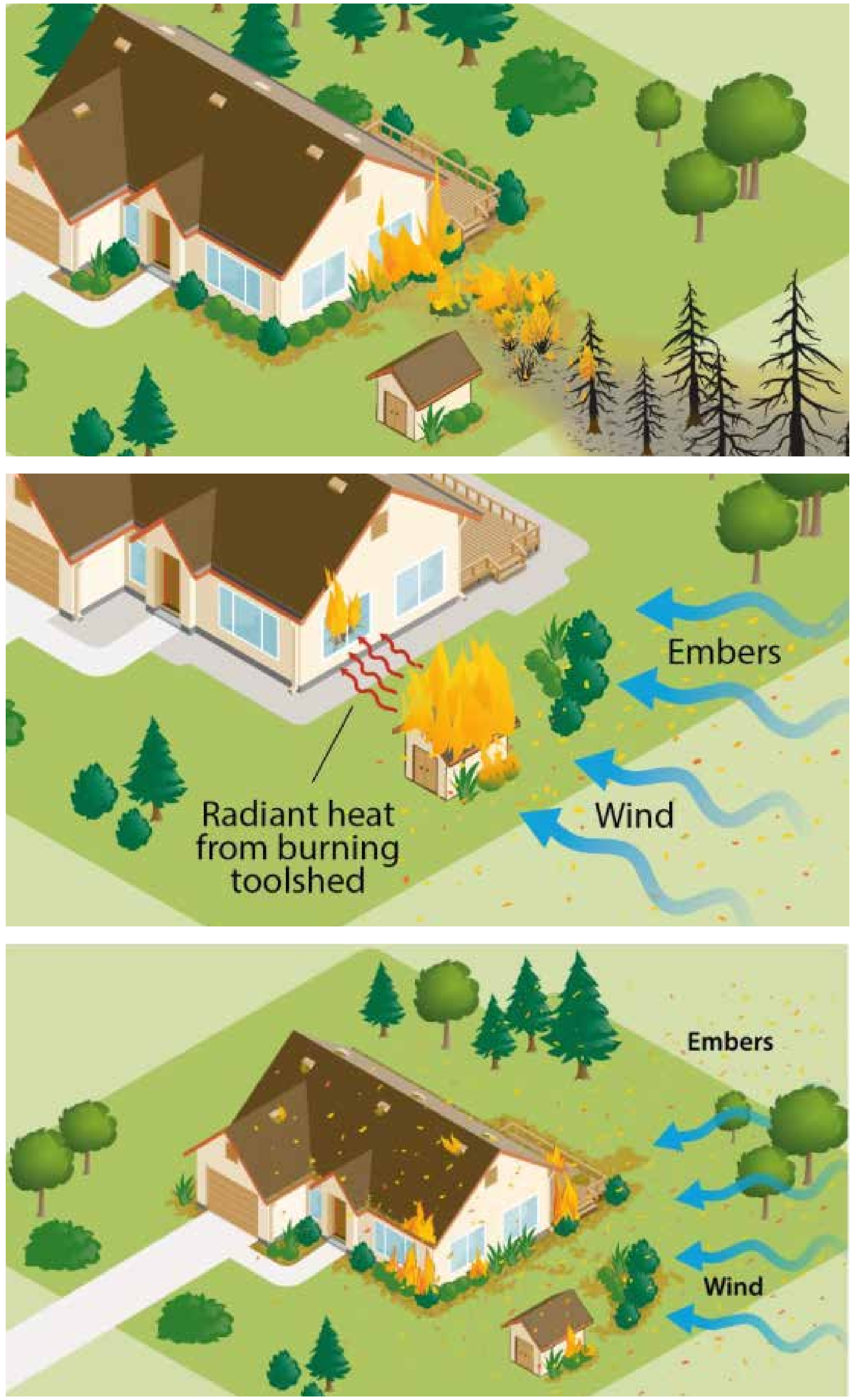


Figure 2.6. Three main heat transfer mechanisms that lead to structure ignition: (1) direct flaming contact, (2) radiant heat, (3) embers or firebrands. Reprinted from UC ANR Publication 8695, CC BY-NC-ND 4.0.

Figure 2.7. Reducing vegetative and man-made fuels around a structure are essential to reduce fire pathways from travelling to a property/structure, while also providing a safer place for firefighting operations. Reprinted from UC ANR Publication 8695, CC BY-NC-ND 4.0.

Figure 2.8a. Example of hazardous defensible space with overgrown vegetation overhanging and touching the structure, significant unmaintained trees, limbs, grasses, and shrubs in Zone 0 (0-5ft) and Zone 1 (50-30ft). Image courtesy of Jensen Hughes/FEMA.

Figure 2.8b. Example of hazardous defensible space with excessive storage of combustibles within Zone 0 (0-5 ft) and Zone 1 (50-30 ft). Image courtesy of Jensen Hughes/FEMA.

Figure 2.8c. Examples of hazardous defensible space with combustible mulch within Zone 0 (0-5 ft). Image courtesy of Jensen Hughes/FEMA.

Figure 2.8d. Examples of hazardous defensible space with pile of firewood and plastic trash bins within Zone 0 (0-5 feet), heavy brush within Zone 1 (5-30 feet). Image courtesy of Jensen Hughes/FEMA.

Figure 2.8e. Example of hazardous defensible space with dense shrub, hazardous trees (e.g., Italian cypress), overhanging trees, and propane tank within Zone 0 (0-5 feet) and Zone 1 (5-30 feet), in combination with wood shake single siding. Image courtesy of Jensen Hughes/FEMA.

Figure 2.8f. Example of hazardous defensible space with open combustible, post and stilt foundation, which allows vegetative debris and embers to accumulate under the home leading to ignition. Image courtesy of Jensen Hughes/FEMA.

Figure 2.9. Example of ember-resistant Zone 0 (0-5') with 6" of non-combustible bottom-of-wall detail, hardscaping, minimal vegetation and well-maintained grass and shrubs. Image courtesy of Jensen Hughes/FEMA.

Figure 2.10. Example of enhanced, non-combustible Zone 0 (0-5') 6" of non-combustible bottom-of-wall detail, well maintained grass and shrubs. Image courtesy of Jensen Hughes/FEMA.

Figure 2.11. Sample plantings and mosaic layout of vegetation in Zone 1 (5-30 ft). Reprinted with permission from Idaho Firewise. https://idahofirewise.org/

Figure 2.12. Example of residential area on a slope highlights the need for increased thinning of plants, shrubs and trees. The properties of some homes are thinned, while others are not.

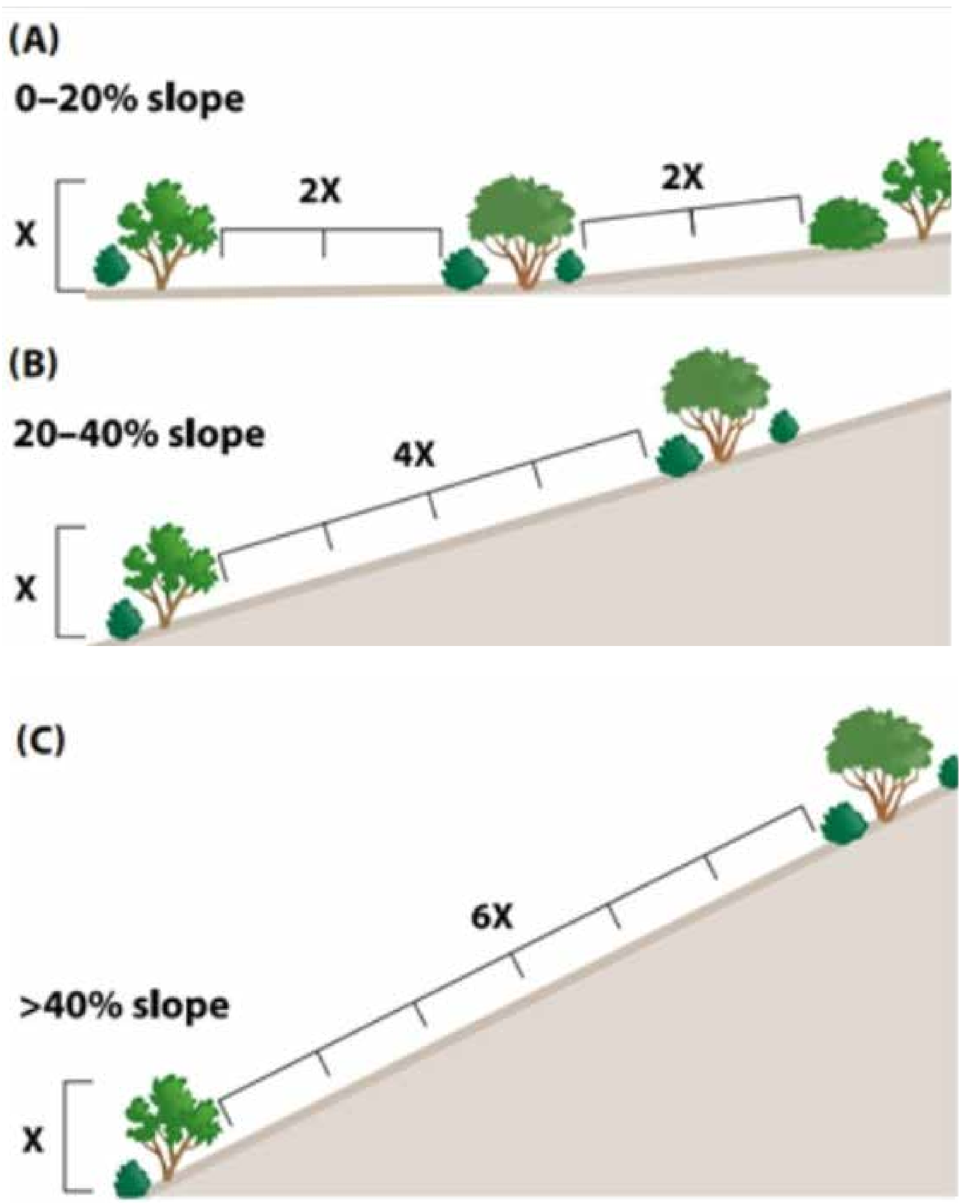


Figure 2.13. As slope increases, recommended distance between vegetation also increases. Steeper slopes should have widely spaced vegetation. Reprinted from UC ANR Publication 8695, CC BY-NC-ND 4.0.

Figure 2.14. Example of closely spaced homes with home on right having hazardous amounts of combustibles stored in Zone 0 (0-5 ft). This presents an increased fuel / fire hazard to both homes. Image courtesy of Jensen Hughes/FEMA.

Figure 2.15. Sample mitigations where site constraints limit setbacks to less than 30 feet. A combination of enhanced structural hardening measures (e.g., 1-hour exterior fire walls, non-combustible, solid fencing, reducing # of windows) and enhanced defensible space measures (e.g., hardscaping extended to 10feet). Image adapted from FEMA Marshall Fire MAT, Wildfire Resilient Detailing, Joint Systems, and Interfaces of Residential Building Components, FEMA, 2023. https://www.fema.gov/.

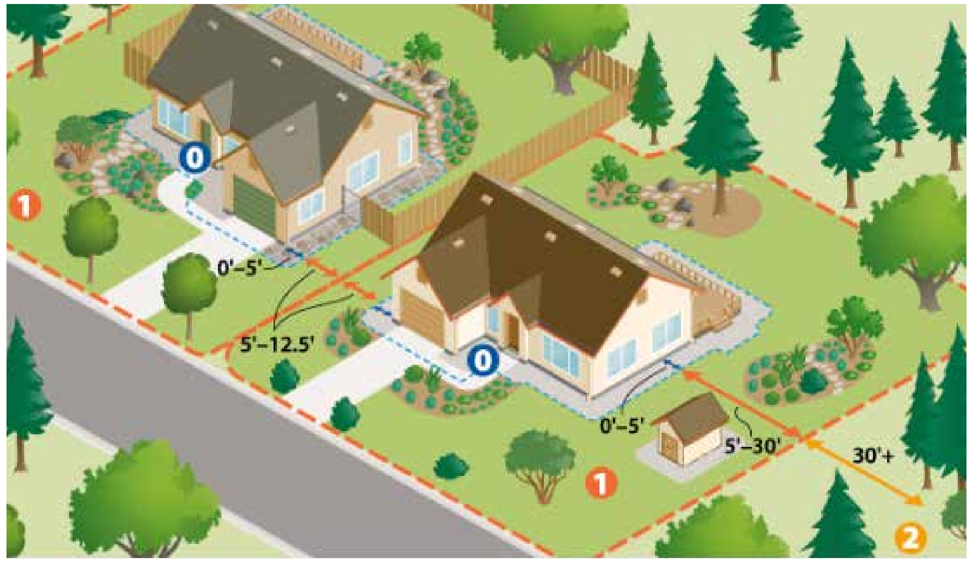


Figure 2.16. Diagram of communal defensible space for overlapping structure ignition zones for residences within thirty feet of each other. Neighbors can work together when their defensible zones overlap to mutually benefit each other and the larger neighborhood to limit fire spread. Reprinted from UC ANR Publication 8695, CC BY-NC-ND 4.0.

PART III - NEIGHBORHOOD AND COMMUNITY-SCALE

Overview

Part III of the Handbook provides a general framework with guidance and strategies to help reduce and/or mitigate hazards that contribute to wildfire risk in the WUI at the neighborhood and community scales. Planning for wildfire at these scales is a critical priority due to ongoing increases in (1) the breadth, depth, and severity of wildfire impacts in the built and natural environments; (2) continued expansion of human development into high fire hazard areas; and (3) the effects of changing climate on environmental settings.

Wildfire hazard, risk, and mitigation concepts and strategies presented in this chapter are for new and existing communities and are based on a combination of published literature, research, model codes, best practices, case studies, and other data from hazard mitigation, wildfire, forestry, engineering, planning, and related professional fields of practice. The goal of these strategies is to limit the risks to life safety, property protection, environmental services, and other values and assets in the natural and built environments. As such, the information and guidance are interrelated with key concepts and provisions at the building and parcel-scales provided in Parts I and II.

Many topics discussed in this chapter are integrally connected to decisions that occur within the wider lens of community planning and land use regulations, which determine where and how land is planned, developed, regulated, protected, or conserved to achieve long-term desired outcomes. Engaging in a thoughtful community planning process yields a range of benefits, including creating a local vision for future growth, aligning services and public safety needs, and proactively avoiding the consequences of unmanaged growth. Taking a holistic approach that integrates WUI planning within a broader planning and regulatory framework can help maximize these benefits [109].

The American Planning Association's report "Planning the Wildland-Urban Interface" can help users learn more about the concepts of WUI planning and its relationship to community plans and regulations. This document highlights collaboration opportunities for local stakeholders and offers case studies from communities [109].

Successful development and implementation of WUI planning strategies at neighborhood and community scales also requires a multidisciplinary and collaborative approach. Many interests pertain to the WUI and, as a result, many stakeholders often wish to be engaged in WUI outcomes that may have an impact on their work or residential areas. Typical stakeholders include, but are not limited to, land use planners, fire and emergency responders, architecture, engineering and urban design professionals, hazard mitigation specialists, land and resource managers, infrastructure and utility companies, business and insurance services, non-profit organizations, neighborhood/community associations, and other federal, state, or local agencies. Although some stakeholders may not engage directly in mitigation or development activities, it's important to establish a process for how groups can provide input on strategies such as regulations, mitigation programs, plan development, and policy priorities that may impact them. Leveraging the collaborative process early will build relationships and trust to support long-term buy-in and implementation [110]. Additional resources for collaboration and community engagement are available from the Fire Adapted Communities Learning Network and the U.S. Fire Administration's Fire-Adapted Communities [111], [112].

Note: *This handbook is not intended to act as a code or standard, but a guidance document and reference tool. Codes referenced herein are the most recent editions at the time of development. Refer to the relevant jurisdiction(s) for adopted codes, standards, and local ordinances for statutory requirements and planning policies.*

Chapter Organization

Definitions

- **Neighborhood:** For the purpose of this handbook, neighborhood is defined as a place with physical and geographic boundaries where people share social networks, space, and other defining features such as common building typologies, shared infrastructure (e.g., roads, utility services), demographics, environmental settings, etc. [113], [114].

- **Community:** A socially organized population living in a physically defined locality often characterized by (a) commonality of interests, attitudes, and values; (b) a general sense of belonging to a unified, socially integrated group; and (c) some system of communication, governance, education, and commerce [115]. For the purpose of this handbook, "community" is used to represent a range of scales such as multiple neighborhoods or subdivisions, one or more master planned communities, town, district, city, or other cohesive geographic area that is larger than a single neighborhood or subdivision.

- **Critical facilities and infrastructure:** Critical facilities and infrastructure are the structures, facilities, systems, and networks, whether physical or virtual, that are considered essential to maintaining the normalcy of daily life and overall functionality of a community or society. As such, they are essential for the efficient functioning, and delivery, of basic services provided in cities, towns, and rural areas. According to the United Nations Office for Disaster Risk Reduction (UNISDR), California Office of Emergency Services (CAL OES) and FEMA, destruction, disruptions, or interruptions in critical facilities and infrastructure, including health and education facilities, could lead to cascading effects across sectors and sometimes across borders [116], [117], [118].

Considerations for Neighborhood and Community Mitigation Tools

Choosing the appropriate mitigation tool(s) will vary depending upon several key considerations, including the local planning framework and whether the mitigation applies to new or existing development.

Whereas wildfire mitigation science and post-fire analysis have focused heavily on building construction and design and/or landscaping at the parcel scale, additional variables and factors can make a prescriptive approach to wildfire mitigation at the neighborhood and community scales more challenging compared to parcel and building scales, including lack of uniform development patterns, a wider range of land uses and property types, additional environmental features, and varying approaches toward land management and regulations. The effect of changing climate is a key factor that should explicitly be evaluated as it can have significant near-term and long-term impacts on the wildfire risk landscape of new and existing sites, developments and communities, and their associated capacities for resiliency. Climate change should be included in evaluations of wildfire hazards, risks, and vulnerabilities at neighborhood and community scales to understand the specific local challenges and needs for mitigation and adaptation.

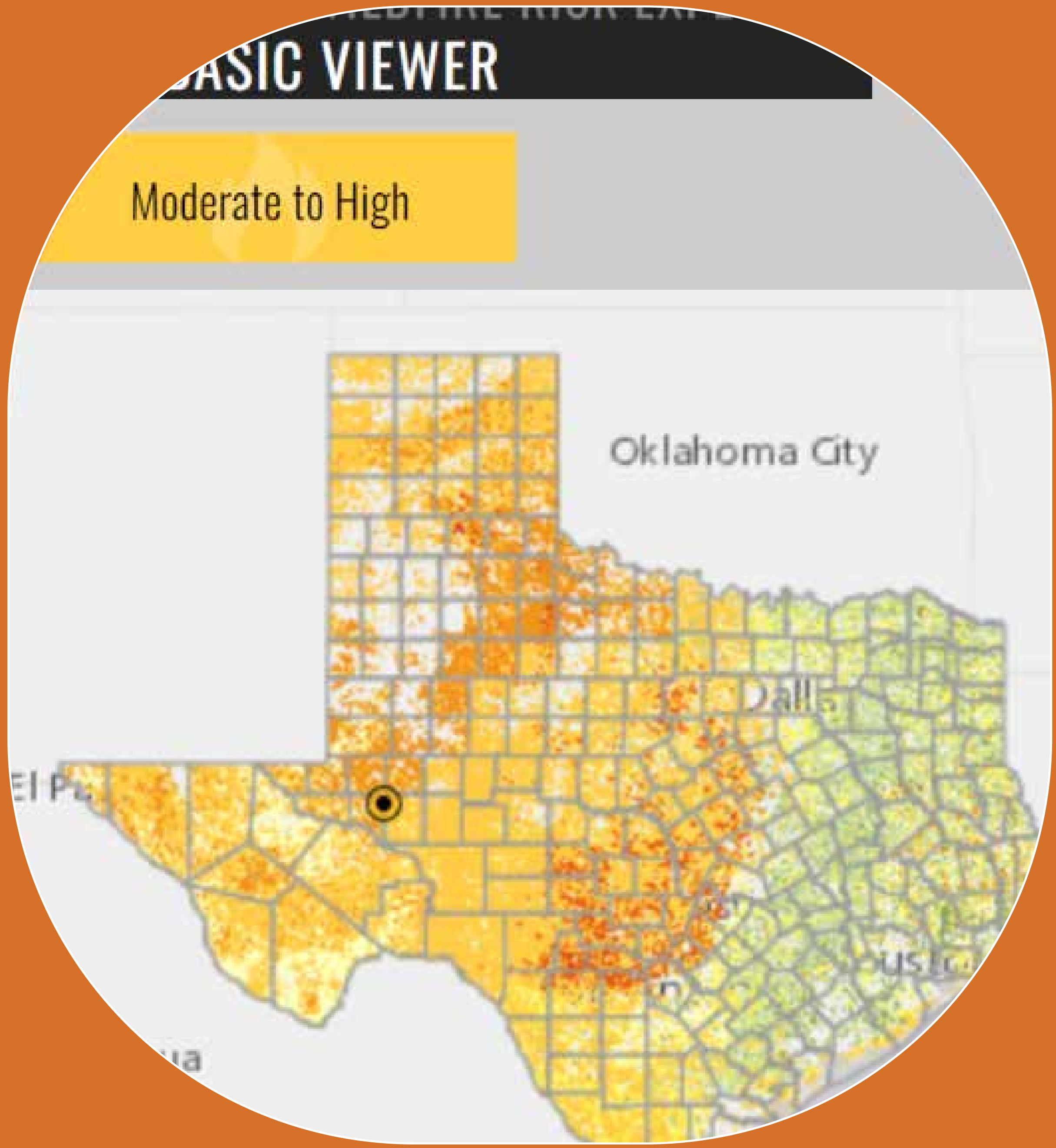
Due to the potential range of factors within a community, practitioners using this portion of the handbook should consult with any applicable federal, state, or local plans, codes, and ordinances (e.g., fire codes, building codes, WUI codes, subdivision regulations, zoning ordinances) that may dictate requirements for topics addressed in this chapter. In addition, practitioners should integrate local expertise and knowledge into their mitigation recommendations to ensure it aligns with site conditions and other considerations.

Further, some mitigation strategies may be more successful when implemented through voluntary approaches, such as community outreach and education events, retrofit programs, or neighborhood chipping days. For example, existing neighborhoods who have a coordination mechanism in place (e.g., participation in the Firewise USA® program or a local HOA mitigation program) can expedite the implementation of local activities for existing properties (See Section 3.7 *Examples of Neighborhood- and Community-Scale Programs*). Other mitigation strategies, such as establishment of multiple access routes and adequate water supply, will be most cost-effective when introduced for new development. Finally, there may be other policy priorities to consider, such as housing needs, environmental services, public health, and economic factors, that inform the development and implementation of mitigation strategies.

Figure B. Various scales, ranging from community down to individual lots.

HAZARD AND ASSESSMENT

NEIGHBORHOOD AND COMMUNITY-SCALE



3.1.1 HAZARD AND RISK ASSESSMENT

Main Concern(s)

A range of wildfire hazard and risk assessments can exist at local, state, and national levels. These assessments and associated maps can provide notable differences in information, terminology, analysis methodologies, inputs, and other variations, depending on the intended purpose, audience, and scale of use for which they are developed. Hazard and risk assessments can be undertaken to inform a variety of needs such as land resource management, firefighting operations, building construction requirements, regional and community planning, education and outreach, etc. These intended uses can span a broad range of audiences including fire agencies, government organizations, fire safety design and planning professionals, private sector, general public and other interested parties. In addition, the scale of analysis and scale of application can also vary from national, regional, county, city, and site-specific scales. Depending on the intended use, audience, and scale of application, the resulting outputs from hazard and risk assessments can look very different. This can present challenges and concerns of misunderstanding and misuse. For example, a national-scale fire hazard map likely provides valuable high-level information for national level decision-making but may not be appropriate (and can sometimes be erroneous) for local planning needs or firefighting operations. Examples of different hazard and risk assessments include the West Wide Wildfire Risk Assessment programs, CALFIRE's Fire Hazard Severity Zone maps, Southern Group of State Foresters, etc.

Most available wildfire hazard and risk assessments/maps are not explicitly designed to inform land-use planning, zoning, building design codes and standards, or other wildfire resiliency construction practices at the local, neighborhood, or building scales. California is one location where state-wide hazard maps are integrated into building and fire code requirements (California Building Code, Chapter 7A), and therefore directly trigger wildfire-specific risk mitigation provisions for new construction. However, most states and local jurisdictions have limited or no available wildfire hazard maps to trigger planning and building safety provisions. This means that numerous buildings and new developments are potentially being planned, designed, and constructed in high fire prone areas without appropriate building fire safety provisions. Additionally, existing building stock and developments may currently be in high fire prone areas, or could be at risk in the future, due to ongoing changes in the wildfire risk landscape, climate change, and other factors. Understanding the current and future levels of risks is a major challenge that is not currently considered in land use planning (Figures 3.1 and 3.2).

Key Terminology

- **Coping Capacity:** The ability of individuals, communities, organizations, and systems to manage adverse conditions, risk, or disasters using available skills and resources. The capacity to cope requires continuing awareness, resources, and good management, both in normal times as well as during disasters or adverse conditions. Coping capacities can be defined by a variety of social, technical, programmatic, economic, and other factors that contribute to the reduction of disaster risks [119].

- **Disaster:** A serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability, and capacity, leading to one or more of the following: human, material, economic, and environmental losses and impacts [116], [120].

- **Exposure:** The situation of people, infrastructure, housing, production capacities and other tangible human assets located in hazard-prone areas. The term exposure, in a wildfire context, is often used to describe what a building, structure, or community will experience when threatened by a wildfire (i.e., embers, radiant heat, and flame contact) [109] (Figure 3.3).

- **Hazard:** A process, phenomenon, or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption, or environmental degradation. Hazards may be natural, anthropogenic, or socio-natural in origin. Each hazard is characterized by its location, intensity or magnitude, frequency, and probability[121], [122] (Figure 3.3).

- **Natural Hazards:** Hazards that are predominantly associated with natural processes and phenomena [121].

- **Anthropogenic Hazards:** Hazards that are induced entirely or predominantly by human activities and choices [121].

- **Socio-natural Hazards:** Hazards that are associated with a combination of natural and anthropogenic factors, including environmental degradation and climate change [121].

- **Risk:** The potential loss of life, injury, or destroyed or damaged assets which could occur to a system, society, or a community in a specific period of time, determined probabilistically as a function of hazard, exposure, and vulnerability [123] (Figure 3.3).

- **Acceptable Risk:** Also referred to as tolerable risk, is the extent to which risk is deemed acceptable or tolerable based on existing social, economic, political, cultural, technical, and environmental conditions. In engineering terms, acceptable risk is also used to assess and define the structural and non-structural measures that are needed in order to reduce possible harm to people, property, services, and systems to a chosen tolerated level, according to codes or "accepted practice", which are based on known probabilities of hazards and other factors [122], [124].

- **Wildfire Hazard Assessment:** A qualitative or quantitative assessment that identifies wildfire prone areas based on natural factors such as fuel/vegetation, slope, and weather patterns that increase the likelihood of wildfire occurring [125].

- **Wildfire Risk Assessment:** Risk assessment identifies where wildfire is most likely to threaten something of community value, such as human life, property, natural/historic resources, or other resources of high value. Risk assessment can also include components of physical or social vulnerability such as pre-WUI code development, limited access/egress, high density housing, vulnerable populations, as well as aspects of coping capacities (e.g., fire department response time coverage, limited firefighting water supplies, limited emergency communications). As risk is the combination of hazard, exposure, and vulnerability, a high hazard location may not be high risk if there are no assets at risk. For example, a high hazard rating in an area with a low likelihood of consequences (e.g., a wildfire in an undeveloped area) could be considered low risk; whereas a medium hazard area with the potential for high consequences could be scored as high risk [125].

- **Vulnerability:** The conditions determined by physical, social, economic, and environmental factors or processes which increase the susceptibility of an individual, a community, assets, or systems to the impacts of hazards (Figure 3.3).

- **Physical Fire Models:** Solves the governing chemical and physical process associated with combustion and heat transfer. These are often developed for research purposes to better understand the fundamental phenomena. They include Computational Fluid Dynamics (CFD) models.

- **Empirical Fire Models:** Statistics-based models that do not capture physical processes.

- **Semi-empirical Fire Models:** Capture some physical aspects with simplifications.

Fire Test Standards

None identified at time of publication.

Referenced Codes and Standards

Development, adoption, and enforcement of wildfire-specific building codes, fire codes and standards, as well as planning requirements will vary depending on the state and individual jurisdictions.

- Check local, county, and state regulations and amendments for any additional requirements.
- Check local general plan, local-hazard mitigation plan, community wildfire protection plan, multi-hazard mitigation plan, or zoning documents for any additional requirements.

Examples of building codes and standards:

- *International Wildland-Urban Interface (IWUI) Code* - Section 502.1 Fire Hazard Severity
- *California Public Resources Code 4201-4204* - Fire Hazard Severity Zones
- *ASTM E1355* - Standard Guide for Evaluating the Predictive Capability of Deterministic Fire Models

Typical Resource(s), Description and Sample References

Table 37. Wildfire hazard or risk resources.

Typical Wildfire Hazard or Risk Resources	Technical Description	Sample References / Tools
Hazard and Risk Maps	• "Wildfire hazard" and "wildfire risk" are often used interchangeably but are distinctly different terms with different meanings and implications for understanding and better planning for wildfires. Refer to terminology section above for definitions of hazard vs risk. • Fire "hazard" maps provide a spatial distribution of the potential likelihood and intensity of fire across the landscape. In many cases, fire hazard maps are based on various factors including fuel loading, slope, fire weather, severe wind conditions, and other relevant factors. Fire hazard maps are NOT "risk" maps if they do not consider both probability of fire and associated consequences. • Fire "risk" maps provide a spatial distribution of the likelihood and intensity of fire, as well as the potential consequences or impacts of fire to assets or values in the built and/or natural environment. These values can include populations, structures, critical infrastructure, natural resources, environmental services, cultural/historical resources, etc. The types and range of values at risk will depend on the purpose and use of the map. • Hazard and risk assessments result in notable differences in information, terminology, analysis methodologies, inputs, and outputs depending on the intended purpose, audience, and scale of application. These factors should be understood to avoid misunderstanding, misinterpretation, and misuse. • Hazard and risk maps can exist at a range of scales (local, state, national levels). • In some locations, such as in California, fire hazard maps are integrated into building and fire code requirements (e.g., California Building Code, Chapter 7A), and therefore directly trigger wildfire-specific hazard mitigation provisions for new construction. • In other locations, hazard mapping may not be explicitly designed to inform land-use planning, zoning, building design codes and standards, or other wildfire resiliency construction practices at the local, neighborhood, or individual home scale.	Local-Level • Refer to local fire agencies. • Refer to local planning documents (e.g., CWPP, Safety Element of General Plan, or Comprehensive Plan). • Refer to local wildfire safety professionals, engineers, planners. State-Level • *California* - California Department of Forestry and Fire Protection (CAL FIRE), Fire Hazard Severity Zone Maps: https://osfm.fire.ca.gov/what-we-do/community-wildfire-preparedness-and-mitigation/fire-hazard-severity-zones/fire-hazard-severity-zones-maps-2022 • *Colorado* - Colorado State Forest Service, Colorado Forest Atlas: https://coloradoforestatlas.org/ • *Oregon* - Oregon Department of Forestry: https://geohub.oregon.gov/apps/9eeb869eabb148c99d48d6ffdf675e0b/explore • *Texas* - Texas A&M Forest Service, Texas Wildfire Risk Explorer: https://texaswildfirerisk.com/ • *Utah* - Utah Department of Natural Resources. https://wildfirerisk.utah.gov/ • Southern Wildfire Risk Assessment Portal (SouthWRAP): https://www.southernwildfirerisk.com Federal-Level • Several federal-level wildfire hazard and "risk" maps exist (e.g., USDA Forest Service wildfirerisk.org). However, these resources are not intended to be used for local or state level planning.

Wildfire Behavior Modelling	• Wildfire modelling is the analytical or computational simulation of wildfire to better understand, characterize, and/or predict wildfire behavior. There is a wide range of wildfire behavior models that can capture various aspects of fire phenomena (e.g., flame length, rate-of-spread, intensity) with varying degrees of sophistication and complexity. These models can be statistical-, empirical-, semi-empirical or physics-based, and be static "snapshots" in time or near-real time simulations. • Wildfire modelling can be used for a variety of applications including to develop hazard maps for building construction requirements, to inform site-development and siting during entitlement, to aid wildfire suppression, to inform insurance coverage, to protect environmental services, to identify hazards and risks for landscape level fuel treatments, land resource management, environmental planning or urban development, etc. • Most well-known wildfire models use statistical data of past fire events to characterize fire behavior, hazards, and/or risks. These models assume fire propagates via simple elliptical, egg- or fan-shaped patterns. Other key inputs for these models include topography, fuel models, wind speed, fuel moisture, etc. • Wildfire behavior models generally assume consistent conditions such as wind, homogenous fuels, or terrain to simplify calculations and variables. Many wildfire models do not consider ignition by firebrands/embers, which is a primary ignition concern in the WUI. Extensive expertise, knowledge and skills in GIS mapping, spatial analytics, and wildfire behavior fundamentals are needed to use and interpret wildfire models appropriately. Most models require some form of verification and validation against real world fire incidents and/or fire testing to justify their use.	• ***FlamMap/FARSITE*** - FlamMap is a PC-based program developed by the USDA Forest Service Rocky Mountain Research Station that describes potential fire behavior under constant environmental conditions (e.g., a single fire weather and fuel scenario). Version 6 of FlamMap incorporates Fire Area Simulator (FARSITE), which was previously a separate wildfire behavior model. FlamMap is GIS compatible, but should only be used by experts in fire behavior to interpret results for planning or operations. [126]. This software is readily available online at: https://research.fs.usda.gov/firelab/products/dataandtools/flammap. • ***Behave[7]*** - Developed by USDA Forest Service, this fire model is a program that can be run without an internet connection on Windows, Mac, or Linux computers. using Java software. It is a point system, which means it calculates fire behavior for a limited area/single point. It uses the same fire spread calculations as FlamMap, integrating surface and active crown fire spread rates. Behave7 includes four different models used to calculate maximum spotting distance, as well as calculating scorch height, taking into account fuel moisture content, wind variability, tree mortality, and firefighting containment actions [127]. Behave7 is available at: https://www.frames.gov/behave/home • ***WFDS*** - Developed through a joint effort between NIST and the USDA Forest Service, Version 6 of Fire Dynamic Simulator (a Computational Fluid Dynamics model) fully incorporates the Wildland-Urban Interface Fire Dynamics Simulator (WFDS). WFDS models fire spread in vegetation and other outdoor combustible materials. WFDS combines FDS's combustion and heat transfer calculations with a surface fire spread akin to that used by 2D fire spread models. The use of the simpler fire spread model reduces the computational requirements that would otherwise be necessary [128]. This software is readily available online at https://pages.nist.gov/fds/downloads.html. • ***LANDFIRE*** - LANDFIRE is a suite of landscape fire and resource management planning tools. It is a shared program between the wildland fire management programs of the USDA Forest Service and U.S. Department of the Interior. The program provides landscape scale geospatial products to support cross-boundary planning, management, and operations. This program provides several databases that can be used as input into wildfire behavior models, but is not a wildfire behavior model itself. This tool and resource are available online at https://landfire.gov/. • ***IFTDSS*** - The Interagency Fuels Treatment Decision Support System (IFTDSS) is a web-based application with three built-in modelling platforms: Landscape Fire Behavior (LFB) (based on FlamMap), Minimum Travel Time Fire Spread (MTT), and Landscape Burn Probability (LBP). The tool is designed to inform fuels treatment planning, prescribed fire planning and landscape-level fire analysis (i.e., 100s- 3.5M acres). This application is available online at https://iftdss.firenet.gov/landing_page/index.html.

Wildfire Planning Documents	• There are numerous planning documents at regional, state, and local levels that may contain wildfire-specific hazard and risk information. These documents can be developed by a variety of government and non-government agencies or organizations such as local fire departments, fire protection districts, planning departments, office of emergency services, fire safe councils, Firewise communities, etc. • Oftentimes, wildfire hazard and risk information may not be consistent across the various scales of planning (i.e., regional, state, county, and city-scales), or even across the various plans that are developed within the same local region. • A critical role for all relevant government and non-government stakeholders is to ensure that local and regional plans are aligned, consistent, and complementary with respect to desired goals, identified wildfire hazards and risks, identification and prioritization of mitigation strategies, recommended policies, and investments in risk reduction programs.	• General Plan or Comprehensive Plan; (Safety Element, Hazard Element). • Community Wildfire Protection Plans (CWPPs). • Unit Strategic Plans or other fire service planning documents. • Local Hazard Mitigation Plans (LHMPs). • Multi-jurisdictional Hazard Mitigation Plans. • Community Plans. • Zoning and Development Codes. • Fire Protection Plan. • Wildfire Mitigation Plans. • CEQA (California Environmental Quality Act) and NEPA (National Environmental Policy Act) plans and reports. • Environmental Impact Reports

General Mitigation Strategies

- Evaluate all relevant state and local wildfire hazard maps. ***Note:*** **Typical hazard and "risk" maps do not identify community-assets-at-risk or vulnerabilities**.
- Consult with wildfire/fire safety experts and environmental specialists to balance public safety and environmental concerns.
- Evaluate all relevant local level community planning documents (e.g., general plans, zoning, CWPPs, LHMPs, emergency operations, unit strategic plans, evacuation plans).
- Consult state and local wildfire building and fire codes. Otherwise, IWUI Code and *NFPA 1140*.

- Consult with the local fire department(s) for:
  - Any local requirements
  - Additional guidance documents
  - Wildfire planning processes and reviews
  - Pre-approved alternative mitigation measures

- Consult with local wildfire behavior specialists to undertake project specific hazard and risk mapping.
- Wildfire hazard and risks maps should be revised and updated periodically as human development, vegetative characteristics, fire incidents, climate change, and other factors alter the WUI risk landscape over time. At a minimum, wildfire hazard and risk maps should be updated every 5 to 10 years.

Training Programs

- Wildfire Fire Modelling Training
  - Society of Fire Protection Engineers Foundation: https://www.sfpe.org/foundation/wildland-urban-interface/wui-initiatives
    - Advanced Engineering Science for the Fire Service: Advanced Training Topics in WUI Fire Risk Assessment & Mitigation
  - Society of Fire Protection Engineers: https://www.sfpe.org/events-education/liveeducation/coursecatalog and https://www.pathlms.com/sfpe/courses
    - Using Wildfire Fire Dynamic Simulator (WFDS) requires an understanding of how to use and interpret Fire Dynamic Simulator. Courses may not explicitly talk about the WFDS elements (vegetation fire spread).
    - Introduction to Fire Dynamic Simulator and Advanced Fire Dynamic Simulator.
  - Behave[7]: https://www.frames.gov/behave/home
    - Online courses under development at time of publication.
  - Interagency Fuels Treatment Decision Support System (IFTDSS) https://iftdss.firenet.gov/firenetHelp/help/pageHelp/content/00-aboutiftdss/online%20courses.htm?TocPath=_____8
    - Includes online courses on Fundamentals, Overview, Prescribed Fire Plans, and Basics Workshop with exercises
- National Fire Academy (NFA): https://www.usfa.fema.gov/nfa/courses/
  - F0663 - Wildland-Urban Interface Risk Assessment & Mitigation for the Fire Service
- National Wildfire Coordinating Group (NWCG): https://wildlandfirelearningportal.net
  - S-190 - Introduction to Wildland Fire Behavior
  - S-290 - Intermediate Wildland Fire Behavior
  - S-390 - Introduction to Wildland Fire Behavior Calculations
  - S-490 - Advanced Fire Behavior Calculations
- University of Idaho - Fire Ecology and Management: https://www.uidaho.edu/cnr/natural-resources-online/master-of-natural-resources/mnr-fire
  - REM 144 - Wildland Fire Management
  - FOR 326 - Fire Ecology and Management
  - FOR 433 - Fire and Fuel Modelling
  - FOR 450 - Fire Behavior
  - REM 429 - Landscape Ecology
  - GEOG 313 - Global Climate Change

Gaps in Knowledge

- Established standards for undertaking wildfire hazard and risk assessments for different intended purposes and scales of application.
- Consistent terminology and style guides for common hazard and risk outputs (e.g., maps).
- Verification and validation of wildfire modelling tools and assessment approaches. Current fire behavior models are not able to simulate structure-to-structure or wildland-to-structure fire spread with accuracy and are in the research-only phase. Thus, the ability to model WUI fire spread is in its infancy.
- The application of machine learning models (MLM) and artificial intelligence to wildland fire behavior is an evolving area of research [129].
- Consensus standard on fire hazard severity maps for building construction requirements.
- Consensus standard on wildfire zoning and land-use maps for planning purposes.

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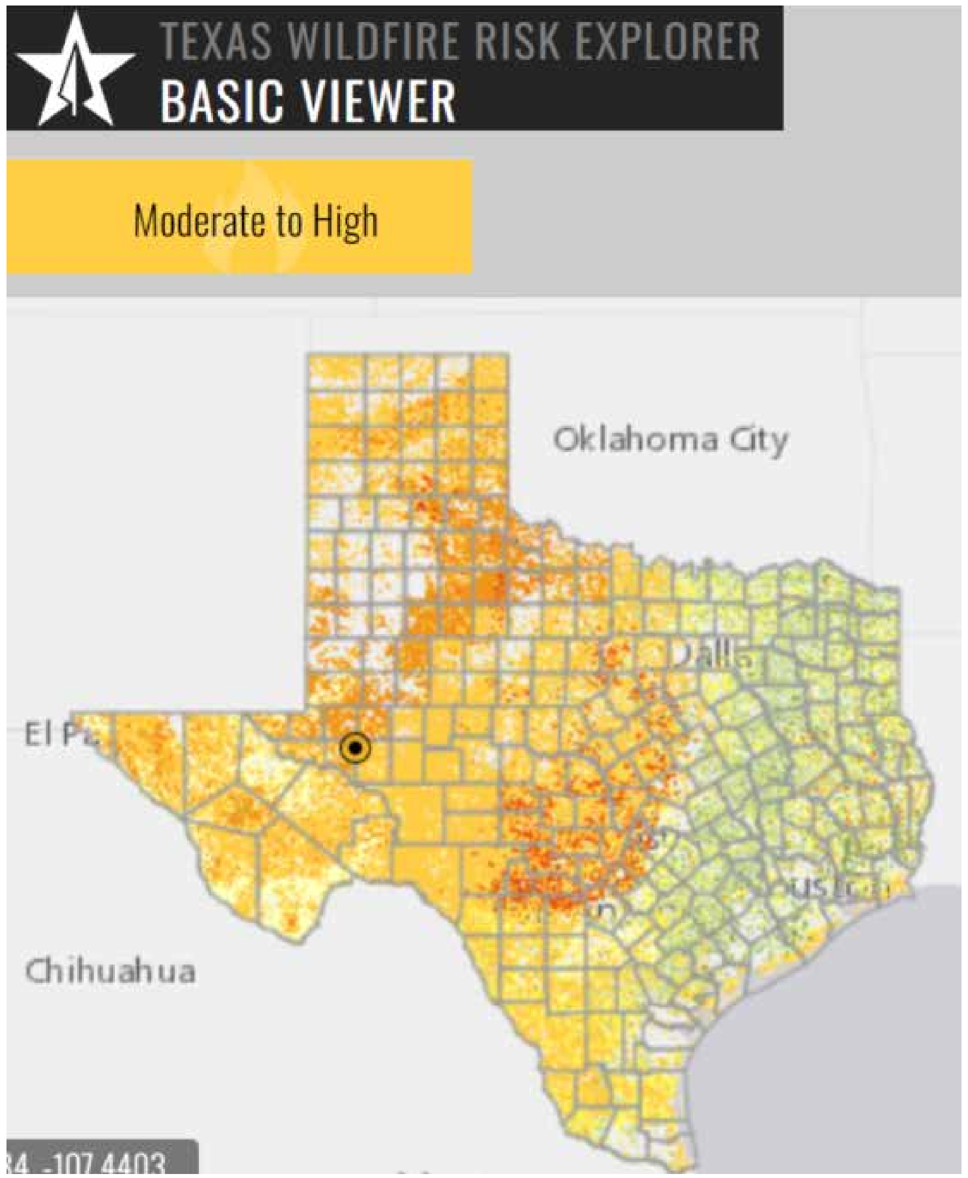


Figure 3.1. Example wildfire "risk" map for the state of Texas. This "risk" map does not take into consideration true risk, which would be based on probability of ignition and consequences. This would be considered a wildfire hazard map. Image courtesy of Texas A&M Forest Service https://tfsweb.tamu.edu/default.aspx

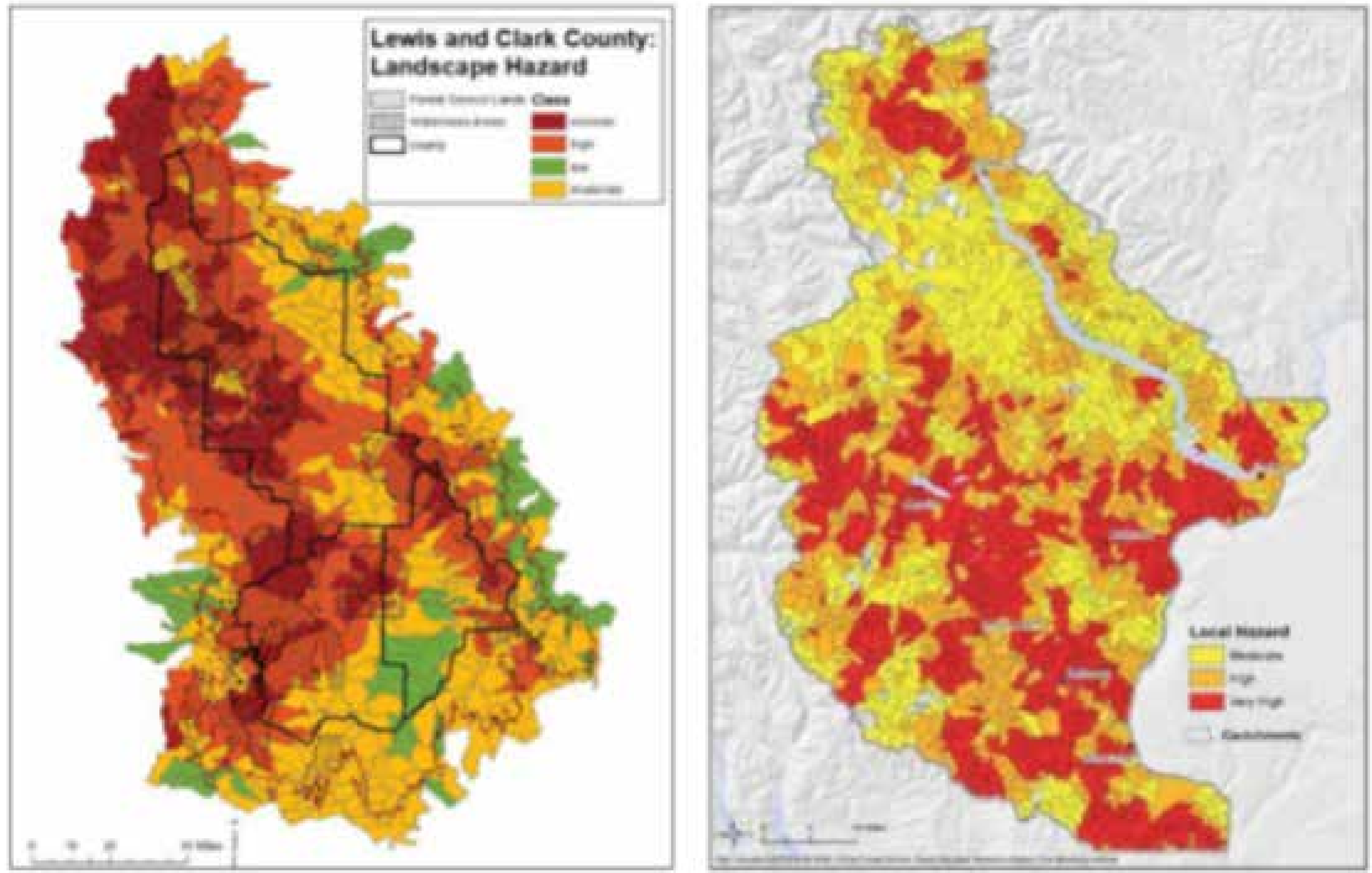


Figure 3.2. Example of wildfire hazard assessments using different analytical scales (i.e., 100m vs 30m resolution), hazard classification systems. Left: Wildfire Hazard in in Chelan County, Washington. Right: Lewis and Clark County: Lanscape Hazaard. Reprinted with permission from Headwaters Economics https://headwaterseconomics.org and Community Planning Assistance for Wildfire. https://cpaw.headwaterseconomics.org

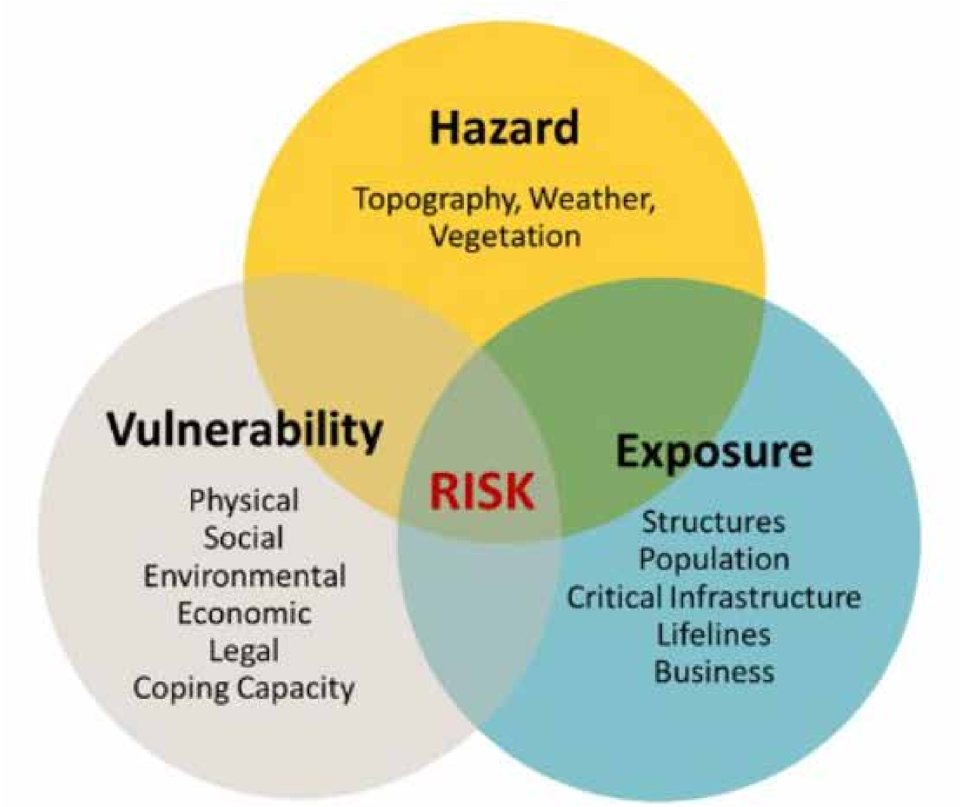
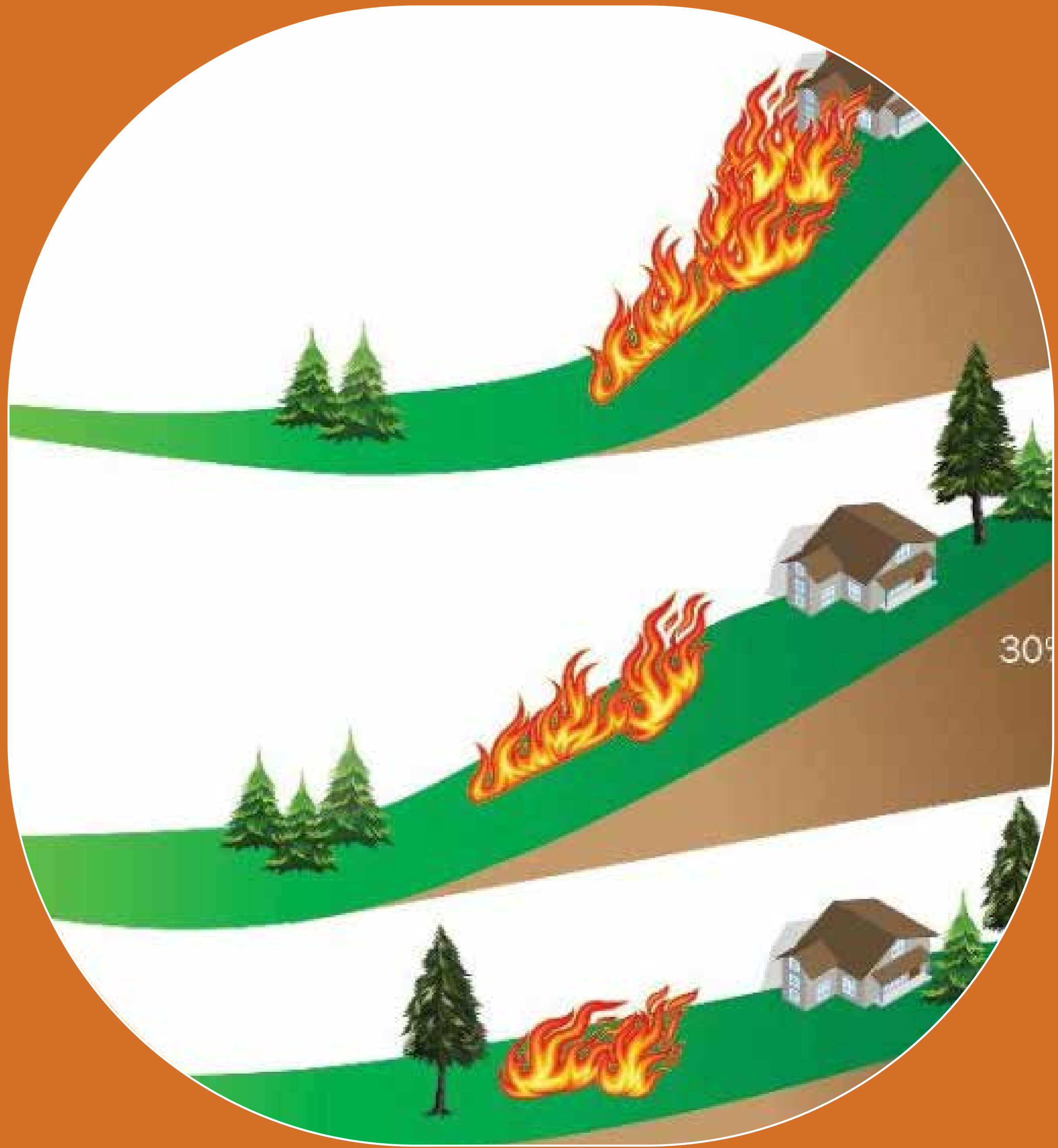


Figure 3.3. Key components of wildfire risk. Image courtesy of Darlene Rini.

RESIDENTIAL DEVELOPMENT & SAFETY



NEIGHBORHOOD AND COMMUNITY-SCALE

3.2.1 DEVELOPMENT SITING

Main Concern(s)

Selecting the location of a new master planned community, subdivision, or other development in relation to its surroundings can greatly influence a community's future wildfire risk. Site conditions such as topography, vegetative characteristics, and proximity of fuels and other developments, can increase or decrease fire behavior and affect the type of wildfire mitigation options that are most effective and appropriate. For example, wildfire severity and rate-of-spread of fire increase at specific topographic features (e.g., saddles, ridgelines, drainages, canyons, and steep slopes), presenting a significant threat to homes or developments in those locations; these threats cannot always be mitigated using standard defensible space, setback, and structural hardening measures [130]. As a result, making well-informed development siting decisions early in the planning process helps avoid costly or less feasible mitigation options later.

Key Terminology

- **Master Planned Community:** Self-contained communities with a range of land uses, public facilities, and services, and a consistent design character. Master planned communities are typically developed by a single-development entity but may have separate builders for each subdivision. These community types are also referred to as planned unit developments, planned communities, or new towns [131].

- **Subdivision:** The process of dividing land into smaller units (lots, parcels, plats, sites, or other divisions of land) for the purpose of sale, lease, offer, or development, whether immediate or future [132]. Local governments are typically authorized by state legislation to develop and enact subdivision regulations.

- **Slope:** The amount or degree of incline of a hillside [133], [134].

- **Aspect:** The cardinal direction toward which a slope faces [133], [134].

- **Terrain:** Variation in land features [109].

- **Development:** Activities that typically include (unless exempted) any building, construction, renovation, mining, extraction, dredging, filling, excavation, or drilling activity or operation; any material change in the use or appearance of any structure or in the land itself; the division of land into parcels; any change in the intensity or use of land, such as an increase in the number of dwelling units in a structure or a change to a commercial or industrial use from a less intensive use; any activity that alters a shore, beach, seacoast, river, stream, lake, pond, canal, marsh, dune area, woodlands, wetland, endangered species habitat, aquifer, or other resource area, including coastal construction or other activity [132].

- **Development Site:** A legally established lot or parcel of land occupied or capable of being occupied by a building or group of buildings, including accessory structure(s) and accessory use(s), together with such yards or open spaces, and setback areas as are required by code and having frontage upon a street [132].

Fire Test Standards

None identified at time of publication.

Referenced Codes and Standards

Development, adoption, and enforcement of wildfire-specific building codes, fire codes, and standards, as well as planning requirements (i.e., master planning, subdivision, and other development siting topics) will vary depending on the state and individual jurisdictions.

- Check local, county, and state regulations and amendments for any additional requirements (e.g., development codes, subdivision regulations, zoning ordinances) to determine if your jurisdiction has requirements.
- Check local plans (general/comprehensive plan, master plan, neighborhood/subarea plans, specific plans, zoning documents) for any additional requirements.

Examples of building codes and standards:

- *2022 NFPA 1140 Standard for Wildland Protection* - Section 25.1.3 Location

Typical Challenge(s), Vulnerability, and Mitigation Considerations

Table 38. Typical challenges, vulnerability, and mitigation considerations for development siting.

Typical Challenges	Vulnerability	Potential Mitigations

Slope	• Slope is one of the key topographical factors affecting fire behavior [109] (Figure 3.4). Refer to section 3.6.1 for further discussion on the dynamic nature of topography and post-fire impacts.
	• Fire usually spreads faster uphill than downhill due to the buoyancy driven nature of fire (i.e., hot air rises), but also because fuels are more efficiently preheated by uphill spreading of heat and flames. Thus, the steeper the slope, the faster the fire can burn [133] (Figure 3.4).
	• A fire at the 30% slope range has the potential to develop and spread uphill at a faster rate [133] (Figure 3.5).
	• Firefighting efforts can also be hampered and slowed on slopes [109].
	• Slopes may also influence areas below the fire (e.g., embers or large burning materials rolling downhill) or above the main fire (convective air carrying embers and igniting spot fires) [109].
	• Development (i.e., structures) located mid-slope or at the crest of a slope can be impacted by convective heat, extreme fire behavior, and embers generated by a wildfire or other structures burning below, which can increase the risk of structures igniting.
		• Avoid placing new development on slopes greater than 30% and on ridgetops. Note: This may vary depending on local jurisdiction.
		• Where new development on slopes is inevitable, locate development on areas of the site with the lowest relative slope or areas at the bottom of a slope.
		• Where new development on a ridgetop is inevitable, select a development site that allows for a minimum 30-100’ setback from the edge of the slope. Setbacks in the 50-100’+ range are generally required when heavier fuels are present (such as a forested environment) [130] (Figure 3.6).
		• For cases when minimum setbacks are less than 15’ for a single-story and 30’ for a two-story building from the edge of a slope, increase vegetation modification to extend between 150’ and 200’ [135].
		• Where new or existing developments are located on steep slopes with insufficient setbacks (see above) and/or insufficient fuel modifications on the proximate steep slopes, augment the side of the home (if not the entire home) fronting the steep slope or other topographic hazard with additional structural hardening measures Below are more specific measures [130]:
		  • Provide vent covers with 1/16” wire mesh or an approved ember and flame-resistant vent. Some jurisdictions have “pre-approved” products such as CALFIRE’s Building Materials Listing Program [73]. Local building and/or fire officials have discretion to approve products.
		  • Provide 1-hour rated exterior wall construction with noncombustible or ignition resistant siding materials (e.g., fiber cement, stucco).
		  • Provide noncombustible decking.
		  • Provide noncombustible materials for non-vegetative features (e.g., ornamental grass, sheds, pergolas, gazebos) or design any combustible elements in surrounding landscape (e.g., trash bins, wood piles, vehicles) to be more than 30’ away from homes or structures or to be enclosed in noncombustible construction.
		  • Provide double-paned windows with one or more tempered pane or tempered-laminated glazing (i.e., 2 panes of tempered glass between which is a layer of clear plastic film).
		  • Recommend reducing the number of openings (e.g.., windows, glazed doors, vents) on the aspect where exterior walls are in close proximity to steep slopes.
		  • Use noncombustible materials (e.g., concrete, masonry, metal), particularly for fences that attach to adjacent homes or structures.
		  • Consider providing a 6’, solid, non-combustible property line wall along the aspects with steep slopes.

Aspect	• The aspect of a slope can also affect fire behavior due to the amount of heating it receives from the sun.
	
	• South (S) and southwest (SW) facing slopes get the most direct heat from the sun [109].
	
	• Although S/SW slopes tend to have less vegetation, they also have higher temperatures, lower relative humidity, and lower fuel moisture. These characteristics can make S/SW aspects more likely to ignite and have increased fire behavior compared to N/NE slopes [133].
		• Where homes are constructed adjacent to S/SW facing slopes, special attention to the other local conditions and potential mitigations based on factors relative to the aspect should be considered.
		
		• Where S/SW facing slopes is unavoidable:
		  • Augment the S/SW facing side of the home with additional structural hardening measures (e.g., 1-hour fire rated exterior wall assemblies, noncombustible siding, additional window protections such as noncombustible shutters, etc.) and ensure that slope vegetation has been thinned.
		  • Avoid constructing combustible decks or patios along the S/SW slope.

Other Terrain Features	Other terrain features can also affect fire behavior by changing wind patterns, funneling air and increasing wind speed at a local level. Terrain restrictions such as narrow portions of valleys can increase wind speed as the wind passes through or around these restrictions. Steep-sided gullies or canyons can create a chimney effect, resulting in increased uphill rate-of-spread and intensity [109] (Figure 3.4).	• When siting new development, assess terrain features to avoid locating structures or other values at risk in locations such as gullies, narrow canyons, saddles, etc. [130].
		
		• When siting new development, work with a local fire mitigation professional to consider incorporating terrain features such as rock outcrops, streams, lakes, or roads that can act as fire barriers or could be used to create a boundary around fires for firefighting or fuel breaks [133] (Figure 3.7).
		
		• Where construction in these high-risk terrain features is unavoidable:
		  • Ensure that structural hardening protections have been included in the design of the home (Refer to Part I).
		  • Locate structures so there is 30' of setback per story of the home from any hazardous terrain.

Wildland Fuels	Open space, parks, grasslands, forests, and other natural areas or spaces that have wildland fuels (grasses, trees, shrubs, plants) can increase a community/subdivision's exposure to the heat transfer process (i.e., radiation, convection, conduction, and embers) [130].	• When new development is proposed in proximity to areas where wildland fuels will remain hazardous (e.g., they are located outside a property boundary and are unmanaged), require development setbacks of 30-100' from the property boundary [130]. • For existing development or new development with setbacks less than 30' from wildland fuels, require increased structure hardening, installation of irrigation systems, or placement of other noncombustible barriers or natural features (e.g., water bodies) that disrupt fuel continuity [130].
Existing Neighborhoods	• Existing neighborhoods that are not compliant with WUI codes and regulations or taking comprehensive voluntary initiatives to reduce their risk are vulnerable not only to themselves but also to nearby developments. • Non-compliant neighborhoods may contain structures and other features (e.g., wooden fences and decks) that readily ignite and generate heat, flames, and embers—posing a threat to other areas in the WUI.	• Developments proposed near non-compliant WUI neighborhoods must consider the additional threat of these areas, similar to options for siting near wildland fuels [130], as well as additional structural hardening provisions suggested for high-density housing in Section 3.2.2 *Subdivision Spatial Design*.

General Mitigation Strategies

- Locate development in areas that present the lowest possible wildfire hazard to people, property, infrastructure, and other assets deemed essential for the safety, welfare, resilience, and sustainability of the community [136].

- Avoid new development in areas where there is high wildfire hazard, and it cannot be reasonably mitigated [136].

- Avoid intensification of existing development in areas that have a high wildfire exposure level that cannot be mitigated to an acceptable exposure level due to site constraints (topography, slope, or fuel loading) without compromising the integrity of the landscape [136].Additional benefits of not developing in certain areas, such as on top of slopes or ridgetops, also include keeping ridgetops free from development so that strategic fuel breaks can be implemented, and preserving regional views [137].

- Develop a fuel modification and long-term vegetation management plan for the steep slopes proximate to the development site [130].

- Avoid development in areas that are in or adjacent to environmentally sensitive areas (e.g., conservation areas, high-biodiversity areas, riparian areas) where vegetation management to protect people and property would compromise sensitive areas [109], [136].

Training Programs

- National Wildfire Coordinating Group (NWCG): https://www.nwcg.gov/nwcg-training
  - S-190 - Introduction to Wildland Fire Behavior

- University of Idaho - Fire Ecology and Management: https://www.uidaho.edu/cnr/natural-resources-online/master-of-natural-resources/mnr-fire
  - FOR 450 - Fire Behavior

Gaps in Knowledge

Current wildfire codes, standards, and planning documents do not provide specific recommendations or requirements to address a wide range of siting challenges. Nor do they provide various options to help mitigate siting issues from a variety of perspectives such as building typology and construction, structural hardening measures, defensible space measures, siting and setback options, active suppression systems, and other design/planning alternatives.

Other References

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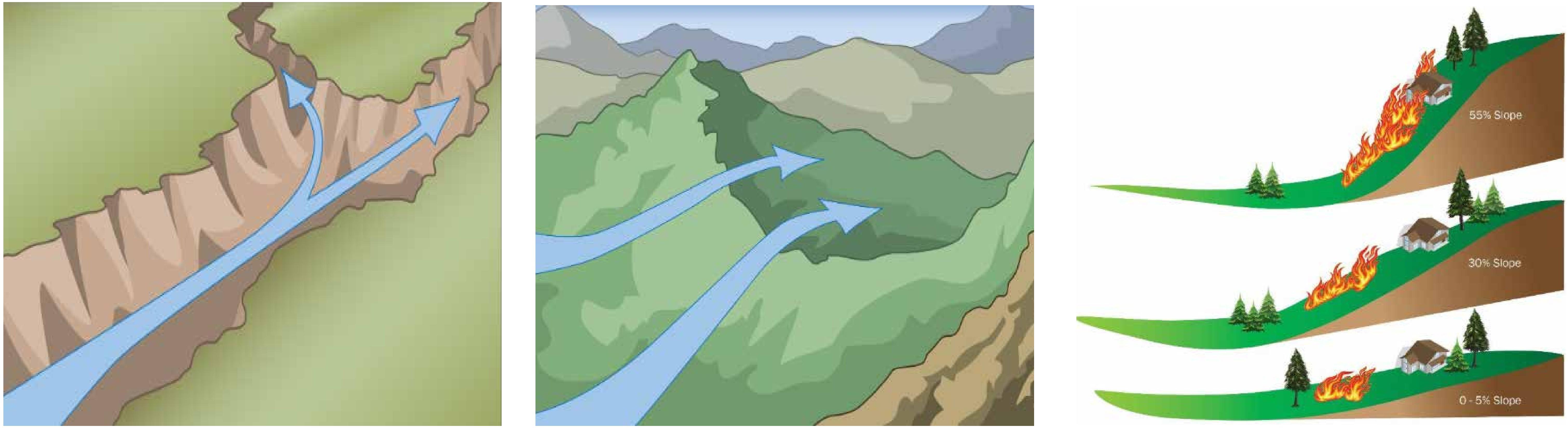

Figure 3.4. Common topographic fire hazards. (left) Canyons can collect heat and funnel superheated air. (middle) Winds are funneled over a saddle between two peaks. Images adapted from Home Builder's Guide to Construction in Wildfire Zones, FEMA, 2008. https://www.fema.gov/ (right) The steepness of the slope can impact fire spread. Image adapted from FEMA Marshall Fire MAT, Best Practices for Wildfire Resilient Subdivision Planning, FEMA, 2023. https://www.fema.gov/

Figure 3.5. Developments located on or proximate to slopes >30% may have increased wildfire risk. Appropriate mitigation actions, such as slope setbacks, vegetation management plans and/or enhanced structural hardening may be needed to offset the increased wildfire risk. Image adapted from FEMA Marshall Fire MAT, Best Practices for Wildfire Resilient Subdivision Planning, FEMA, 2023. https://www.fema.gov/

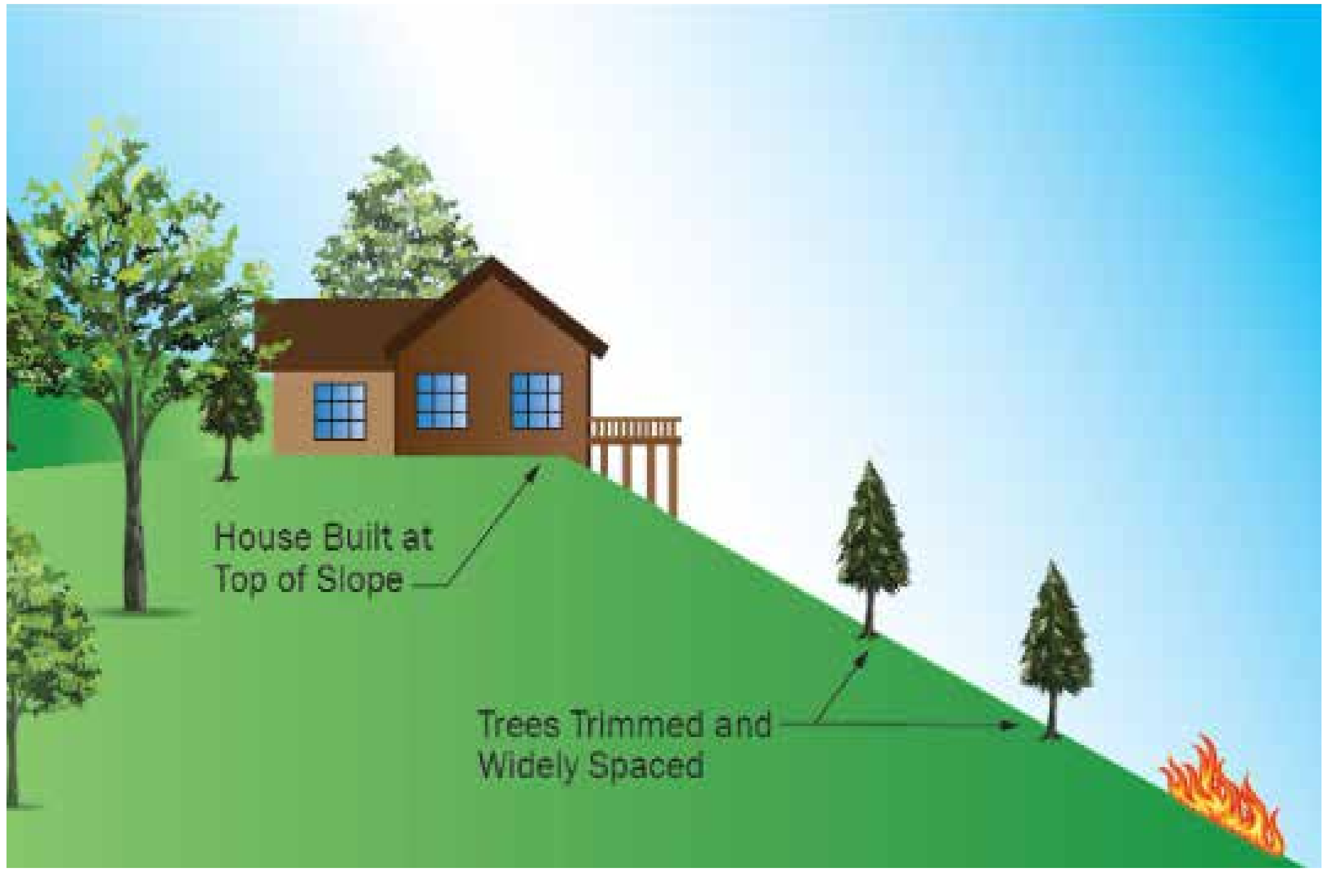

Figure 3.6. Topography and vegetation influence wildfire risk. Where 50-foot setback to steep slopes is not feasible, a minimum of 100-200 feet of fuel modifications along the proximate slope may be needed to reduce wildfire risk. Image adapted from FEMA Marshall Fire MAT, Best Practices for Wildfire Resilient Subdivision Planning, FEMA, 2023. https://www.fema.gov/

Figure 3.7. Example of integrating an inherent fuel break such as a golf course around a development fronting on large, unmanaged wildland or open space. Image adapted from FEMA Marshall Fire MAT, Best Practices for Wildfire Resilient Subdivision Planning, FEMA, 2023. https://www.fema.gov/

3.2.2 SUBDIVISION SPATIAL DESIGN

Main Concern(s)

The spatial design and density of a community or subdivision relates to the number and size of homes (or structures) in an area, the proximity of homes to one another, as well as other potential features. Resulting development patterns influence how wildfires affect a community. For example, urban and suburban areas with more structures on smaller lots (e.g., high-density, compact, or clustered designs) will have an increased likelihood of wildfires transitioning into urban conflagrations with multiple home-to-home ignitions because of the proximity and interrelationship of structure ignition zones [109]. However, this type of development may also be easier to defend during a wildfire because the overall amount of area is typically smaller and more accessible for suppression resources [137]. As a result, different spatial design and densities influence the amount of potential exposure and type of mitigation options that are most effective or available to property owners.

Key Terminology

- **Lot Size (or Area):** The total plan-view area within the defined property lines of a lot, typically expressed in square feet or acres. Lot area is often defined in a local zoning code/ordinance (or subdivision) as a minimum or maximum allowable lot size based on the zoning district.
- **Density:** The number of allowable dwelling units on a lot in relation to the lot size, expressed in units per acre [132].
- **High Density:** In this context, smaller lot areas with minimal property setbacks and structures, resulting in overlapping structure ignitions zones where adequate defensible space cannot be achieved independently on a single lot (Figure 3.8).
- **Low Density:** In this context, larger lot areas with property setbacks and structures that allow for management of structure ignition zones independent of adjacent lots and structures (Figures 3.8 and 3.9).
- **Cluster Subdivision:** A subdivision in which the lot sizes are reduced below those normally required in the zoning district in which the development is located, in return for the provision of permanent (or common) open space [132].
- **Urban Conflagration:** A large, destructive fire that spreads unimpeded by fire suppression efforts or barriers, destroying large areas of structures and infrastructure [109].

Fire Test Standards

None identified at time of publication.

Referenced Codes and Standards

Requirements for the spatial design and density of a community or subdivision will be based on any number of applicable state and local government regulations.

- Check local plans (general/comprehensive plan, master plan, neighborhood/subarea plans, specific plans, zoning documents).
- Check local, county, and state regulations and amendments (e.g., development codes, subdivision regulations, zoning ordinances) to determine if your jurisdiction has requirements.

Examples of building codes and standards:
- *2022 NFPA 1140 Standard for Wildland Protection* - Section 12.2 Building Separation

Typical Design(s), Vulnerability, and Mitigation Considerations

Table 39. Vulnerabilities and potential mitigations of high- and low-density lots.

Typical Challenges	Vulnerability	Potential Mitigations

High-density (small lot development patterns)	• Typical spatial design features of high-density neighborhoods include building footprints within 0-10’ of a lot line (depending on local zoning code allowances). This results in homes that have minimal structure separation from one another, in some cases only 5-10’. However, typical fire separation requirements under current building codes were designed for limiting urban conflagrations that originated from a single interior building fire, not multiple structure ignitions [130].
	
	• Further, overlapping home ignition zones that have not been mitigated will have additional combustible features (e.g., landscaping, fences, decks, sheds, vehicles) that increase the number of structure ignition pathways for home-to-home ignitions [20]. When wildland fires transition into high density neighborhoods, vulnerable structures can quickly ignite one another from radiation or direct flame contact. Fire response and suppression tactics can become overwhelmed when this transition to an urban conflagration occurs [73], [109].
		• Assess high-density neighborhoods as a single “building” or development, which includes a fuel modification zone with a minimum distance of 100’ that surrounds the perimeter of the entire development site. This zone can be further extended through increased fuel modification distances, installation of irrigation systems, or placement of other “low flammability” land uses such as maintained orchards, golf courses, and roads [130], [139], [140] (Figure 3.7).
		
		• Require additional fire safety mitigations to offset reduced fire separations. Additional mitigations include fire-rated exterior walls, noncombustible construction materials, ember resistant vent protection, and 5’ ember-resistant zones around every structure. Below are more specific measures [130]:
		  • Provide vent covers with 1/16” wire mesh or an approved ember and flame-resistant vent. Some jurisdictions have “pre-approved” products such as CAL FIRE’s Building Materials Listing Program [73]. Local building and/or fire officials have discretion to approve products.
		  • Provide combustible siding with noncombustible or ignition resistant materials (e.g., fiber cement, stucco).
		  • Provide noncombustible or ignition-resistant decking (See Part 1 for more specific guidance).
		  • Provide noncombustible materials for non-vegetative features (e.g., ornamental grass, sheds, pergolas, gazebos) or design any combustible elements in surrounding landscape (e.g., trash bins, wood piles, vehicles) to be more than 30’ away from homes or structures, or to be enclosed in noncombustible construction.
		  • Provide double-paned windows with one or more tempered pane or tempered-laminated glazing (i.e., 2 panes of tempered glass between which is a layer of clear plastic film).
		  • Recommend reducing the number of openings (i.e., windows, glazed doors, vents) on the aspect where exterior walls are in close proximity to other buildings.
		  • Use noncombustible materials (e.g., concrete, masonry, metal), particularly for fences that attach to adjacent homes or structures.
		
		• Adopt a landscaping or vegetation management ordinance that prohibits high-flammability plantings or landscaping (e.g., junipers) between homes that do not have a minimum of 30’ separation distance.

Low-density (large lot development patterns)	• Low-density housing typically has higher amounts of flammable vegetation (compared to high-density) [141], contributing to potential fire spread throughout a community. • Although low-density housing allows individual structures to implement their own defensible space measures, this type of development pattern requires a higher amount of land area dedicated to defensible space (compared to high density developments). This can have negative impacts on environmental services and other ecological goals of the community. • Low-density developments can also result in the need to disperse firefighting resources and suppression activities in the event of a major wildfire incident, given the larger spread of development [141], and make evacuations more inefficient if access is limited.	• For new developments, consider clustering homes to reduce the expansion of development in high-wildfire hazard areas, while also achieving other benefits, such as limiting impacts to sensitive areas [109], protecting habitat, meeting recreational goals for open spaces, reducing the distribution of firefighting resources during a major wildfire incident [137]. • In cases where low-density housing is unable to meet the required minimum defensible space on all sides of an individual structure, require structural hardening measures on all affected properties, and encourage community approaches to implementing defensible space measures [130].

General Mitigation Strategies

- Review Homeowner Association (HOA) rules and covenants to ensure there are no landscaping requirements at odds with fire mitigation (e.g., mulch or plantings within 5' of a home) and there is no prohibition on using noncombustible materials as community design features (e.g., ignition-resistant fencing) [109]. This approach may also reflect any state requirements, such as Colorado's legislation that prohibits covenants and other restrictions that disallow the installation, use, or maintenance of fire-hardening building materials in residential real property, including in common interest communities [142].

- Establish the maximum number of lots in subdivisions by considering the ability for all habitable structures to follow recommended home ignition zone requirements [136].

- With clustering and high-density development patterns, the near-home noncombustible zone and vegetation management/location of other combustibles and ember-resistant construction becomes critical to mitigate due to the potential consequences with home-to-home fire spread. These development designs should only be approved when adequate structural mitigation and ember-resistant measures can occur to reduce the threat of home-to-home ignitions in these areas [109].

Training Programs

Community Wildfire Planning Center - Land Use Planning for Wildfire Training: https://www.communitywildfire.org/trainings/

Gaps in Knowledge

- Currently, there is limited formal guidance to assist developers, design professionals, and planners in providing appropriate wildfire safety provisions given the range of housing density and layout considerations in practice [20], [130], [141].

- There are a limited number of studies that evaluate whether overall WUI losses are highest in high density versus low density developments. A study by Syphard et al. found that losses in urban areas (in California) were only a portion of the total number of structures destroyed and that overall, most structure loss tends to occur in areas of low-density [143]. A separate study by Kramer et al. found that the interface WUI (or, areas with higher density housing), was where most buildings were destroyed (in California) despite less wildland fuel [144]. More research is needed to evaluate long-term data from WUI losses in more geographic areas with diverse housing and land use patterns.

Other References

None identified at time of publication.

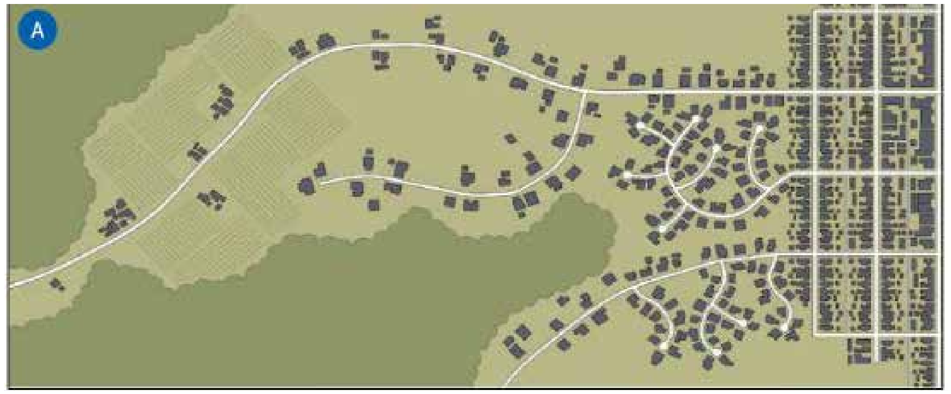

Figure 3.8. Conventional, or traditional, development with low-density houses (A) versus clustered development with several high-density clusters of structures (B). Image reprinted with permission from Martin Dreiling, Dreiling Terrones Architecture and the Smart Code.

Figure 3.9. Sample lower-density spatial design for suburban, residential housing. Even in this context, 100 feet of defensible space for all side yards is not practically available. Image courtesy of the Insurance Institute for Business & Home Safety.

3.2.3 MEANS OF EGRESS AND EVACUATION PLANNING

Main Concern(s)

In recent years, major wildfires have highlighted the critical need to plan, design, and implement safe means of egress for use by the public and first responders during wildfires. Major wildfire incidents, particularly large-scale, fast-moving fires, can expose both residents and first responders to unsafe and/or dangerous conditions due to a variety of factors including high temperatures, poor visibility, untenable conditions, congestion, blocked roadways, etc.

While existing building codes and standards provides numerous means-of-egress requirements for interior building fires to get occupants out of a building safely and efficiently (e.g., number, capacity, and protection of egress routes), equivalent requirements or guidance for wildfires incidents at neighborhood or community scale do not exist or are limited. This means that many new and existing neighborhoods and developments may not have a sufficient number, arrangement, capacity, or protection of routes to allow all residents to egress, while simultaneously allowing first responder access during a wildfire emergency (Figures 3.10, and 3.11).

In addition to limited prescriptive requirements for means of egress for wildfires at various scales, comprehensive technical and programmatic planning, and preparedness for wildfire evacuations at neighborhood and community scales is also limited. That is, in addition to the physical design and layout of means of egress ("evacuation routes"), the design, implementation, and operations of early warning detection systems, public emergency communications and messaging, large-scale people management strategies and associated facilities, as well as coordinated operational procedures, drills and training across relevant agencies and organizations (e.g., fire, law enforcement, office of emergency services or OES, municipalities, community groups, etc.) are also limited.

These technical, practical, and operational considerations specific to wildfire emergencies are essential for people to be able to evacuate safely and quickly before being endangered by fire, smoke, or hot gases, or other hazards that may occur during a major wildfire (e.g., downed trees or powerlines, congestion, loss of communication). *Note: Means of egress and evacuation planning are closely tied to access for first responders and therefore should be considered in parallel [130].* Refer to Section 3.3.1 *Fire Department Access* for details.

Key Terminology

- **Access:** Access, related to wildfire, refers to relatively safe and unobstructed travel into an area threatened by a wildfire by firefighters and other emergency responders.

- **Means of Egress:** The route or path of vertical and horizontal egress travel from any occupied portion of a building, structure, space, or community to a place of relative safety [145].

- **Evacuation:** The action of directing and/or moving people and assets temporarily to places of relative safety during a hazardous event. In a wildfire context, this typically refers to the evacuation of people from an area threatened by a fire to an area unthreatened by the fire [130]. Evacuations may include the development and implementation of an evacuation plan, which refers to the technical, programmatic, and operational arrangements established in advance to enable various combinations of people management strategies (e.g., total or phased-evacuation, shelter-in place). The specifics of the evacuation plan or people management strategies will differ based on the specifics of the wildfire incident as well as the preferences, vulnerabilities, and needs of individuals and communities. Evacuation planning may also include strategies for repopulation after the fire [145].

- **Fuel Breaks:** Natural or human-made changes in fuel characteristics that affect fire behavior so that fires burning into them can be more readily controlled [122], [146].

- **Total Evacuation:** Total evacuation refers to moving all individuals exposed to or threatened by a hazard away from the risk and to a place of safety. The use of total evacuation and specifics of the plan will depend on the wildfire incident, as well as the population to be evacuated, and specifics of the transportation network [147].

- **Phased Evacuation:** In a phased evacuation, not all areas or individuals evacuate at the same time. Those closest to the hazard or those with impaired capabilities evacuate first, followed by other areas and groups as the hazard develops, moves, and changes. A phased evacuation can reduce loading, and thus congestion, of the transportation network [147].

- **Separation of Exits:** A key principle of means-of-egress is that, if multiple exits exist, they should be separated from one another in such a way as to maximize likelihood that at least one exit will remain open if other(s) are blocked due to an emergency event. This concept is also applied to emergency planning in neighborhoods and subdivisions, where the exits to be separated are access roads, which connect to the regional transportation network and the diagonal distance is that of the entire neighborhood/subdivision [130] (Figures 3.12 and 3.13).

- **Maximum Travel Distance:** Maximum travel distance, in the context of building egress, is the maximum permittable distance that an individual would have to travel from a location to the nearest exit (e.g., stair enclosure, door to outside) [148]. A similar concept can be applied at the neighborhood or community scale via the transit network. The distance can be measured from any structure along the road network to the nearest primary road, though there is not a universally accepted maximum travel distance, nor definition of what constitutes an "exit" (Figure 3.14).

- **Dead End:** A dead-end road, and related "no through" road or cul-de-sac, has a single inlet/outlet, and at one end does not connect to another road or street. Dead-end roads are utilized by planners to reduce through-traffic in residential areas, but can pose a challenge for access and egress during emergency events. The International Fire Code requires that dead-end access roads in excess of 150' in length meet specific width and turnaround provisions, details of which may vary with local fire authorities [148].

- **Demand Model:** A mathematical model to predict how people will travel within a transportation system. These are used to forecast traffic flows and travel patterns. Demand models are typically applied to transportation systems to determine long-term predictions and needs but can also be utilized for emergency evacuation assessment and planning.

- **Evacuation Time Estimate (ETE):** The calculated time needed to evacuate an area, neighborhood or community during an emergency incident.

- **Wildland-Urban Interface Required Safe Evacuation Time (WRSET):** The time needed for an entire area, neighborhood, or community in the wildland-urban-interface to reach a place of relative safety during a wildfire incident. A place of relative safety may either be a location that is considered sufficiently remote from the area at risk or in a safe shelter within the community [149].

- **Wildland-Urban Interface Available Safe Evacuation Time (WASET):** The time it takes a fire to reach an area, neighborhood or community in the wildland-urban-interface or the time when tenability criteria (e.g., high temperatures, hot gases, direct flaming, poor visibility, smoke) for safe egress from an area, neighborhood or community are exceeded [149].

- **Community Shelter-in-Place or Temporary Evacuation Points:** A building or place that is "hardened" or considered relatively safe in fire conditions, and to which emergency management agencies will direct people during a major wildfire incident when total evacuation is considered unsafe. A variety of terms are used for similar concepts. Community shelter-in-place typically refers to staying inside of a building while temporary evacuation points may be inside or outside. The shelter-in-place and temporary evacuation point locations are typically identified in advance by emergency management agencies The use of community shelter-in-place or temporary evacuation points by the general public is a jurisdiction-by-jurisdiction decision, and depends on a variety of factors including wildfire environmental conditions, availability of egress options, capacity of egress routes, people management strategies, etc.

- **Temporary Refuge Area (TRA):** Temporary refuge areas provide a place of relative safety that can be used temporarily for short-term relief, to wait while a fire passes, or to minimize/control traffic on key transportation routes. TRAs are typically outdoor areas with limited or no vegetation, such as parking lots, irrigated fields, lawns, or greenbelts. TRAs are primarily intended for fire or emergency response personnel use. In certain scenarios and conditions, members of the public may be directed to a TRA as one step in an evacuation process or as a last resort option. Firefighter activities may be required to maintain a level of safety at a TRA (e.g., fire suppression), especially if members of the public are present. The use of TRAs by the general public is a jurisdiction-by-jurisdiction decision, and depends on a variety of factors including wildfire environmental conditions, availability of egress options, capacity of egress routes, people management strategies, etc.

- **Contraflow:** Temporarily allowing vehicles to travel in the opposite direction of the usual flow of traffic to reduce traffic congestion. If contraflow is implemented, the potential for inbound emergency response vehicles from mutual aid, should be considered.

- **Trigger Point or Trigger Boundary:** A trigger point is a prominent landmark such as roads, rivers or ridgelines whereby an evacuation is recommended if an advancing fire crosses this point. Historically, trigger points have been determined at the time of an event based on live or near-real time understanding of the situation but are increasingly being developed in advance as part of a comprehensive emergency planning effort to identify candidate points. A trigger boundary is similar concept to trigger point and is defined as the notional perimeter in the landscape around a community where a wildfire is as far away as the time required to evacuate the community. This is equivalent to the physical location of the wildfire front when WASET is equal to WRSET [150].

- **Critical Evacuation or Dire Evacuation Condition:** A condition or situation where people are exposed to critical or dangerous fire conditions such as high temperatures, hot gases, direct flaming, poor visibility or untenable conditions from smoke during the evacuation process. These conditions are more likely to occur when the community's WRSET is longer than the WASET for the approaching wildfire [151], [152], [153].

Fire Test Standards

None identified at time of publication.

Referenced Codes and Standards

Requirements for means of egress and/or evacuation planning at parcel-, neighborhood-, subdivision-, or community-scales will vary depending on state or local agencies, including transit authorities, planning agencies, fire agencies, etc. However, comprehensive regulations and/or consensus standards are limited.

- Check local plans (general/comprehensive plan, master plan, neighborhood/subarea plans, specific plans).
- Check wildfire specific planning documents (e.g., community wildfire protection plan, wildfire evacuation assessments or studies).
- Check local, county, and state regulations and amendments (e.g., development codes, fire codes, subdivision regulations) to determine if your jurisdiction has requirements.

Example(s) of Codes and Standards:

- *2021 International Fire Code* - Appendix D
- *2024 International Wildland-Urban Interface Code* - Chapter 4

Typical Challenge(s), Vulnerability, and Mitigation Considerations

Table 40. Vulnerabilities and potential mitigations for access/egress challenges.

Types of Access/ Egress Challenges	Vulnerability	Potential Mitigations
Single Means of Egress	• Single means-of-egress developments, neighborhoods, or subdivisions can pose a major risk to life safety of the public; a single fire incident could result in the loss of this single route due to any number of scenarios including severe fire conditions, poor visibility, downed trees, downed powerlines, vehicle breakdown etc. Any of these scenarios could further increase the public's exposure to high temperatures and other untenable conditions, or completely prevent safe egress, leading to potential injuries and/or loss of life. • First responders may also be less able to provide emergency services to developments and/or neighborhoods with single access/egress routes due to the potential life safety threats to first responders, where there's a high likelihood of unsafe conditions and potential loss of an escape route (Figures 3.10 and 3.11).	• For multi-family residential developments having more than 100 dwelling units, a minimum of two separate and approved egress roads should be provided out of the development (Figure 3.12) and from the development (Figure 3.13) [144]. • Developments of one- or two-family dwellings, where the number of dwelling units exceeds 30, should be provided with two separate and approved access/egress roads out of the development (Figure 3.12) and from the development (Figure 3.13) [144]. • Where two access/egress roads are required out of the development, they shall be separated by a distance of not less than one-half of the length of the maximum overall diagonal dimension of the property or area to be served, measured in a straight line between accesses [153]. • Where two or more egress routes are impractical due to topography or other physical site constraints, additional fire safety measures should be provided to ensure an equivalent level of safety. This may include the design and construction of fire-resistant community shelter-in-place facilities, and/or increasing the fire resistance rating of the exterior envelope of all structures (e.g., non-fire rated to 1-hour for roof assemblies, wall assemblies).

Insufficient Separation of Egress Routes	• In some new or existing neighborhoods, while multiple egress routes may exist, they can oftentimes have insufficient separation. That is, one or more egress routes converge to a single primary road/discharge point. This configuration can essentially create a single means of egress that is vulnerable to a single fire event, rendering all routes impassable (Figure 3.12). • Currently, there is limited prescriptive guidance on what is deemed "sufficiently separated" for wildfire threats at development, neighborhood, and community scales. This means that egress route design can be inconsistent and subjective. • In some cases, additional independent means of egress from a development or neighborhood may not be possible due to a variety of constraints including topography, wildfire behavior, poor legacy transit planning and infrastructure, etc. In these contexts, designers, engineers, planners, and local authorities have limited prescriptive (i.e., codes and standards) and performance-based (i.e., designs based on testing rather than codes and standards) guidance on alternative methods for providing an equivalent level of safety.	• Where possible, add additional access/egress routes that are separated from existing routes to mitigate "single means of egress conditions." Refer to guidance in "Single Means of Egress" in the row above. • Where these mitigations are not possible, additional fire safety measures should be provided. See possible mitigations for "Single Means of Egress" conditions in the row above.

Excessive Travel Distances	• Depending on the location of a development, maximum travel distances to primary roads may be greater than evacuation standards (where standards exist). In some locations, maximum travel distances are based on the number of housing units or structures that are served by a specific road or set of roads. For example, lengths of dead-end roads are limited based on number of parcels and dwelling units served, as well as parcel size, by some jurisdictions (see potential mitigations column for more detail) [153].
	
	• Longer travel distances equate to longer evacuation times, which can impact life safety of evacuees, and response time and safety of first responders.
	
	• Excessive travel distances also pose a greater likelihood of the road being impacted (e.g., downed trees, power lines), which would further increase travel time or decrease evacuation capacity.
		• For new developments, maximum travel distances from a building should be limited based on the number of housing units, structures, and/or number of people being served. Sample maximums are as follows [153]:
		  • Dead-end roads serving up to 20 parcels and not more than 40 dwelling units should not exceed 5,280'.
		  • Dead-end roads serving up to 30 parcels and not more than 60 dwelling units should not exceed 2,640'.
		  • All other dead-end roads should not exceed 800'.
		
		• As most jurisdictions will likely not have established maximum travel distances for wildfire incidents, fire safety design professionals are encouraged to work with local authorities and relevant agencies (e.g., fire, law enforcement, OES) to develop appropriate performance criteria taking into consideration number of buildings, number of people, occupancy use, topography, vegetation type, climate, design basis fire scenarios, and existing transit network capacities and conditions.
		
		• Where travel distances or estimated evacuation times exceed "approved" maximums, additional fire safety measures (e.g., increase road capacities, introduce control measures, turnouts, enhanced roadside fuel treatments) or alternative people management strategies (e.g., phased evacuation coupled with shelter-in-place facilities) should be adopted in consultation with local first responders.

Limited Egress Route Capacity	• Egress route capacity is influenced by roadway length, width, turning radii, roadway conditions, presence of vehicle parking, cross traffic/signaling, design basis vehicle trips, etc. Specific parameters of a roadway, such as width and turning radii, may be limited by topographic setting. During wildfire emergencies, egress route capacity may be further limited by a variety of factors including crush loading by vehicle trips, number of first responder vehicles, vehicles or trees blocking the roadway or limited visibility. All of these conditions may pose risks to the safety of evacuees and emergency responders. • In general, the transit network for most communities is designed to accommodate day-to-day transit demands, and not necessarily the capacity demands for large scale evacuations. As such, total evacuation can oftentimes lead to severe congestion and major delays during a large-scale wildfire evacuation, which may result in residents being exposed to hazardous conditions potentially impacting life safety.	• Communities in high-fire prone areas should undertake a wildfire evacuation assessment to assess a variety of vulnerabilities in the road network given various design fire scenarios (e.g., location, onset of incident, weather conditions), people management strategies, and various analytical scales. Vulnerabilities can include capacity constraints, bottlenecks, excessive evacuation timetime, single/access egress routes, hazardous roadside vegetation, etc. The analysis should identify appropriate mitigation measures to increase capacities and reduce likelihood of loss of transit infrastructure, including traffic control measures, signaling, roadside fuel treatments, various people management strategies, etc. • For new developments, design egress route layout and capacities to meet local roadway standards, limit single access/egress routes, provide sufficient separation of exits, limit maximum travel distances, etc. Refer to above guidance. • For new developments in high-fire prone areas, planners and design teams should evaluate the impact of the new development on the travel demand needs of the existing community or regional road network during a major wildfire incident. The study should be conducted in consultation with relevant local agencies (e.g., fire, law enforcement, OES).
Challenging Terrain	• Developments, both new and existing, which are in high hazard topographies (e.g., mountainous areas, along ridgelines, narrow canyons), coupled with hazardous vegetation for fire, oftentimes have limited in number, separation, and capacity of access/egress routes. These vulnerabilities, summarized above, may all contribute to longer evacuation times, limited access by emergency responders, and greater threats to life safety of both evacuees and responders.	• Depending on specific limitations present due to challenging terrain, mitigation actions beyond the minimum recommendations (such as making use of community shelter-in-place facilities) should be evaluated and provided where possible. This should be informed by a wildfire evacuation assessment and associated planning processes. Refer to above for additional guidance.
Hazardous Vegetation	• Hazardous vegetation adjacent to egress routes can pose a major threat to the physical and functional use of the road network due to a variety of factors, including providing a fuel source that (if ignited) could render the road impassable, physically reduce the width or capacity of the roadway, provide potential fall-in, lean-in, or grow-in hazards, and/or limit the ability of emergency response vehicles to pass safely (Figure 3.15).	• Roadside fuel treatments and ongoing maintenance along primary and secondary egress routes are key to protecting means of egress. A minimum of 10' should be provided; however, this may need to be increased to 100+' depending on the topography, vegetation type, and local weather (Figure 3.16). • Fuel treatments and vegetation management practices should be specifically tailored for the given vegetation type, terrain, and climate to satisfy not only fire safety needs, but also other performance objectives such as healthy forests, ecological services, slope stability, erosion and flooding control, etc. • An assessment by a fuels specialist or forester is important for prescribing appropriate fuel mitigations and maintenance schedules.

Downed Power-lines and Other Hazards	• During a major wildfire incident, particularly under severe wind/weather conditions, powerlines, utility poles and other electrical equipment can create dangerous conditions for safe passage whether due to pole collapse, downed energized lines or equipment. • Other sources of hazards such as disabled, broken-down or abandoned vehicles can also block roadways and render them unusable.	• An assessment of critical travel corridors that are shared with electrical equipment, in particular to overhead distribution lines, poles and equipment should be identified and evaluated for resiliency to high winds or severe fire conditions. Where possible, vulnerable electrical distribution equipment should be underground or hardened such that the likelihood of failure onto the roadway is minimized. • Pullouts, road widening and other capital improvements should be considered such that critical evacuation routes can be maintained cleared, or route diversions are possible in an emergency.

General Mitigation Strategies

- Consult with relevant local agencies (e.g., fire, planning, law enforcement and transit) for requirements and guidance on the physical design of the means-of-egress system at development, neighborhood, and community scales (e.g., number of routes, route separation distances, maximum travel distances, capacities) for wildfire incidents.

- Existing communities or larger regions with limited evacuation capacities may consider a combination of mitigation strategies to help increase life safety for both first responders and the general public. This may include roadside fuel treatments, capital improvements (e.g., road widening, pullouts, adding secondary roads, upgrading fire trails or other alternative routes to higher road standards), operational practices (e.g., use of counterflow, signaling, traffic control personnel), temporary or permanent signage, emergency communications and messaging, etc.

- Roadside fuel treatments should be undertaken and maintained for a minimum of 10’ for all primary and secondary access/egress routes. Distance may need to be increased to 100+’ depending on the topography, vegetation type, and local weather, or if there are limited access/egress routes. Coordination of rights-of-way and private property permissions require consideration when planning for extensive fuel treatment at a significant distance from a road [154], [155]. Any roadside fuel treatment plan should include appropriate treatment prescriptions, monitoring, and maintenance schedules based on the specific safety needs, environmental settings (e.g., vegetation type, weather), and anticipated development trends. These plans should be informed by a variety of stakeholders to ensure fire safety needs are in balance with other performance objectives (e.g., ecology services, flood control, erosion control, costs).

- As part of the planning and design process for new subdivisions or developments in areas of high fire hazard and risk, wildfire evacuation analysis should be undertaken to both plan means of egress for the new development and understand how the addition of structures and people will influence broader community egress capacities. This analysis should include consideration of likely wildfire scenarios, impact on the local and regional roadway network, impact and needs of vulnerable populations, physical fire hazards/threats to infrastructure, etc. A wildfire-specific assessment is crucial to prepare for sufficient evacuation capacity or alternative people management strategies (e.g., phased evacuation, temporary refuge areas). Consult with local agencies and departments (e.g. planning, fire, law enforcement) for local guidance and requirements.

- In existing communities with no new development planned or underway, evacuation analysis as outlined in the bullet above undertaken every 5-10 years is important to understanding and mitigating vulnerabilities. This may include identifying especially likely or dangerous wildfire scenarios, evacuation bottlenecks or challenges that are likely to occur in those scenarios and determining mitigations to alleviate impacts and risks.

Training Programs

- Community Wildfire Planning Center & CAL FIRE - Land Use Planning for Wildfires in California: https://www.communitywildfire.org/trainings/
- CAL FIRE Building Firewise Communities: https://readyforwildfire.org/prepare-for-wildfire/firewise-communities/
- Society of Fire Protection Engineers Foundation: https://www.sfpe.org/foundation/wildland-urban-interface/wui-initiatives
  - Advanced Engineering Science for the Fire Service: Advanced Training Topics in WUI Fire Risk Assessment & Mitigation

Gaps in Knowledge

- Roadway networks are typically designed for day-to-day transportation needs, not large-scale disaster or emergency events. Best practices for balancing emergency evacuation situations with daily transportation needs are underdeveloped.

- There are no widely adopted codes, standards, analytical methods (from simple to more complex), or consensus guidance to inform the design, performance, and maintenance of the physical characteristics of the means of egress system (e.g., number of egress points, spacing, and separation of exits and/or routes, maximum travel distances, capacity of routes) for new developments, neighborhoods, or communities for major wildfire incidents.

- There are no widely adopted codes, standards, or consensus guidance in the United States to inform the design, performance, and maintenance for appropriate construction, and/or retrofitting of community shelter-in-place facilities.

- There is limited knowledge, research, guidance, and performance criteria for management strategies during wildfire evacuations, including total evacuation or phased evacuation, temporary refuge areas, etc.

- Potential shelter-in-place or temporary evacuation locations for a community should be evaluated and selected in advance. However, there is a lack of guidance on location selection and standards on performance criteria for appropriate construction, and/or retrofitting of community shelter-in-place facilities, temporary evacuation points, or temporary refuge areas, that take into account fire exposure from adjacent buildings, vegetation, or vehicles.

- There is variability and uncertainty around how individuals and households from different backgrounds, cultures, demographics or disabilities will perceive wildfire hazards, respond to emergency communications, and behave during a wildfire incident requiring the need for evacuation or other form of emergency response. While a lot of research has been undertaken in these areas additional research is still needed to better inform evacuation assessments and analysis, as well has how infrastructure, public emergency communications, training, individual and family response capacities, and preparedness measures can best be designed to optimize use in real-world evacuation conditions.

- Detailed evacuation modeling (which may combine pedestrian, traffic, and/or wildfire behavior models), while important to assessing performance of access/egress routes during an evacuation (i.e. to calculate WRSET) or determining trigger boundaries, can be computationally complex, limiting the situations in which it can and is applied. Integrating new research, such as that detailed in the bullet above, into these models is an area for improvement. Bringing together fire departments, law enforcement, other emergency response and management entities, and other relevant parties to understand and analyze a) likely hazard scenarios and b) likely evacuation scenarios, is needed to understand limitations of transportation systems and identify potential mitigations.

- Most fire safety experts, transit professionals, and government agencies may require additional training and experience in wildfire evacuation assessments to better understand and apply key concepts, appropriate frameworks, modelling assumptions and limitations, people management approaches, and other mitigation strategies to help inform planning, decision-making, policies, and programs.

- Evacuation routes can be impacted by smoke conditions. The ability to predict smoke (fire emissions) and thus impacts on evacuations is potentially beneficial (i.e. direct evacuation away from heavy smoke areas). Plume dispersion models can estimate wildfire emissions, which are primarily vegetation fires. Plume dispersion models are not yet capable of predicting emissions from WUI fires, which are more complex because they are a combination of structure, industrial, chemical, and vegetation fires. WUI fire emissions can include fine particles, heavy metals, volatile organic compounds, semi-volatile organic compounds, irritants, and asphyxiants, all of which negatively impact human health, but are difficult to predict for WUI fires.

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Figure 3.10. Schematic illustrating some common life safety concerns and stresses to the general public, first responders and overall transit network during major wildfire incidents. Note: Few neighborhoods and communities have been properly planned for timely and safe egress during a wildfire. Image adapted from FEMA Marshall Fire MAT, Best Practices for Wildfire Resilient Subdivision Planning, FEMA, 2023. https://www.fema.gov/

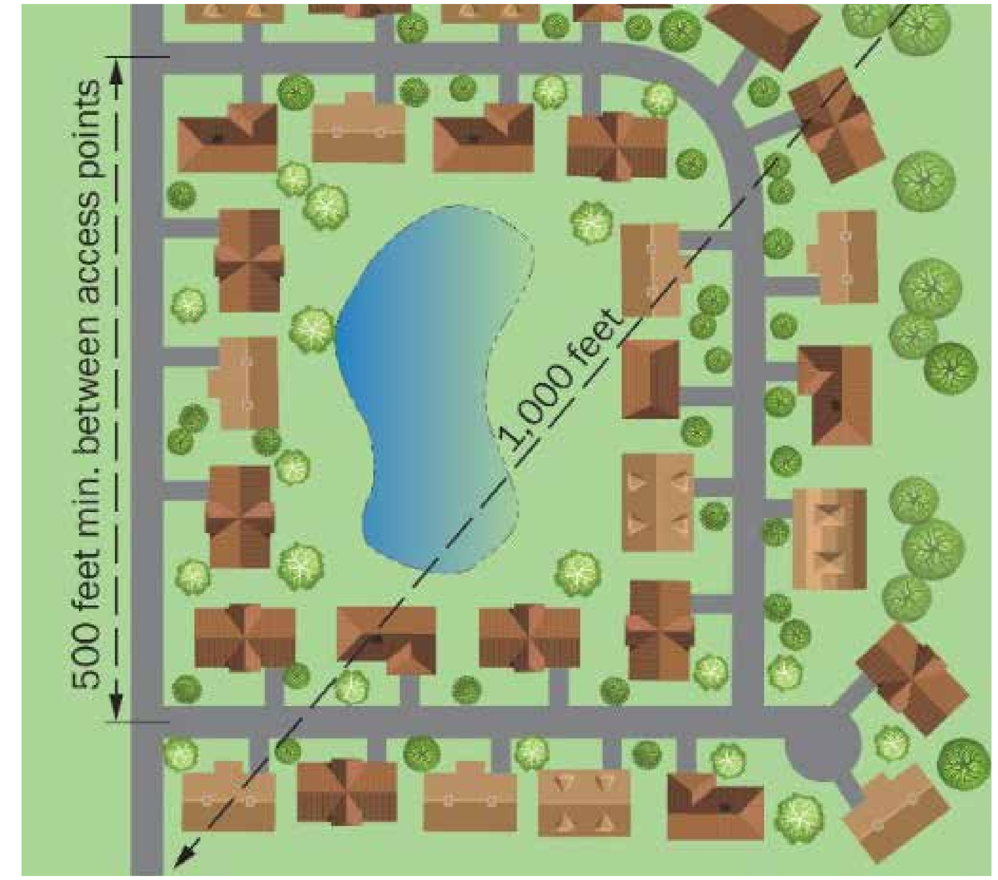

Figure 3.12. Diagram illustrating the concept of separation of egress routes from a neighborhood. Image adapted from FEMA Marshall Fire MAT, Best Practices for Wildfire Resilient Subdivision Planning, FEMA, 2023. https://www.fema.gov/

Figure 3.11. Example of single access/egress route for a residential neighborhood. During a major wildfire, the single point of access/egress could be blocked by the fire incident (e.g., severe conditions, downed trees, car breakdown), potentially trapping or exposing a large number of people to untenable conditions, as well as limiting effective access by first responders. Image courtesy of Jensen Hughes/FEMA.

Figure 3.13. Diagram illustrating the concept of how separation of egress routes extends beyond the neighborhood scale. Image courtesy of Jensen Hughes/FEMA.

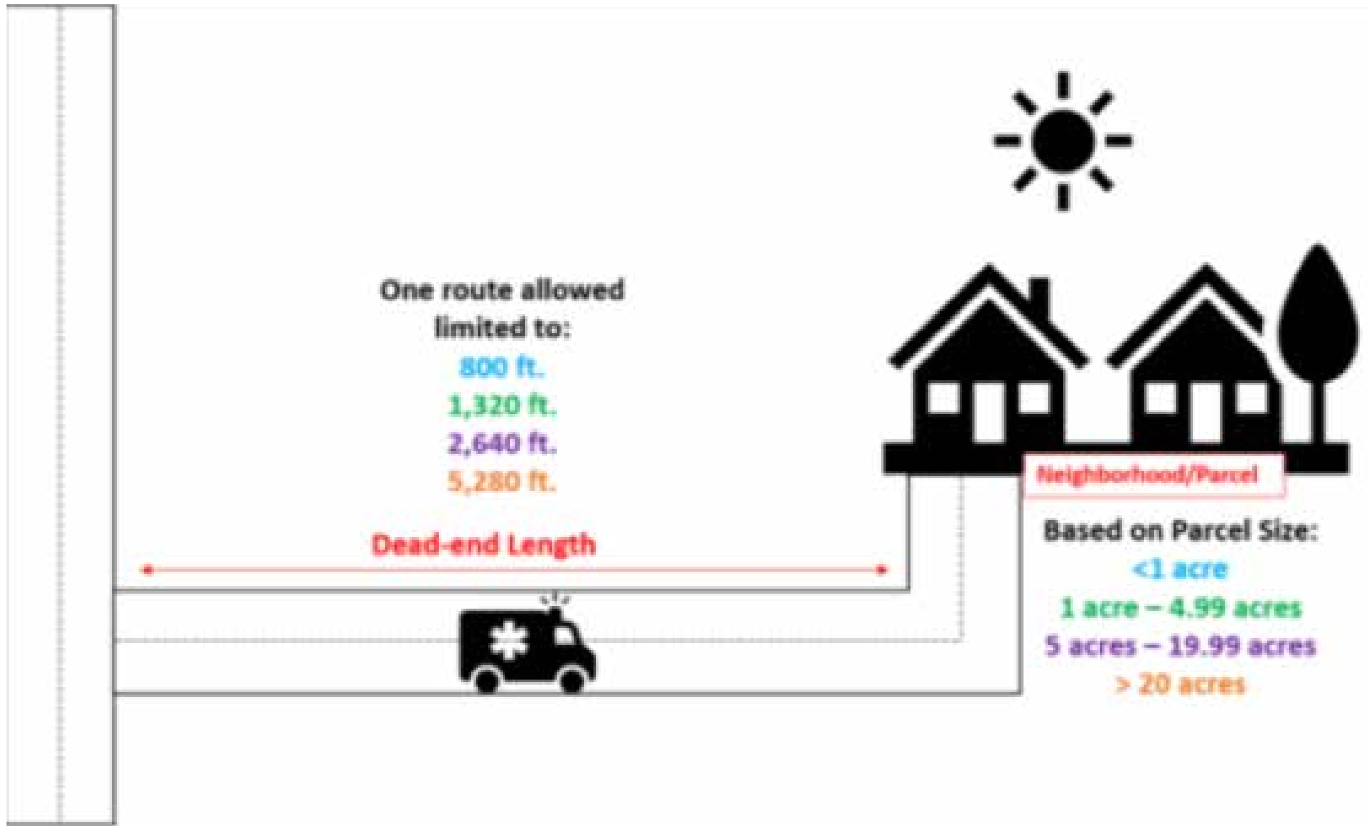

Figure 3.14. Diagram illustrating sample excessive travel distances for a wildfire incident to/from a neighborhood. Image courtesy of Jensen Hughes/FEMA.

Figure 3.15. Example of overgrown, high hazard roadside vegetation. Image courtesy of Jensen Hughes/El Dorado County.

Figure 3.16. Examples of roadside fuel treatments in different topographies, vegetation types and climates. (top) Image courtesy of Jensen Hughes/City of Malibu. (bottom) Image courtesy of Jensen Hughes/Tuolumne County.

3.2.4 COMMON AREAS (NEIGHBORHOOD-SCALE PARKS, OPEN SPACE, HOMEOWNER ASSOCIATION LAND)

Main Concern(s)

Within a subdivision, master planned community, or neighborhood, there are oftentimes numerous areas or spaces that have potential “fuels” in the form of natural or cultivated vegetation, as well as non-vegetative fuels loads that are generally beyond the responsibility of any single landowner. These defined areas include neighborhood-scale parks, open spaces, play areas, Homeowner Association (HOA) land, vacant parcels, neglected or absentee lots and other common areas. Depending on the type of community and ownership structure, some areas may be commonly owned and managed (e.g., Common Interest Subdivision), may have permanent protections, such as designated open space areas within a Conservation Subdivision. The presence, location, quantity, arrangement, type, and maintenance of vegetative and non-vegetative fuels can present an ignition source or a fire hazard (e.g., receptive fuel beds, hazardous plant), or help facilitate fire spread through a WUI environment, particularly when these areas are overgrown, not managed, or poorly managed in a manner that is intended to limit wildfire hazards [106], [130].

Key Terminology

- **Common Interest Subdivision:** An owner has exclusive ownership of a certain plot combined with beneficial use of common area(s), which are often managed by a Homeowner Association (HOA) or some type of community organization (examples include planned developments, condominiums, stock cooperatives).
- **Conservation Subdivision:** A residential subdivision that devotes at least half of its potentially buildable land area to undivided, permanently protected open space [156], [157].
- **Standard Subdivision:** Subdivisions with no common areas or mutual rights of ownership among owners of the lots. Every plot or tract is owned by a single landowner.
- **Common Area:** Any portion of a development that is not part of a lot or tract and is designed for the common usage of the development. These areas may include green open spaces and other uses [132].
- **Nuisance:** Any item, condition, or conduct that endangers health and safety, or unreasonably offends the senses, or obstructs the free use and comfortable enjoyment of property, or essentially interferes with the comfortable enjoyment of life.

Fire Test Standards

None identified at time of publication.

Referenced Codes and Standards

Planning codes and standards will vary depending on location and adoption in individual jurisdictions.

- Check local, county, and state amendments for any additional requirements.
- Check local general plan, multi-hazard mitigation plan, or zoning documents for any additional requirements.

Example(s) of Codes and Standards:

- *2024 International Wildland-Urban Interface (IWUI) Code* - Appendix F: Characteristics of Fire-Resistive Vegetation

Typical Design(s), Vulnerability, and Mitigation Considerations

Table 41. Typical challenges for common areas and their vulnerabilities and potential mitigations.

Typical Challenges	Vulnerability	Potential Mitigations
Neighbor-hood-Scale Parks and Open Spaces	• Neigborhood-scale parks, HOA lands, open spaces and other common areas with wildlands or unmanaged fuels that border or mix with communities and neighborhoods, can pose a threat to homes and community assets. through elevated radiative exposures, convective heat, and embers [130], [106] (Figures 3.17 and 3.19). • While unlikely to cause a major fire threat (depending on the size, topography, weather and vegetation type) common areas still present added risks to adjacent structures due to the potential for ignition, ember production and source of fire spread.	• For new developments, assess local site conditions to determine wildfire hazard prior to subdivision layout. This assessment can inform the location and design of planned neighborhood parks and open spaces to provide minimum separation distances between structures and unmanaged common spaces. Minimum distances (e.g., 30 - 100ft+) should be based on the type of vegetation, slope, and other site conditions and will vary by community [130]. • For all developments, develop a long-term management and maintenance plan for all neighborhood-scale common areas, parks, open spaces, etc., to reduce potential fuel sources and other fire hazards over the lifetime of the development. Management techniques may include prescribed grazing, thinning, mowing, mechanical treatments, or other appropriate treatment options that align with the type of vegetation, hazard reduction goals, and environmental considerations. This may be established through a required Vegetation Management Plan (e.g., IWUIC Appendix B, NFPA 1 Chapter 17), Fire Protection Plan (e.g., CA Building Code Chapter 7A and 49), or similar planning and maintenance instrument (Figures 3.20 and 3.21). • Smaller open spaces that are interior to a community should be designed to include vegetation that maintains relatively high-water content in their leaves to reduce fire spread [140]. • Larger open spaces that are interior to a neighborhood that contain flammable vegetation should be surrounded by defensible space to create a buffer between open space and homes [140]. However, where ownership constraints or maintenance practices limit the ability to safely managed fuels, consider providing additional or enhanced fire safety features of landscaping and/or structural hardening features of neighboring lots to mitigate these "unmanaged" spaces.

Vacant or Underdeveloped Lots	• Vacant or undeveloped lots can become a public health and safety nuisance if not maintained. A common nuisance is overgrown grass, weeds, and shrubs that can ignite during a wildfire. Similar to neighborhood parks and open spaces, these areas can be highly susceptible to ignition, fire spread, radiant heat and/or ember production that can threaten nearby structures or other receptive fuels (Figure 3.18).	• Require weed abatement through a local nuisance ordinance (or similar regulation) to address overgrown lots. • Require property maintenance of hazardous vegetation conditions through the adoption of a local ordinance that requires adjacent property owners to clear any areas of their property that may pose a fire hazard to neighboring parcels when a neighboring structure is less than 100' from a property line (e.g., Napa County Fire and Ventura County Fire local standards) [158].

General Mitigation Strategies

- The strategic placement of trails, roads, or other landscape features within a community can be utilized to break up fuel continuity between parks, open spaces, and other natural areas and provide access for more efficient response and suppression activities [136]. For example, reduce fuel loading adjacent to structures by locating paved walkways or maintained trails along the perimeter of a development [130].

- Vegetated open spaces where relatively high-water content is desired to be maintained in leaves, which makes plants less likely to ignite but also requires consideration of plant selection, irrigation systems, and regular maintenance schedule [130], [140].

- Establish maintenance agreements with developers and property owners to maintain fuel management in common areas and individual properties [136].

- Select specific plant types based on fire-resistance. There may be an approved or recommended plant list for your location. Also be aware of plants to avoid specific to your local area. Be aware that native plants may not be fire resistant and some may be extremely flammable [130]. Refer to Part II of this handbook for more information.

Training Programs

- Community Wildfire Planning Center (CWPC) & CAL FIRE - Land Use Planning for Wildfires in California: https://www.communitywildfire.org/trainings/
- International Association of Wildland Fire (IAWF):
  - N9073 Mitigation Best Practices - Pre-workshop Training - Cohesive Wildland Fire Management Strategy Workshop: https://cohesivestrategyworkshop.org/

Gaps in Knowledge

- Limited codes, standards, and guidance documents exists on planning, designing, and maintaining common spaces for wildfire resiliency for a variety of audiences (e.g., planners, designers, authorities, contractors, and HOAs).

- Limited research on the role and significance of various types and characteristics of common use areas on subdivision and parcel-scale WUI hazards and risks. This would include variations on size, vegetative characteristics (e.g., plant/tree types, layout, fire-resistant, drought resistance), topography, local fire weather, man-made fuel characteristics (e.g., fuel types, layout, mass/density), maintenance practices, and scheduling.

- Consensus standards and/or guidance on alternative methods for providing wildfire resiliency for existing subdivisions with limited or constrained resources to maintain common areas (e.g., potential enhancements to harden structures).

Other References

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Figure 3.17. Example of unmanaged (left side of image) vs managed (right side of image) land in a subdivision. In this example, the common area was inconsistently maintained, presenting various fire hazards to the community (e.g., receptive fuel beds and potential avenue for fire spread). Image courtesy of Jensen Hughes/FEMA.

Figure 3.18. Example of unmaintained vacant lot abutting a residential neighborhood and posing a fire hazard to proximate homes. Image courtesy of Jensen Hughes/FEMA.

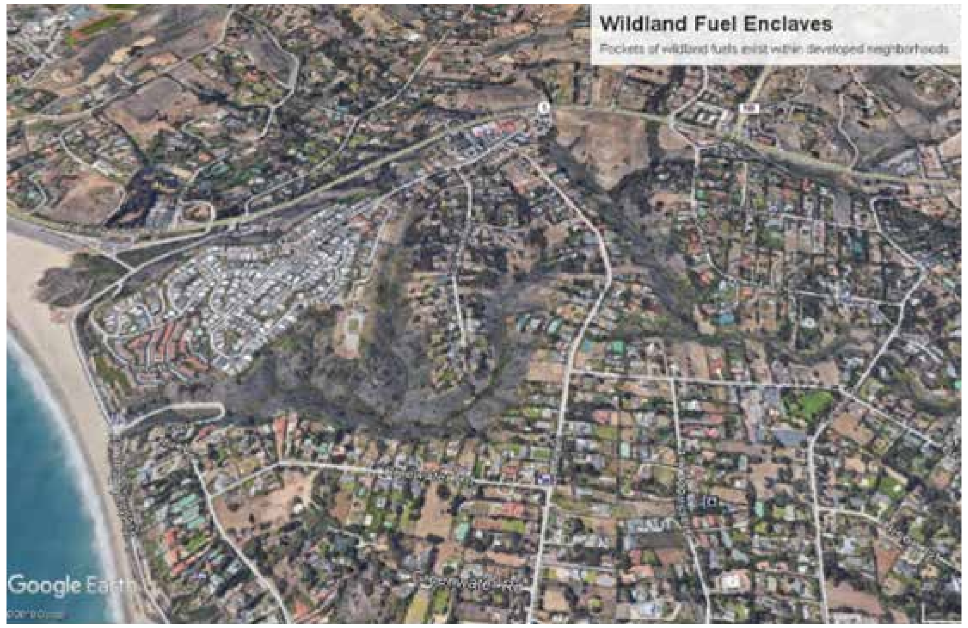


Figure 3.19. Example of wildland fuel enclaves intermixed with a suburban neighborhood. Image courtesy of Jensen Hughes/FEMA.

Figure 3.20. Example of small, open space with well-maintained landscaping (left side) that is within the 100foot defensible space zone of structures, while more remote land to the right retains its more "natural" state. Image courtesy of Jensen Hughes/FEMA.

Figure 3.21. Example of small, well-maintained common area (e.g., neighborhood park) in a subdivision. Image courtesy of Jensen Hughes/FEMA.

3.2.5 ENTITLEMENT AND CONSTRUCTION PHASES

Main Concern(s)

Different phases of building development life-cycle—including entitlement, design, construction, commissioning, and long-term maintenance—each may require additional or unique approaches to mitigate wildfire to a site and potentially the existing community. For example, the initial construction phase of any project can carry risks due to potential ignition sources from equipment or other high-risk activities such as heavy machinery, various fuels, and hot work (Figure 3.22). Multi-phase construction schedules for master planned communities or other large-scale developments can require multiple years or even decades before the full project construction is complete, requiring strategic planning for critical infrastructure (e.g., water supplies and distribution, emergency notification), fire department access, and evacuation needs during early phases of development for both the new development and existing community. Awareness, planning, and appropriate mitigation can help address these risks.

Key Terminology

- **Entitlement Phase:** Entitlement phase refers to the period during which a new development is evaluated and approved by the local jurisdiction to allow for construction/development of the area. Major conditions of approval for a specific development are typically defined during the entitlement phase so they can be incorporated into the approved design basis and included in project financing.

- **Long-Term or Multi-Phase Buildouts:** Long-term or multi-phase buildouts refers to large construction projects that span long timeframes. These projects often use phased permitting/buildout of specific areas with potential for occupancy/use of initial phases prior to overall project completion. This could include the phasing of subdivision construction, or the phasing of large commercial projects.

- **Fire Protection Plan:** A fire protection plan is a document prepared during the planning/entitlement phase for a specific project or development proposed in a Wildland-Urban Interface (WUI) area and includes a project-specific wildfire hazard assessment that considers location, topography, aspect, climatic and fire history, and contains proposed strategies for addressing wildfire-specific hazards and risks (e.g., fuel modification plan, access/egress provisions, firefighting water resources, wildfire-safety construction materials) [159].

- **Wildfire Prevention Plan:** A wildfire prevention plan is a document prepared for a specific project or development in a Wildland-Urban Interface (WUI) that details fire safety measures, protocols, and procedures during the construction phase to reduce the likelihood of an ignition that could start or exacerbate a wildfire. This includes proposed strategies and systems for addressing construction phase hazards and risks (e.g., access/egress provisions, firefighting water supplies, stop work orders, hot works protocols, storage of hazardous materials). This plan could potentially be included in the Fire Prevention Program detailed in *NFPA 241*.

Fire Test Standards

None identified at time of publication.

Referenced Codes and Standards

Examples of building codes and standards:

- *2021 International Building Code* - Chapter 33 Safeguards during Construction.
- *2022 NFPA 241* - Standard for Safeguarding Construction, Alteration, and Demolition Operations.
- *2022 NFPA 1140 Standard for Wildland Fire Protection* - Chapter 16 Fire Protection During Construction.

Typical Design(s), Vulnerability, and Mitigation Considerations

Table 42. Typical entitlement and constructions phases challenges and their vulnerabilities and potential mitigations.

Typical Challenges	Vulnerability	Potential Mitigations

Entitlement or Planning Phase	• Oftentimes, land-use planning and zoning maps may not recognize or explicitly account for wildfire hazards. This could mean that planners, design professionals, and local government agencies may not be familiar with the potential risks to life safety, property protection, and environment of introducing a new development in high-fire prone areas. This also includes understanding a minimum set of performance criteria, wildfire safety provisions (e.g., water supplies, access/egress), as well as mitigations to provide appropriate fire safety.
	
	• Wildfire hazard and risk mitigation during the planning and entitlement phase of a new development is a relatively new area of practice, with limited jurisdictions having policies, processes, or requirements to evaluate potential wildfire risks.
		• Local jurisdictions should develop and adopt wildfire hazard and risk assessment ordinances as part of the entitlement/planning phases process for new developments. This process should involve the development of a fire protection plan that evaluates potential wildfire hazards and risks of the development, and an assessment of various mitigation measures to help offset those risks. This should be documented in a fire protection plan prepared by a fire safety professional, and reviewed and approved by relevant agencies (i.e., planning and fire departments at a minimum).
		
		• Provide supporting guidance documents on the wildfire planning process and fire protection plan requirements.
		
		• The Fire Protection Plan should address planning level wildfire hazards, risks, and mitigation, including but not limited to [159]:
		  • Plans for vegetation reduction around emergency access and evacuation routes.
		  • Identification of proposed plants, information on species proposed, and irrigated/non-irrigated zones.
		  • Details of access and equipment storage points for personnel who are performing vegetation management duties in common areas.
		  • Include relevant legally binding statements to ensure communities uphold responsibility for fuel modification zones, and owners to uphold responsibility for vegetation management.
		• Refer to sample fire protection planning processes and requirements below:
		  • Orange County Fire Authority
		  • California Fire Code Section 4903

Construction Phase	• The construction management team, contractors, and workers may not be familiar with what is considered high danger days and associated weather conditions that can create hazardous scenarios. As such, high risk activities may occur during unsafe weather conditions, increasing the potential for wildfire ignitions. • Construction sites oftentimes introduce additional ignition sources (e.g., hot works), exposed combustible materials (e.g., foam insulation, lightweight timber), and other hazardous materials (e.g., paint, battery storage, chemicals) that can present multiple fire hazards and risks to both the new development site and existing community. • Sites contain additional hazardous/flammable materials that might be stored out in the open (Figure 3.22).	• For projects located in the WUI or high fire prone areas, develop a Wildfire Prevention Plan before construction begins or in the very early stages of construction (as approved by the local fire jurisdiction). The Plan must address the following, at minimum [160]: • Ensure that the construction site has adequate water supply for fire protection, whether temporary or permanent. • Plan to train supervisors and employees on the causes and control measures for wildfires, such as construction site-related ignition sources (e.g., welding sparks). • Verify and document local or regional impact (for example, proximity to critical infrastructure). • Document the fire suppression equipment that is needed for onsite crews and ensure that the equipment is ready when work begins. All employees associated with the use of equipment should be trained for proper use. • Establish a daily pre-task wildfire assessment form and train employees on its use. As part of the form, work location, egress routes, weather predictions, vegetation types, proximity to staffed fire stations for each day of work should be documented. • Establish and use "Stop Work" guidelines. This could include weather monitoring, work type, and work locations that, when documented, will trigger a temporary stop work.
Long-Term or Multi-Year Buildouts	• Emergency access potentially blocked and/or regularly changing due to different phases of development. • Water supplies stretched thin if homes are occupied / in use while construction activities are still occurring. • If subdivision is planned with specific land use "buffers" around to protect from wildfire, there is potential for homes to be built/occupied before any kind of community protections are put in place. • Alternatively, areas left undeveloped during construction, but adjacent to built homes, could potentially provide an avenue for wildfire to reach homes.	• Where multiple phases of development are planned over time (e.g., a master planned community), it is helpful to identify features that are essential to emergency management and safety, such as secondary emergency access, water supply, and other critical facilities. These features should be included in the first phase of development to ensure adequate fire protection, response, and evacuation can all occur [136].
Long-Term Site Maintenance	• Some construction sites may have areas that are left undeveloped for long periods, which could be susceptible to ignition if left unmaintained. • Long-term site maintenance vulnerabilities are largely the same as those for the long-term buildout phase. See section above for other vulnerabilities.	• Ensure that undeveloped portions of the site have some degree of routine vegetation management performed (i.e., not overgrown). • Maintain features identified in the long-term buildout phase (see above) as critical to emergency management and safety.

General Mitigation Strategies

- Ensure ongoing vegetation management on vacant or undeveloped parcels of land to ensure that they do not pose a threat to adjacent developed properties [136].
- During construction [160]:
  - Clear brush and combustible materials from immediate work areas, and pre-wet areas where there are known potential ignition sources.
  - Notify local authorities that potential high-risk work is being conducted in their jurisdiction.

Training Programs

- National Fire Protection Association (NFPA):
  - Construction Safety Training - https://www.nfpa.org/education-and-research/building-and-life-safety/construction-safety#fire-prevention-program-manager-online-training

Gaps in Knowledge

- Generally, there is very little guidance on the development of Wildfire Prevention Plans for construction sites.

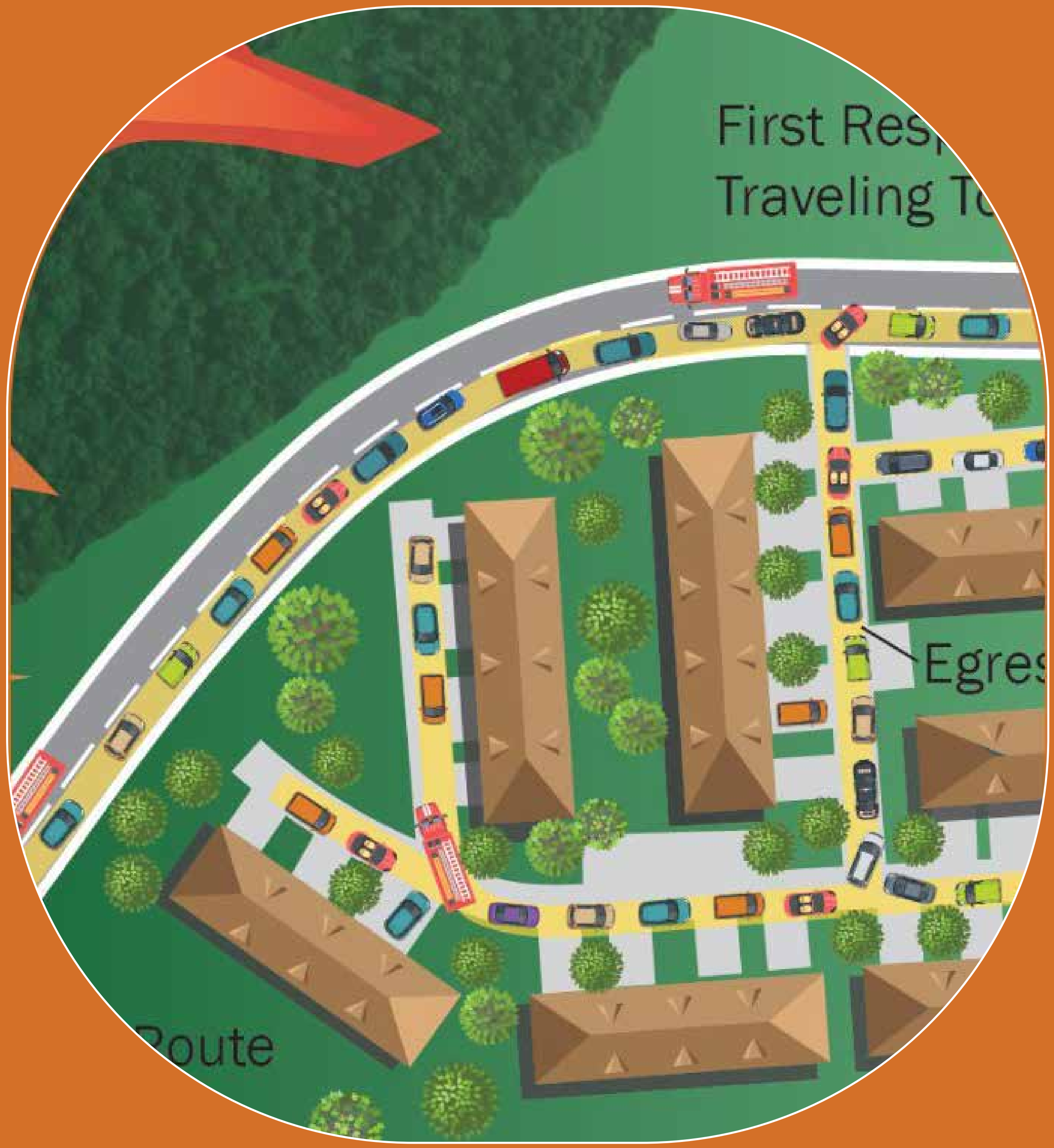
Other References

- Federal Emergency Management Agency, "Home builder's guide to construction in wildfire zones: Technical Fact Sheet No 17, Community Infrastructure." Government Printing Office, Sep. 2008. [Online]. Available: https://www.govinfo.gov/content/pkg/GOVPUB-HS5-PURL-gpo60104/pdf/GOVPUB-HS5-PURL-gpo60104.pdf

Figure 3.22. Example of a residential development under construction, where light frame timber construction and staging areas with combustible materials pose potential sources of ignition during a wildfire. Image courtesy of Jensen Hughes/FEMA.

FIREFIGHTING INFRASTRUCTURE

NEIGHBORHOOD AND COMMUNITY-SCALE



3.3.1 FIRE DEPARTMENT ACCESS

Main Concern(s)

Adequate fire department personnel and vehicle access provisions allow first responders to safely and efficiently respond during emergency situations. These situations often necessitate emergency response vehicles accessing active wildfire areas, while simultaneously evacuation movement is occurring from those same areas. Deficient infrastructure can delay firefighting efforts. Road access is critical for firefighters to efficiently reach the wildfire area and effectively identify/utilize available water and firefighting resources (Figure 3.23). Community planning and maintenance must consider fire access measures that can be taken to enhance the effectiveness of wildfire response resources. Similar to evacuation route planning, access route redundancy, separation, and resilience must be prioritized during planning and development. See also Section 3.2.3 *Means of Egress and Evacuation Planning*, because access/egress concerns and associated mitigations are inter-related.

Key Terminology

- **Access:** Related to wildfire, refers to the relatively safe and unobstructed travel into an area threatened by a wildfire by firefighters and other emergency responders.
- **Means of Access:** The routes or paths by which vehicles travel, including roadways, driveways, fire lanes, and parking lots.
- **Firefighting Apparatus:** Motor vehicle that is designed and constructed for the purpose of fighting fires.
- **Driveway:** Vehicular access means on private property that extends from a roadway or highway and serves a limited number of buildings (typically 2-5 buildings maximum).
- **Fire Lane:** A means of access that is provided, designated, and identified for emergency apparatus use. Parking is not allowed along a fire lane.
- **Fuel Break:** An area, strategically located for fighting anticipated fires, where the native vegetation has been permanently modified or replaced so that fires burning into it can be more easily controlled. Fuel breaks divide fire-prone areas into smaller areas for easier fire control and to provide access for firefighting.
- **Road:** Any means of access that provides vehicular access to more than one parcel but not a driveway.
- **Roadway:** Any public or private street, including bridges and crossings.
- **Street, Private:** Any means of access normally used for vehicular access but not designated as a public street.
- **Street, Public**: A means of vehicular access that is designated for use by the public.

Fire Test Standards

None identified at time of publication.

Referenced Codes and Standards

Examples of building codes and standards:

- *International Fire Code (IFC)* - Chapter 5
- *California Fire Code (CFC)* - Chapter 49
- *2024 International Wildland-Urban Interface Code (IWUIC)* - Section 403
- *2022 NFPA 1140 Standard for Wildland Protection* - Chapters 11 and 12

Planning codes and standards will vary depending on location and adoption in individual jurisdictions.

- Check local, county, and state amendments for any additional requirements.
- Check local general plan, multi-hazard mitigation plan, or zoning documents for any additional requirements.
- Consult state and local building, fire, and wildfire building codes. Otherwise, IWUI Code and *NFPA 1140*.
- Consult with the local fire department(s) for:
    - Any local access requirements.
    - Additional guidance documents for providing for emergency access.
    - Wildfire planning processes and reviews related to emergency access.
    - Pre-approved alternative access mitigation measures.

Typical Design, Vulnerability, and Mitigation Considerations

Table 43. Typical access challenges, their vulnerabilities, and potential mitigations.

Typical Challenges	Vulnerability	Potential Mitigations
Single Means of Access	• See Section 3.2.3 *Means of Egress and Evacuation Planning*	• See Section 3.2.3 *Means of Egress and Evacuation Planning*

Limited Roadway Width	• During an emergency, narrow roads can significantly reduce driving speeds by emergency vehicles, thereby causing significant delays. Further delays can be caused during periods of evacuation, when response and general public vehicles must share the same narrow roadways (Figure 3.24). • During access and evacuation conditions, narrow roads can also result in bottlenecks due to insufficient drive aisles, lack of turnouts, and broken-down vehicles. • In some existing neighborhoods, parked vehicles can further reduce drive aisles widths and travel speeds. • Many traffic calming devices and designs (such as speed bumps, chicanes, raised islands, etc.) can increase fire vehicle travel time.	• Where minimum road widths are not provided for existing roads: increase shoulders, provide additional clear area along roadside, introduce turnouts every 50' where feasible. • Develop a traffic control plan to secure narrow roads during an incident. • For existing neighborhoods, consider various roadway widening measures such as increasing shoulders, introducing turnouts every 50'. • Prohibit or limit roadside parking on Red Flag Warning Days, etc. • Increase road width along curved or sloped sections of roadway to provide a minimum of 26' width to allow for fire department apparatus maneuvering clearances. • Review traffic calming devices and designs with the local fire department prior to installation.
Insufficient Vertical Clearance	• Typical fire department vehicles sizes require a minimum road vertical clearance to move freely to and from an emergency. Where clearance is not maintained, a fire department vehicle may be unable to reach the emergency (Figure 3.25).	• Tree and fuel maintenance must maintain minimum required vertical clearance (typically 13.5' or more, but seek local guidance) over emergency access roads and extended driveways.
Long Driveways	• Buildings set far back from access roads are not readily identifiable. • Driveways must serve as primary access means for buildings with large setback distances.	• Provide clear address signage at the public roadway. Refer to the building and fire code (Typically IFC Section 505) and relevant local amendments and/or ordinances for requirements for signage. • Provide turnarounds with 45' outer radius for extended driveways (over 150').
Unmaintained Driveways	• Narrow and/or unmaintained driveways can hinder or prevent wildland fire response. • Driveway entrances frequently include narrow culvert crossings, which may be supported by plastic piping or other combustible elements, which can be compromised by wildland fire exposure.	• Maintain driveways 12' wide with 13.5' vertical clearance (see above for details), extending a minimum of 50' from the access road. • Reinforce existing access roadways (including driveways) to support fire apparatus loads and to withstand fire impacts [161].
Restricted Access	• Areas that are not accessible to fire department vehicles and personnel can delay or prevent incident response to the restricted area as well as adjacent areas.	• For areas with restricted access, key safes must be provided in approved locations and marked [144]. • Gated access must be set back from the road to allow emergency vehicles to exit the roadway traffic lanes (50' is recommended). Gate openings should provide additional width to allow for apparatus to maneuver.

Steep Road Slope	• Steep slopes present a challenge for firefighting equipment. Wet or dusty conditions can cause loss of traction. Sloped roads are more likely to become unstable due to erosion and/or fire exposure. Standard firefighting apparatus is typically designed for operation on grades of 6% or less. • Steep slopes can obstruct sight lines along the road, which limits view of road and fire hazards along the road.	• Maintain access roads below maximum slope defined by the local jurisdiction. Roads should not exceed 16% slope in any case [159]. • Design roads based on site and surrounding topography conditions. • Consult local fire department for insight relevant to local equipment.
Fuels Along Roads	• Vegetation and other fuels adjacent to roadways pose a hazard that can hamper emergency access and cutoff access to other wildfire areas (Figures 3.24 and 3.25). • See Section 3.2.2 *Subdivision Spatial Design* for additional guidance for hazardous roadside fuels.	• Maintain roadside areas free of fuels and vegetation. • Establish and maintain roadside fuel treatment plans, whether using mechanical methods or controlled burning. Consider negative impacts of fuel treatment, such as potential effects on erosion and/or flood control.
Insufficient or Uncertain Road and Bridge Capacity Design Load	• Poorly designed roads can degrade during fire department access and hamper responses efforts (Figure 3.24). • Unmarked bridges and roads pose an access challenge for fire fighters to determine the load capacity of bridges. • Subsurface road construction must be marked clearly. Unmarked roads will delay or prevent use by fire department vehicles.	• Roads must provide all-weather access, such as concrete or asphalt surfaces. • Access roads must be designed for minimum capacity to allow for heavy fire response vehicles (typically 40,000 pounds, but seek local guidance). • Bridges and crossings must be designed in anticipation of firefighting access equipment loads and potential fire exposure. • Provide load limit signage identifying weight and vertical clearance limitations at all reduced roads and bridge crossings.
Water Resource Access	• Water resources may not be identified if not clearly indicated and/or if access routes do not indicate their presence/availability.	• Roads leading to water resources must provide enhanced protection and resilience to allow for distribution and use of available water resources. • Provide dual-sided access and connection means for water storage locations located within the wildland fire risk area.

General Mitigation Strategies

- Fire access analysis must be included as part of the planning process for new subdivisions or developments in areas of high fire hazard. Likely wildfire scenarios, as well as impacts on the local and regional roadway network during evacuation, must be assessed. Wildfire-specific analysis and consideration is crucial to plan fire access arrangements. Consult early with local planning and fire protection agencies for local guidance and requirements.

- Fire access should include planning rights-of-way for future street widening that may become necessary as adjacent communities are developed. Development planning and forecasting must inform access roadway planning and phased expansion.

- Tactical operations locations require additional roadway width to be effective. Tactical operations should be considered during fire access planning.

- Construction phasing of new development areas should prioritize fire department access roadway construction. Fire service access must be available prior to significant combustible building construction on site.

- Design water source access roads in accordance with NFPA 1142 [162].

- Fire access roads and driveways should be provided with signage for identification and to prohibit obstruction. Bridges and crossings should be provided with load limit signage. All fire access identification signage must be fully visible, use non-combustible signs and posts, and include large reflective lettering.

- Community site design requirements and recommendations should provide criteria to address potentially hazard conditions, such as extended setbacks and driveways or restricted access.

- Vegetation and fuel treatments should be undertaken and maintained for a minimum of 10' on either side of all major access/egress routes. This distance should be increased for steep slopes or if there are limited access/egress routes. Utilize fuel treatment methods that will reduce long-term fire risks to roadways. Avoid treatments that could increase erosion and/or flood risks in low areas.

- Evaluate the community wildland fire access arrangement every 5-10 years for adequacy.

Training Programs

- National Wildfire Coordinating Group (NWCG): https://wildlandfirelearningportal.net/
  - S-215 - Fire Operations in the Wildland-Urban Interface
  - G-131, G-231, G-330 - Wildland Training for Structural Firefighters
  - RT-130 - Wildland Fire Safety Training Annual Refresher (WFSTAR)

Gaps in Knowledge

- Roadway design and layout research in high fire hazard areas is limited. Strategies to balance access and egress needs of roadway systems are underdeveloped.

- Residential development and design education typically does not include wildfire fire access concepts.

- Fire department access road requirements frequently do not include additional criteria that is specific to high fire hazard and WUI areas.

Other References

- California Department of Forestry and Fire Protection, CALFIRE, “Wildland Urban Interface Operating Principles.” 2014. [Online]. Available: https://www.iaff.org/wp-content/uploads/2019/05/CAL-FIRE-Wildland-Urban-Interface-Book.pdf
- Federal Emergency Management Agency, “Home builder’s guide to construction in wildfire zones: Technical fact sheet series.” Government Printing Office, Sep. 2008. Accessed: Mar. 15, 2025. [Online]. Available: https://www.govinfo.gov/content/pkg/GOVPUB-HS5-PURL-gpo60104/pdf/GOVPUB-HS5-PURL-gpo60104.pdf
- Federal Emergency Management Agency, “Marshall Fire Mitigation Assessment Team: Practices for wildfire-resilient subdivision planning,” Federal Emergency Management Agency, DR-4634, 2023. [Online]. Available: https://www.superiorcolorado.gov/files/assets/town/v/1/disaster-preparedness-amp-recovery/documents/fema_marshall-fire-mat-best-practices-wildfire-resilient-subdivision-planning.pdf
- Firescope California, “Wildland Urban Interface (WUI) Structure Defense.” Oct. 21, 2013. [Online]. Available: https://firescope.caloes.ca.gov/ICS%20Documents/WUI-SD.pdf

Figure 3.23. Example of small subdivision with single access road. Image adapted from FEMA Marshall Fire MAT, Best Practices for Wildfire Resilient Subdivision Planning, FEMA, 2023. https://www.fema.gov/

Figure 3.24. Narrow combustible bridge along fire access road. Image courtesy of Jensen Hughes/FEMA.

Figure 3.25. Fire access road with insufficient maintenance of hazardous vegetation (roadside and overhead). Image courtesy of Jensen Hughes/FEMA.

3.3.2 FIREFIGHTING WATER SUPPLIES

Main Concern(s)

Firefighting water resources must be made available and readily accessible for responding firefighters. Vegetation must be maintained around each water source to allow safe access. Community water supply systems may use tanks, underground vaults, or cisterns to store water supplies. Properties may be supplied with a variety of systems, ranging from municipal water systems to limited distribution systems, or on-site wells in rural areas.

The minimum water supply must be determined based on the community/structures evaluated, fire exposure level, installed fire protection systems, and any existing water supply sources. Minimum water supply should be increased where there are limited firefighting resources, extended response conditions, potential for delayed discovery or reporting, unusually hazardous terrain or vegetation, and other factors that may increase the need for firefighting water. Inadequate water supply arrangements can delay or hinder firefighter response and capability. Unclear communication of water supply location, type, and volume can have the same effect. Insufficient physical protection of water supply resources can also render water supplies unusable. Water supply arrangements must be determined early in planning and development of new communities and should consider adjacent legacy communities that may not be provided with suitable water supply arrangements.

To supplement water supply and pressure, hydrant-to-hydrant connections (with backflow prevention valves) between adjacent public water supply systems may be necessary to meet firefighting system demand [163]. When firefighting water is dependent upon public water supply systems, considerations identified in Section 3.5.2 *Non-Emergency Water and Wastewater Infrastructure* may also be applicable.

Key Terminology

- **Alternative Water Supply:** Water supplies that provide fire water where no municipal-type water system exists, or to supplement an inadequate municipal water supply.
- **Availability:** The amount of time during one year that a defined usable volume of water is available and usable for firefighting purposes.
- **Availability Study:** Technical evaluation of a water source that determines the availability of a defined usable volume of water. The evaluation considers historical and predicted weather and seasonal variation as well as potential adverse operational conditions.
- **Dry Hydrant:** Fixed piping that is part of a static or stored fire protection water source that is used by drafting (suction) with a fire department pump.
- **Fire Flow:** The water supply volumetric flow rate that is available for firefighting, typically expressed in gallons per minute (gpm).

- **Fire Hydrant:** A valved connection on a water supply system having one or more outlets and that is used to supply hose and fire department pumpers with water.

- **Municipal Fire Water System:** A water supply system where pipes feed fire hydrants and the system is designed to provide anticipated fire flow demands, typically providing a minimum of 250 gpm usable for fire fighting for a minimum 2-hour duration.

- **Open Water Source:** Water sources, either static or flowing, that are open to sky and may be usable for fire service gathering of water using either land-based or airborne firefighting equipment.

- **Recognized Water Supply System:** A water supply system that is designed and demonstrated to provide a minimum fire flow over a minimum duration.

- **Standpipe:** A pipe and attached hose valves and hose (if provided) used for conveying water to various parts of a building for fire-fighting purposes.

- **Usable Water Volume:** Water source capacity that is actually usable for firefighting, considering losses and inefficiencies related to inefficiency in extraction methods and access arrangements.

- **Water Supply, Minimum:** The quantity of water required for fire service control and extinguishment of a fire incident.

Fire Test Standards

None identified at time of publication.

Referenced Codes and Standards

Examples of building codes and standards:

- *2022 NFPA 1140 Standard for Wildland Protection* - Chapter 15
- *2022 NFPA 1142 Standard on Water Supplies for Suburban and Rural Firefighting*
- *2024 International Wildland-Urban Interface Code (IWUIC)* - Section 404

Planning codes and standards will vary depending on location and adoption in individual jurisdictions.

- Check local, county, and state amendments for any additional requirements.
- Check local general plan, multi-hazard mitigation plan, or zoning documents for any additional requirements.
- International Residential Code (if applicable - check for wildfire amendments).

Typical Design, Vulnerability, and Mitigation Considerations

Table 44. Typical water supply conditions and their vulnerabilities and potential mitigations.

Typical Challenges	Vulnerability	Potential Mitigations
Municipal Hydrants	• Water distribution systems within high fire risk zones may be susceptible to failure under fire exposure. • Wildland fire protection demands on water supply can quickly deplete water supply capacity and storage volume.	• Locate water distribution infrastructure away from potential wildland fire exposures, or provide/maintain defensible space around water supplies where necessary to locate near wildland exposure (50’ minimum) (Figures 3.26, 3.28, and 3.29). • Site-specific analyses may be needed to determine appropriate clearances, management practices, inspection and maintenance schedules based on the vegetation type, topography, climate/weather, etc. • Design municipal fire protection water systems based on community fire risk and plan/design for future increases in capacity and flow.
Limited Water Availability	• Water supplies in legacy or underserved communities are typically minimal and insufficient for fire response to severe wildfire exposure. • Robust rural water supplies that rely on water storage for peak demands may be depleted quickly under wildfire response demands.	• Conduct legacy community fire safety evaluations and provide findings and education to affected communities. • Pre-position water tanks at strategic locations during peak wildfire season, based on community fire safety evaluations.
Water Storage Tanks	• Above-ground tanks may be vulnerable to wildfire damage (Figures 3.28 and 3.30).	• Exposed water tanks must be of fire-resistant materials such as steel or concrete. • Fiberglass tanks must only be used underground.
Cisterns	• Underground cisterns may not be identifiable or available during a wildland fire incident.	• Provide means of identification (e.g., non-combustible signage). • Maintain means of access and fire department connection.
Reservoirs, Retention Pods, Open Waterways, Irrigation Canals	• Water may not be present/available in open bodies of water when needed for firefighting (Figures 3.31, 3.32, and 3.33).	• Provide water level meter, automatic fill arrangement to maintain water volume for critical water supplies. • Conduct availability studies and pre-fire season inspection of critical water supplies. • Consider remote monitoring means for critical water supplies (include them in camera or level monitoring systems, where provided).

Access to Home Wells, Rain Catchment Systems	• Owner may not provide a method for fire personnel to attach and pull water from house wells or rain catchment systems (i.e., fire department draft connection) (Figure 3.27). • Well pumps and rain catchment pumps are dependent on power. • Rain catchment systems are not standardized. They may also be above ground or a below ground holding tank. • Above ground tanks and pump houses are vulnerable to wildfire damage.	• Provide signage to indicate what homes have available water sources and the type of source for the fire department to access, or provide reference documentation of addresses and types of sources. • Homes must have backup power source to run water pumps (e.g., generators, solar power, battery backup) in order to provide a reliable source.
Access to Water Supplies	• Fuels and vegetation adjacent to water supplies can prevent access and use of important resources (Figures 3.26 and 3.29). • Water supplies may not be designed for use by emergency responders. • Access to emergency water supplies may not be available and accessible at all times. • Emergency water supplies may not be readily identifiable.	• Defensible space must be maintained around water pumps and pump houses (see details below). • Emergency water supplies must be provided with fire department pump access points, draft sites, and appropriate fire department connections. • Provide noncombustible signage to identify water supply locations and to prevent parking and other potential obstructions.
Water Pressure and Flow Rates	• Overall water demand in an area experiencing wildland fire incident can overcome available flow and capacity of the available water supply/supplies. • Individual emergency water sources or portions of distribution systems may be compromised by wildfire exposure.	• Community water supply system planning should consider maximum potential firefighting demands. • Pre-incident planning should include areas with limited water availability as well as scenarios with reduced supply and/or compromised resources.

Pumps and Associated Power Supplies	• Municipal and community water pump installations are dependent on power.	• Provide standby power supplies for critical pump infrastructure that supports emergency water supplies. Fuel for standby power should not be subject to potential cut-offs due to the fire (i.e. natural gas line) [163]. • Alternatively ensure that pumps and associated power supplies are provided with hardening measures (e.g., enclosed in fire-resistant enclosure) and brush clearance (e.g., 30-50') to increase wildfire resiliency. • A site-specific analysis may be needed to determine appropriate clearances, management practices, inspection and maintenance schedules based on the vegetation type, topography, climate/weather, etc.
Gravity Fed Systems	• Gravity fed water supplies utilize water storage at upper elevation, which could be threatened during a wildfire incident.	• Maintain sufficient clear space around water storage that is provided on hilltop or ridgeline locations (e.g., 30-100') (Figure 3.28). • A site-specific analysis may be needed to determine appropriate clearances, management practices, inspection and maintenance schedules based on the vegetation type, topography, climate/weather, etc.

General Mitigation Strategies

- Locate fire protection water storage away from wildland fire hazard areas where feasible. Where infeasible, design water storage with defensible space and protection from adjacent fire hazards. Where water storage and/or pumping infrastructure locations must be adjacent to high fire risk areas, include increased setbacks from hazardous vegetation and treat fuels where necessary.

- Size fire protection water supply distribution and storage based on availability study as outlined in *NFPA 1142* [162].

- Construction phasing of new development areas should prioritize construction and commissioning of the fire protection water supply. Where a development includes emergency fire water storage features, these should be available for fire service use prior to significant combustible building construction on site.

- Incident pre-plan information must include accurate information regarding available water supply locations.

Training Programs

- National Wildfire Coordinating Group (NWCG): https://wildlandfirelearningportal.net/
  - S-215 - Fire Operations in the Wildland-Urban Interface
  - G-131, G-231, G-330 - Wildland Training for Structural Firefighters
  - RT-130 - Wildland Fire Safety Training Annual Refresher (WFSTAR)

Gaps in Knowledge

- Water supply design requirements for high fire hazard areas are limited. Municipal water supply systems/zones are typically not designed to support severe wildland fire response demands, particularly in legacy and underserved communities.

- Residential development and design education typically does not include water supply/storage concepts relevant to high fire hazard areas.

- Water supply and water storage requirements frequently do not include additional criteria specific to WUI areas. Responding fire personnel must be aware of water supply limitations for the areas they serve and understand options to augment water availability during peak fire season.

Other References

- California Department of Forestry and Fire Protection, CALFIRE, “Wildland Urban Interface Operating Principles.” 2014. [Online]. Available: https://www.iaff.org/wp-content/uploads/2019/05/CAL-FIRE-Wildland-Urban-Interface-Book.pdf.
- Federal Emergency Management Agency, “Home builder’s guide to construction in wildfire zones: Technical fact sheet series.” Government Printing Office, Sep. 2008. Accessed: Mar. 15, 2025. [Online]. Available: https://www.govinfo.gov/content/pkg/GOVPUB-HS5-PURL-gpo60104/pdf/GOVPUB-HS5-PURL-gpo60104.pdf

Figure 3.26. Municipal hydrant in unmanaged vegetation. Image courtesy of Jensen Hughes/FEMA.

Figure 3.27. Water storage tank on private property, adjacent to structures. Image courtesy of Jensen Hughes/FEMA.

Figure 3.28. Water storage tank located on hill, with vegetation clearance. Image courtesy of Jensen Hughes/FEMA.

Figure 3.29. Fire department water supply connection. Image courtesy of Jensen Hughes/FEMA.

Figure 3.30. Water storage tank. Image courtesy of Jensen Hughes/FEMA.

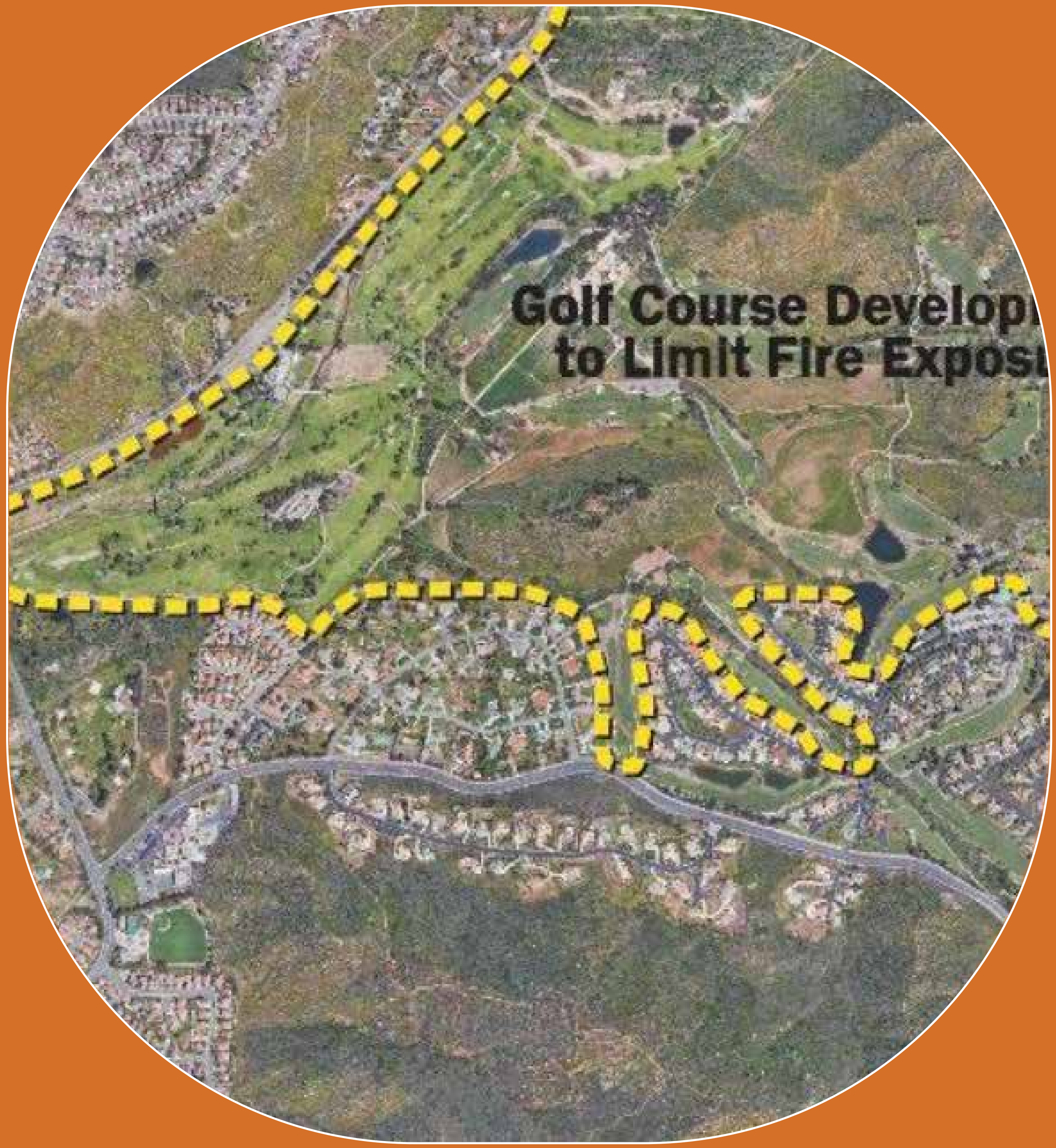
Figure 3.31. Open water storage. Image courtesy of Jensen Hughes/FEMA.

Figure 3.32. Wooden Flume. Image courtesy of Jensen Hughes/FEMA.

Figure 3.33. Large water reservoir, filling automatically, serves private gravity fed system. Image courtesy of Jensen Hughes/FEMA.

LANDSCAPE-SCALE VEGETATION MANAGEMENT

NEIGHBORHOOD AND COMMUNITY-SCALE



3.4.1 LANDSCAPE-SCALE VEGETATION MANAGEMENT

Main Concern(s)

Many communities have several "landscape" level areas and land-use spaces that contain a variety and range of vegetation types, topographic features and management practices, that under certain conditions, can pose a hazard to people, built environments, and natural environments. These "landscape" level areas, or land uses, include open spaces (e.g., water resources, ecological habitats, historical/cultural resources), recreational areas (golf courses, athletic facilities, greenways), agricultural zones (orchards, grazing lands), or other areas (drainage ditches, greenbelts, urban forests, land conservation areas, etc.). Depending on a variety of factors, the vegetation in these areas may pose threats to adjacent or nearby development by spreading fire from wildland areas into a developed area, or acting as wicks to continue fire spread throughout a community. Managing these large-scale land uses with wildfire risk reduction objectives is necessary to address the vegetation in a manner that mitigates its capability to ignite and contribute to fire spread near other community values.

Key Terminology

- **Land Use:** Land use describes the basic type and intensity of uses of land by category. For residential projects, this means the appropriate number of units per acre. For commercial and industrial projects, this means the most floor area based on lot size.
- **Greenway:** Linear open spaces or corridors that link parks and neighborhoods within a community through natural or manmade trails and paths [164].
- **Greenbelt:** An area where measures such as fuel management, land-use planning, and development standards are applied to mitigate fire, flood, and erosion hazard. More traditionally, an irrigated landscaped buffer zone between development and woodlands, usually put to additional uses (e.g., golf course, park, etc.) [132].
- **Fuel Break:** An area, strategically located for fighting anticipated fires, where the native vegetation has been permanently modified or replaced so that fires burning into it can be more easily controlled. Fuel breaks divide fire-prone areas into smaller areas for easier fire control and to provide access for firefighting [146].
- **Open Space:** Land and water areas retained for use as active or passive recreation areas or for resource protection in an essentially undeveloped state [132].

Fire Test Standards

None identified at time of publication.

Referenced Codes and Standards

Planning codes and standards will vary depending on location and adoption in individual jurisdictions.

- Check local, county, and state amendments for any additional requirements.
- Check local general plan, multi-hazard mitigation plan, or zoning documents for any additional requirements.
- International Residential Code (if applicable - check for wildfire amendments).

Typical Design, Vulnerability, and Mitigation Considerations

Table 45. Typical challenges of landscape-scale vegetation management, and their vulnerabilities and potential mitigations.

Typical Challenges	Vulnerability	Potential Mitigations
Large, Uninterrupted Open Spaces or Wildlands	• Large, uninterrupted open spaces or wildlands that border or mix with communities and neighborhoods, if not managed, can present a major fire hazard, particularly if ignited under extreme fire weather conditions (e.g., high winds, drought, low humidity). Under these circumstances, a fire in these areas can result in fire rapidly spreading to uncontrollable levels and with little warning across hundreds to thousands of acres, even in moderately flat terrain (Figure 3.34). • If access is constrained, first responders will have limited capacities to contain, let alone suppress, the fire before reaching more densely populated areas, where it can readily ignite homes and other buildings. • Depending on the type, location, and quantity of vegetation, open space adjacent to a development can provide pathways for wildfire to enter a community [130].	• Landscape-level wildfire hazard and risk assessments should be undertaken to understand the potential threat of large, unmanaged spaces to community values and assets. • Refer to Section 3.2.4 *Neighborhood-Scale Parks and Open Spaces* for other mitigations. • Where ownership constraints limit the design and maintenance of proximate, large undeveloped lands, open spaces and parks, consider providing additional or enhanced fire safety features to the proximate values at risk in the built environment to mitigate these "unmanaged" high hazard spaces. This may include providing a minimum 100' "green" fuel break or other low fire hazard managed land-uses (e.g., fruit orchards, irrigated landscaping, golf courses, roads), increasing the fire resistance of bordering structures, introduce a solid noncombustible property line wall, etc.
Greenways	• Many greenways have vegetation (trees, shrubs, grasses) that accompany the linear nature of these type of parks. They also can attract many recreational users, increasing the risk of human-caused ignitions and the need to consider evacuation routes (Figure 3.35).	• Manage natural and ornamental vegetation along a greenway by planting low flammability species, reducing horizontal fuel continuity, and reducing the overall fuel loading [165]. • Create signage to guide users to where access or evacuation routes are along the greenway.
Greenbelts, Large Parks and Recreational Areas	• Similar to open spaces if unmanaged. See top row in this chart (Figures 3.35 and 3.36).	• Install irrigated and mowed turf areas to reduce the likelihood of ignitions from embers and slow fire spread [165] (Figures 3.37 and 3.38). • Utilize parking areas or other paved surfaces as staging areas or safety zones for firefighting resources and personnel. Consult local fire authority for additional guidance.

Agricultural Landscapes and Rangelands	• The arrangement, continuity, and flammability of crops, as well as management of any associated grasses or dead plant material can influence the likelihood that they burn and facilitate fire spread [165].	• Use low flammability crops when seeking to create a buffer between wildland areas and residential neighborhoods [165]. • Rotate grazing areas to minimize large contiguous ungrazed pastures and to stagger vegetation/fuel continuity [165]. • Consider irrigated areas and smaller pastures that are more intensively grazed as potential fuel breaks [165].

General Mitigation Strategies

- Strategically locate and manage land uses (greenbelts, open space, recreational fields, golf courses, grazed areas, orchards, agricultural lands) that can alter fire behavior before it enters a community. In order to be effective, land uses must be maintained in a way that minimizes hazardous vegetation near development or other values (such as through mowing, grazing, irrigation, specified plant lists, and other techniques).

- When considering vegetation management in natural areas, note that some measures may be restricted, such as vegetation management in riparian areas or sensitive habitats [109].

- Consider trails that are integrated into parks, open space, greenways, or other land uses that can be managed as fuel breaks and provide access for firefighting resources. This will depend on trail width, proximity to urban areas, type and quantity of vegetation, and other factors, and should be done in consultation with local fire authorities [165].

Training Programs

- International Association of Wildland Fire (IAWF):
  - N9073 Mitigation Best Practices - Pre-workshop Training - Cohesive Wildland Fire Management Strategy Workshop (https://cohesivestrategyworkshop.org/)

Gaps in Knowledge

The effectiveness of fuel treatments in changing fire behavior is well documented [166], however the application of specific land uses as fuel treatments to reduce losses in the WUI is largely anecdotal [167]. Guidance provided here is based on the principles of fuel break implementation [139].

Other References

None identified at time of publication.

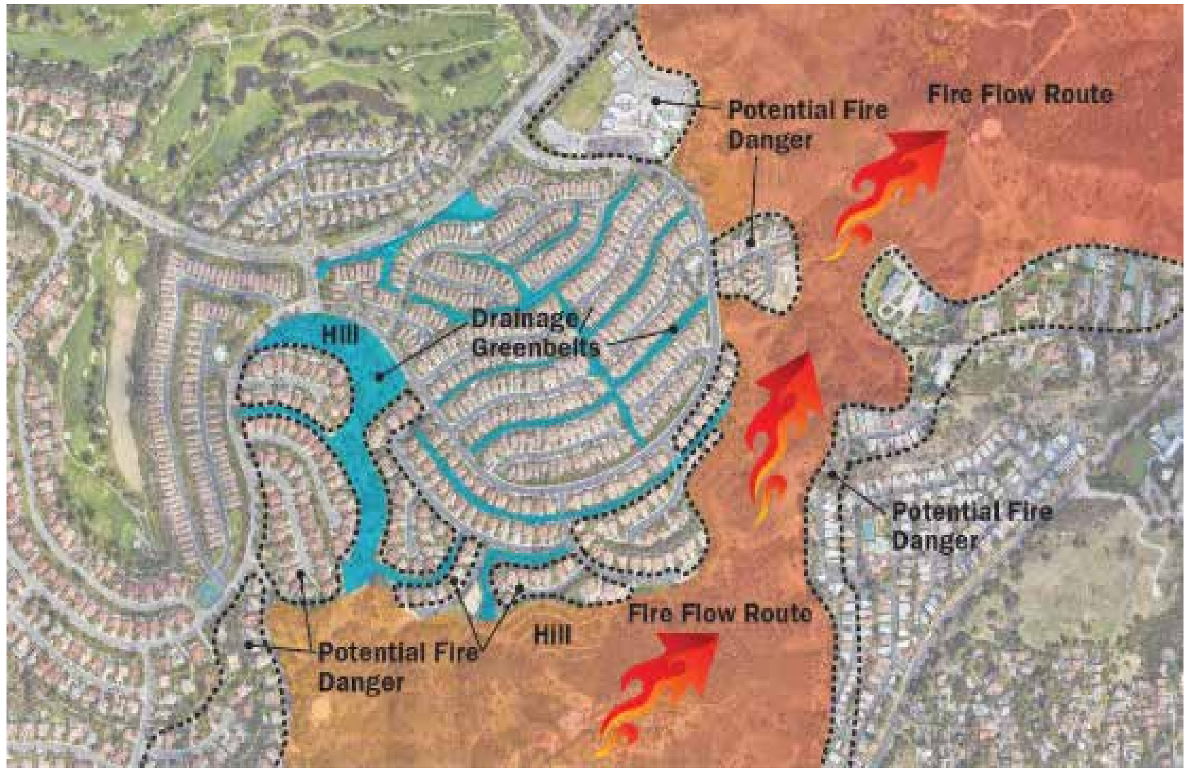


Figure 3.34. Example of common areas spaces in or adjacent to communities that present various fire hazards such as ignition sources, receptive fuel beds or facilitate fire to flow into the built environment. Image adapted from FEMA Marshall Fire MAT, Best Practices for Wildfire Resilient Subdivision Planning, FEMA, 2023. https://www.fema.gov/

Figure 3.36. Example use of golf course to limit fire exposure and spread to nearby development. Image adapted from FEMA Marshall Fire MAT, Best Practices for Wildfire Resilient Subdivision Planning, FEMA, 2023. https://www.fema.gov/

Figure 3.35. Examples of community greenbelts and drainage ditches that can present potential sources for ignition, receptive fuel beds and rapid fire spread into the WUI. Once ignited, they can produce significant embers from burning vegetative fuels, and sources of surface and ladder fuels that lead to ignition of decks, fences, or other combustible fuels along the WUI and well into the urban-suburban environment. Image courtesy of Jensen Hughes/FEMA.

Figure 3.37. Example of a well-maintained golf course buffer. Image courtesy of Jensen Hughes/FEMA.

Figure 3.38. Example of unmanaged greenway/greenbelt (right) vs. well maintained home landscaping (left). Image courtesy of Jensen Hughes/FEMA.

OTHER CRITICAL INFRASTRUCTURE

NEIGHBORHOOD AND COMMUNITY-SCALE

3.5.1 ELECTRIC UTILITIESSTRUCTURE

Main Concern(s)

Electrical utility infrastructure across the U.S. is estimated to cause approximately 2% of all wildfires, with some regions being as high as 7-10% [168]. In addition to causing some of the most destructive and deadliest wildfires in U.S. history [169], electrical infrastructure is also vulnerable to wildfire impacts such as loss of equipment, service, and other resources. Oftentimes, electrical utility infrastructure (e.g., transmission and distribution lines, substations) is located in remote areas and along the outskirts of human development for practical purposes (e.g., costs, spatial efficiencies, reduced nuisance). These locations, however, can be more hazardous from a fire safety perspective due to the potential for (1) proximity to large, uninterrupted wildland fuels, (2) challenging terrain, (3) challenging weather conditions, (4) limited access for inspections and maintenance of equipment and vegetation, (5) inaccessible or slow response times for firefighting. Any potential faults, given high fire threat conditions (e.g., steep terrain, high winds, hazardous fuels), could readily lead to ignition of surrounding fuels, and a large wildfire incident, in addition to loss of power, downed poles/lines, etc.

Understanding the fire hazards and risks utilities impose on communities and the natural environment, as well as the potential impacts wildfires can have on the infrastructure are critical to developing appropriate mitigation measures to limit losses to both utility and community assets and values (before, during, and after an incident) [130].

Other key concerns for electrical utility infrastructure include:

- Aging infrastructure and how to maintain or replace, given the diverse set of owners/operators and financing mechanisms.

- Poor, limited and/or inconsistent vegetation management along the utility right of way (Figures 3.39 and 3.40).

- Limited regulations, codes, and standards at national, state, and local levels to help prevent, mitigate against, recover from, and respond to electrical utility-related wildfire hazards and risks, specifically:
  - Risk assessment frameworks, quantitative and qualitative methodologies, key modelling assumptions and input data, risk modelling tools, and associated verification and validation standards.
  - Acceptable risk tolerances and thresholds.
  - Design, engineering, construction, and operations standards on various mitigation measures (e.g., grid hardening, fast trips, public safety power shutoffs, re-energization, situational awareness, early warning detection and alarm systems, and other technologies and systems).
  - Ongoing inspections, testing, and maintenance standards and best practices.
  - Emergency public communications, messaging, and outreach before, during, and after wildfire incident.
  - Exceptions, alternative requirements, and variations of above components given the size of utility, ownership, and operations structure, regulatory governance, etc.

- Limited regulations, codes, and standards on public safety power shutoff (PSPS). This de-energization method commonly used by utilities during high-wind advisories, while significantly reducing potential wildfire ignitions, oftentimes introduces other risks to people and communities that rely on continuous power for various health and safety needs (e.g., medical baseline customers, food preservation, extreme temperature control). ***Note:*** *This aspect of electric utilities is covered in Section 3.6.1 Multi-Hazard Considerations.*

Key Terminology

- **Electric Utilities:** An electric utility (sometimes referred to as a power company) is often a public utility that engages in generation, storage, transmission, and distribution of electricity in a regulated market. Electric utilities can have a variety of ownership and operational structures, depending on the location, ranging from investor-owned utilities (IOUs), publicly owned utilities (POUs), and cooperatives.

- **Transmission Lines:** Transmission lines carry bulk amounts of electricity from power generation facilities to substations across large stretches of land. Transmission lines are significantly larger and taller than distribution lines. Transmission lines and associated equipment typically have voltages of 100 kV and above [170].

- **Distribution Lines:** Distribution lines carry electricity that has been reduced via transformers to deliver power directly to homes and businesses. Distribution lines are typically constructed of wood, and smaller than transmission lines. Distribution lines typically have voltages of about 13 kV [170].

- **Transformers:** Transformers within electrical utility infrastructure reduce, or "step down" the voltage level sent through transmission lines so that electricity can be safely distributed to customers via distribution lines. Transformers typically have voltages of 100 kV and above [170].

- **Battery Storage:** Battery storage, also referred to as Battery Energy Storage Systems (BESS), store the energy generated from renewables, such as solar and wind power, to be released when the energy is needed [171].

- **Public Safety Power Shutoff (PSPS):** During a Public Safety Power Shutoff (PSPS), utilities temporarily turn off power to specific areas to reduce the risk of fires caused by electric infrastructure [172].

Fire Test Standards

None identified at time of publication.

Referenced Codes and Standards

Planning codes and standards will vary depending on location and adoption in individual jurisdictions.

- Check local, county, and state amendments for any additional requirements.
- Check local general plan, multi-hazard mitigation plan, or zoning documents for any additional requirements.
- International Residential Code (if applicable - check for wildfire amendments).

Examples of building codes and standards:

- *2021 NFPA 1 Fire Code* - Section 17.3.5 Clearance of Brush and Vegetative Growth
- *2022 NFPA 1140 Standard for Wildland Fire Protection* - Section 19.6.7 Infrastructure
- 2024 International Wildland-Urban Interface Code - Appendix A, Section A102 Vegetation Control
    - ***Note:*** *For jurisdictions where the 2024 IWUIC is adopted, requirements contained in Appendix A do not apply unless specifically adopted.*

Typical Design, Vulnerability, and Mitigation Considerations

Table 46. Typical electric utility challenges and their vulnerabilities and potential mitigations.

Typical Challenges	Vulnerability	Potential Mitigations

Overhead Distribution Lines and Equipment	• Traditionally, the distribution system (DS) for electrical utilities (< 33kV) is located aboveground. While undergrounding of DSs has already occurred in major cities and associated suburbs, DSs in other areas are still on overhead lines and poles.
	
	• Overhead or aboveground DS is vulnerable to severe weather including wind, fire, and ice, which accounts for 51 percent of major events, and affecting 92.4 percent of customers [173].
	
	• In high fire prone regions, high winds are of particular concern, as these conditions can lead to a variety of faults including lean-in/fall-in of proximate vegetation, downed lines, downed poles, etc., leading to potential ignitions.
	
	• Some other common vulnerabilities for overhead DSs that can lead to wildfire ignitions include lean-in/fall-in/grow-in of proximate vegetation, contact from metallic balloons, contact from animals, etc.
		• One of the most effective ways to reduce the likelihood of DS lines and equipment from causing wildfire ignitions and/or being damaged by a wildfire is to underground. However, undergrounding has disadvantages such as higher costs, more disruptive maintenance, vulnerability to seismic and flooding, need for insulation and reduced distances.
		
		• Where undergrounding is infeasible, other mitigations include:
		  • Grid hardening (e.g., covered conductors)
		  • Grid operations and protocols (e.g., fast trips)
		  • Vegetation management (see *Vegetation Contact* row below)
		  • De-energization (e.g., public safety power shutoff)
		
		• Consult relevant state and local fire safety ordinances and utility commission guidance and/or regulations to adequately design overhead DS and associated equipment (e.g., transformers) to reduce the likelihood of ignition.
		
		• See Section 3.5.1 *Other References* for additional guidance

Overhead Transmission Lines and Equipment	• Transmission systems (usually 110kV and above) are typically located aboveground and are comprised of towers, conductors, and other associated equipment (e.g., transformers, circuit breakers, switches, and control systems). Because of the higher voltages, transmission lines require greater separation distances from conductors, from the tower, from the ground and from other structures to prevent faults. This also results in larger, more robust structural designs of the towers, lines and foundations necessary due to the weight of the equipment and other loads from wind, ice, earthquakes, and possible impacts. • Because of the spatial separation distances and robustness of the structural design of the overall transmission system, fewer faults due to weather, vegetation contact, etc. occur.	• While wildfire ignitions from transmission systems are relatively small compared to overhead distribution systems, they can still occur. • Refer to DS row above for potential mitigation measures.

Vegetation Contact	• Contact (grow-in, lean-in, and fall-in) from proximate trees and other vegetation can result in electrical faults (e.g., downed line, arcing, arcing to breaking/downed line) for overhead transmission and distribution (T&D) lines and associated equipment.
	• In addition to providing potential sources for electrical faults, proximate vegetation, particularly in the right-of-way, can also provide a fuel source for wildfire spread (Figures 3.39 and 3.40).
	• The vegetation type, topography, local weather, climate, and maintenance of vegetation all impact wildfire risk.
		• Plant and tree selection, vegetation management practices, inspection and maintenance schedules should be developed by the owner/ operator of the electrical system, in collaboration with local landowners, fire ecology experts, and other relevant stakeholders.
		• Vegetation management planning should consider vegetation type, topography, local weather, climate, phenology, fire regime and other relevant factors to more effectively reduce the likelihood of faults due to fall-in, grow-in and lean-in over the lifetime of the electrical infrastructure.
		• Consult with any federal, state, and local guidance, where available.
		• Where state or local guidance is not available, Chapter 17 of NFPA 1 provides some limited, general guidance on clearance of brush and vegetation growth around electrical lines. This includes:
		  • A combustible free zone around poles and towers of not less than 10' in each direction (Figure 3.41).
		  • For distribution lines, vegetation clearances are defined as a function of line voltage and time of trimming (e.g., a 4160V line requires a minimum of 4' clearance, so trimming requirements are triggered when vegetation is 4' from the line and must be trimmed to 6' clearance, to allow for growth in between trimming cycles) [130] (Figure 3.42).
		  • Regular vegetation maintenance should be planned and carried out to maintain appropriate clearances, and should take into consideration species' growth rates, trim cycle, and line sway.

Electrical Arcs	• All electrical equipment can be subject to high energy electrical arcs. Even with systems in place to mitigate the hazard, arcs can still happen. • The energy in an arc can melt or vaporize the metallic conductors used in electrical transmission, and the molten metal has the potential to be expelled from the arc location and travel a significant distance. This has the potential to ignite surrounding brush if left unmitigated and could cause a potentially large wildfire event.	• Develop established inspection cycles and record-keeping of fire safety and vegetation management practices of T&D lines and equipment. • Ensure that T&D lines and infrastructure are provided with sufficient clearance (See Vegetation Contact challenges above).
Remote Substations	• Materials used for performing maintenance or construction within equipment substations are often combustible. If combustible materials are left exposed, there is a higher hazard for an emergency within a substation to become a large fire event. If substations are remote, there is the potential for long periods of time to go between maintenance or monitoring of the condition of the substation. • Equipment can oftentimes be in remote areas that are difficult for firefighters to access.	• Ensure that additional vegetation management and fire hazard reduction measures are adopted for high-value asset structures/ outbuildings, as well as structures containing fire protection equipment. • Establish procedures for verifying that all extraneous combustibles not essential to the function of the substation equipment are removed after any maintenance or construction efforts. • Provide roadside fuel treatments to ensure that firefighters have sufficient space for operations, and to ensure safe evacuation routes for any staff. Typical recommendations include providing a minimum 10' laterally on each side of roadways, with 13'6" of vertical clearance. However, this should be verified with the local fire department.

Exposed Transmission & Distribution (T&D) Structures (e.g., Towers, Poles)	• Exposed metals and combustible materials used for T&D support structures and other equipment can be damaged and/or destroyed in a major wildfire, because electrical utility infrastructure can suffer severe fire exposures due to radiation, hot gases, and direct flaming.	• To reduce the potential for loss or damage of T&D structures/equipment from due to wildfire exposure, consider providing one or a combination of protection features:
		  • Vegetation clearance around infrastructure (Refer to guidance above).
		  • Replace wooden poles and other structures with noncombustible, corrosion resistant materials (e.g., steel). Providing a fire-resistant sleeve or externally applied fire-resistant material (e.g., intumescent paint) can offer increased resiliency.
		
		• As needed, undertake a performance-based structural fire engineering analysis to evaluate site- and design-specific conditions. Consult with structural fire experts for guidance and input.

Public Safety Power Shutoff (PSPS) Risks	• Electrical utilities have used and continue to use, PSPSs as a reliable and effective method of reducing the likelihood of utility-related wildfire ignitions, particularly during severe fire danger days (e.g., high wind, low humidity, high temperature). However, PSPS programs have introduced knock-on hazards and risks to the impacted communities, in particular vulnerable populations that may rely on continuous power sources for health needs (e.g., medical baseline customers, elderly). • Poorly planned, coordinated and communicated PSPS programs can oftentimes result in a variety of elevated risks to the community, including loss of perishable foods, business continuity, etc. Refer to Section 3.6.1 *Multi-Hazard Considerations* for additional concerns.	• Refer to Section 3.6.1 *Multi-Hazard Considerations* for additional details. • Refer to Section 3.5.1 *Other References* for examples of existing guidance on PSPS programs.

General Mitigation Strategies

- Coordinate utility-related wildfire hazard and risk assessment reports, and mitigation planning documents (e.g., Wildfire Mitigation Plan) with all relevant stakeholder groups and other planning documents such as General or Comprehensive Plan Safety Elements, Community Wildfire Protection Plan (CWPP), Hazard Mitigation Plans (HMP) and any other relevant plans. Relevant parties and stakeholders should seek alignment and connection across all relevant plans.

- Consider hiring a fire protection engineer or wildfire safety specialist to evaluate and recommend wildfire safety provisions, protection measures, etc.

- Develop and enforce a vegetation management plan based on all the required and elective fuel treatment to ensure ongoing, long-term management. Coordinate between specialists such as landscape architects, arborists, or fuel treatment vendors to ensure practices align with specific ecological/environmental needs and fire safety performance goals.

- Create a fire danger rating implementation plan that addresses activities common to the utility equipment and how those activities relate to fire danger and the potential for a wildland ignition. As part of this plan, identify and enforce limitations of high fire risk activities, particularly during Red Flag Warning days.

- Ensure that any emergency protocols or emergency procedures handbooks are updated to include any additional mitigation measures that have been adopted.

Training Programs

- California Office of Energy Infrastructure Safety Workshops: https://energysafety.ca.gov/events-and-meetings/workshops/

- National Fire Protection Association (NFPA):
  - Certified Wildfire Mitigation Specialist Training: https://www.nfpa.org/for-professionals/certification/cwms#who-it's-for

Gaps in Knowledge

- There are limited regulations, codes, and standards at national, state, and local levels to help prevent, mitigate against, recover from, and respond to electrical utility-related wildfire hazards and risks, specifically:
  - Risk assessment frameworks, quantitative and qualitative methodologies, key modelling assumptions and input data, risk modelling tools, and associated verification and validation standards.
  - Acceptable risk tolerances and thresholds.
  - Design, engineering, construction, and operations standards on various mitigation measures (e.g., grid hardening, fast trips, public safety power shutoffs, re-energization, situational awareness, early warning detection and alarm systems, and other technologies and systems).
  - Ongoing inspections, testing, and maintenance standards and best practices.
  - Emergency public communications, messaging, and outreach before, during, and after wildfire incident.
  - Exceptions, alternative requirements, and variations of above components given the size of utility, ownership and operations structure, regulatory governance, etc.

- There are limited regulations, codes, and standards on public safety power shutoff (PSPS).

Other References

- U.S. Fire Administration, "Assess Community Risk," Assess Community Risk. [Online]. Available: https://www.usfa.fema.gov/wui/communities/assess-risk.html
- Federal Energy Regulatory Commission, "Tree Trimming and Vegetation Management Landowners FAQ." [Online]. Available: https://www.ferc.gov/about/what-ferc/frequently-asked-questions-faqs/tree-trimming-and-vegetation-management-landowners
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- G. Severino, A. Fuentes, A. Valdivia, F. Auat-Cheein, and P. Reszka, "Assessing Wildfire Risk to Critical Infrastructure in Central Chile: Application to an Electrical Substation," Int. J. Wildland Fire, vol. 33, no. 4, Apr. 2024, doi: https://doi.org/10.1071/WF22113

Figure 3.39. Electrical utility infrastructure, particularly aboveground lines and equipment located proximate to hazardous vegetation, challenging terrain, severe weather and remote locations can both cause and be threatened by wildfire. Image courtesy of Jensen Hughes/Tuolumne County.

Figure 3.40. Example of a distribution line with unmanaged, dry vegetation in close proximity. Image courtesy of Jensen Hughes/FEMA.

Figure 3.41. Example of 10' vegetation clearance around a distribution pole. Image courtesy of Jensen Hughes/FEMA.

Figure 3.42. Example of tree removal clearance around distribution lines. Image reused under the Open Government - Alberta License https://open.alberta.ca/licence

3.5.2 NON-EMERGENCY WATER AND WASTEWATER INFRASTRUCTURE

Main Concern(s)

The provision of water and wastewater services is a key utility service for individuals and communities. Water and wastewater infrastructure and services can be impacted during wildfire events via two main pathways - the damage or destruction of infrastructure and the pollution of water resources.

Water and wastewater infrastructure is vulnerable to wildland and wildland-urban interface fires, if it is constructed of materials that may be vulnerable to fire (e.g., wood, plastic), if vegetation is proximate to infrastructure and vegetation management is limited, or reliant upon electricity that may be interrupted during a wildfire (see Section 3.5.1 Electrical Utilities). If emergency power is available, the fuel source may also be interrupted or cut off due to the wildfire (i.e. natural gas lines shut off due to wildfire threat), thus preventing generators from providing power. Alternative fuels (i.e. diesel) or fuel sources (tank instead of service line) may need to be considered [163]. When water resources are above ground and open air, they are especially susceptible to pollution during wildfire events, including volatile organic compounds and semi-volatile organic compounds.

The protection of non-emergency water and wastewater infrastructure during wildfire events is critical to the return to normal activities for communities following a wildfire. Understanding potential impacts of wildfire on water and wastewater infrastructure is important to developing appropriate mitigation measures to limit losses to both infrastructure and impacts on people.

Other key concerns include:

- As with other types of critical infrastructure, most water infrastructure is designed and managed at city or regional scales and may serve multiple jurisdictions, as well as be overseen by various entities.
- There are few codes, standards, or other guidance for resiliency and recovery of these non-emergency water systems.

Note: *the topics outlined in this section are closely related to those in Section 3.3.2 Firefighting Water Supplies.*

Key Terminology

- **Public Water Supply:** A public water system provides water for human consumption to 15 or more connections and includes community water supplies, non-community non-transient water systems, and transient water systems [174].

- **Community Water Systems:** Community or municipal water systems include city, county, regulated utilities, and regional water systems that typically serve residential areas [174].
- **Non-Community Non-Transient Water Systems:** These systems serve locations including schools and businesses that provide their own water [174].
- **Transient Water Systems:** These systems serve entities including rural gas stations and public lands State and National parks that provide their own potable water source. Most people that consume the water neither reside nor regularly spend time there [174].
- **Private Water Supply:** A private or individual water system is water derived from non-public sources and typically serving only a single or few residences or properties. The water source(s) may include private groundwater wells, springs, or surface water [175].
- **Volatile Organic Compounds (VOCs):** Organic chemicals that are gases under normal atmospheric conditions. VOC's are an inhalation hazard. Wildfires produce VOCs [176].
- **Semi-Volatile Organic Compounds (SVOCs):** Organic chemicals that remain as solids or liquids under normal atmospheric conditions. SVOCs can accumulate in air, water, soil, and humans. Wildfires produce SVOCs [176].

Fire Test Standards

None identified at time of publication.

Referenced Codes and Standards

Planning codes and standards will vary depending on location and adoption in individual jurisdictions.

- Check local, county, and state amendments for any additional requirements.
- Check local general plan, multi-hazard mitigation plan, or zoning documents for any additional requirements.
- International Residential Code (if applicable - check for wildfire amendments).

Examples of building codes and standards:

- *2021 NFPA 1 Fire Cod* - Section 17.3.5 Clearance of Brush and Vegetative Growth
- *NFPA 820 Fire Protection for Wastewater Treatment Facilities*
- *2024 International Wildland-Urban Interface (IWUI) Code* - Appendix F: Characteristics of Fire-Resistive Vegetation

Typical Design, Vulnerability, and Mitigation Considerations

Table 47. Typical water infrastructure challenges and their vulnerabilities and potential mitigations.

Typical Challenges	Vulnerability	Potential Mitigations
Enclosed Water Storage and Water Supply Infrastructure (e.g., Tanks, Cisterns, Pumphouses)	• Aboveground water supply storage may be vulnerable to wildfire damage due to their materials and construction (e.g., wiring, PVC casings, plastic construction) if they are in high hazard areas. This includes both components of public water systems and private water systems (e.g., pump houses, well junction boxes). • Water systems are typically dependent on a power supply to run pumps and supply water to users.	• A minimum of 30' of fuel modification should be maintained around water infrastructure (Figure 3.43). • Any above-ground water storage infrastructure should be hardened to be fire-resistant. • Provide backup power supplies for wells. In the case that wiring or power supply for a well is damaged, consult a well technician to determine the appropriate size generator to use to avoid damage [177]. Fuel for emergency power should not be subject to potential cut-offs due to the fire (i.e. natural gas line) [163]. • For residents with private wells, if the area near the well burned, a licensed well technician should inspect the system to assess operation and safety of the water supply. If fire retardant was used near a wellhead, monitor ammonia and nitrate concentrations for several months [177].
Open Water Storage and Transportation (e.g., Reservoirs, Open Waterways, Irrigation Canals, Flumes)	• The construction of open water storage and transport systems may be vulnerable to wildfire due to materials or construction (e.g., wooden flumes). • Many reservoirs are in mountain areas prone to wildfire. Because these water sources are exposed, they are also vulnerable to impacts of wildfire including particulates and increased runoff/erosion following a wildfire. These impacts of wildfire on water sources may impact drinking water availability and quality following a wildfire.	• Retrofit water systems to fire resistant construction. • Monitor water quality following a wildfire. Install systems such as backflow preventers or implement network zoning that can be isolated, to prevent contaminants from spreading through the water system following a wildfire [163].
Wastewater	• Public wastewater infrastructure and treatment systems may be vulnerable to wildfire due to materials and construction (e.g., PVC pipes, open treatment tanks) that are susceptible to both damage and the introduction of pollutants, which may further damage systems. • Onsite wastewater (septic) systems are typically below ground and fairly resistant to wildfire. However, any PVC piping above ground may be susceptible to damage.	• Public wastewater infrastructure should be retrofitted to fire-resistant construction. Following a wildfire, any open facilities should be monitored for pollutants. • Onsite wastewater (septic) systems - any above ground components should be inspected for damage following a wildfire [177].

General Mitigation Strategies

- Water systems may span across multiple jurisdictions and may have multiple responsible entities (e.g., public utilities, city, county). Coordinate with all responsible parties. Infrastructure should be inventoried and assessed to determine vulnerability. Mitigation strategies, such as the removal of hazardous vegetation, may be part of an existing CWPP or HMP. If a critical infrastructure plan exists separately, planners should seek connections between these plans [109].

- Where cross-connections between adjacent water supply systems are possible, one water distribution system may be cross-connected to supplement supply and assist in maintaining pressure. Hydrant-to-hydrant connections with backflow prevention valves may also be used to supplement supply and pressure. The potential for such cross-connections can be included in mutual aid discussions and agreements [163].

- Locate water supply infrastructure away from wildland fire hazards where feasible. Where infeasible, utilize defensible space, undergrounding of infrastructure, or infrastructure hardening (e.g., fire-resistant construction).

- Effective notification of water advisories, based on information about both biological and chemical water contamination, should be integrated into pre and post-fire communications with affected communities [163]. See Section 3.5.3 *Public Emergency Communications*.

Training Programs

None identified at time of publication.

Gaps in Knowledge

- There are limited codes and standards providing explicit planning, design, construction and long-term maintenance of non-emergency water infrastructure and wastewater systems to wildfire threats.

- There is limited research on the potential impacts of wildfire threats on the robustness and resiliency of the water and wastewater infrastructure at various scales, design typologies, environmental settings (e.g., topography, urban vs rural, surrounding vegetation type, fire exposures), materials, water supply sources, delivery mechanisms, private wells, etc.

- As wildfires increasingly burn into urban areas, new pollutants that have previously not been considered may be introduced into water systems. Because of the lack of understanding of these pollutants, water quality managers lack information regarding sampling, testing, and appropriately addressing their impacts [178].

- The mechanisms for private and public water system contamination as a result of system depressurization, damage to the water distribution system, and damage to properties served by the water system are not well understood [179], [180].

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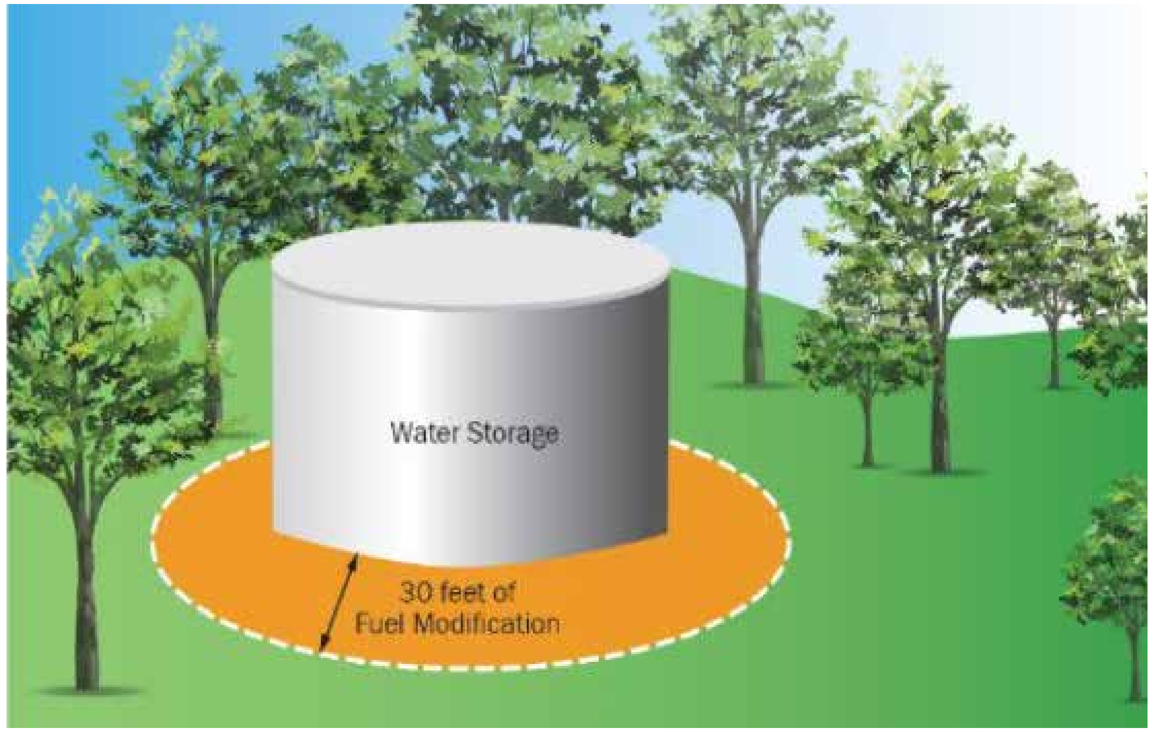

Figure 3.43. A minimum of 30 feet of fuel modification should be maintained around water infrastructure. Image adapted from FEMA Marshall Fire MAT, Best Practices for Wildfire Resilient Subdivision Planning, FEMA, 2023. https://www.fema.gov/

3.5.3 PUBLIC NOTIFICATION SYSTEMS, COMMUNICATION AND MESSAGING

Main Concern(s)

Public notification and communication systems are considered critical infrastructure for wildfires and other emergency incidents. For functional reasons, notification and communication infrastructure (e.g., radio towers, cell towers) are located along ridgelines and other high points on the landscape to more effectively transmit communication signals. These locations are also the most hazardous from a fire perspective because this is where wildfire intensities are the most severe. In most major wildfire incidents, these systems may be lost early in the incident due to a variety of factors such as damage from direct exposure to fire, impairment due to loss of power, downed poles/towers from fire or high winds, etc.

In addition to physical vulnerabilities, past wildfire incidents have also highlighted several practical challenges in providing effective, timely, and coordinated messaging and information to the general public. The public increasingly relies on short electronic messages, such as text messages, social media, Wireless Emergency Alerts, or specific smartphone applications for wildfire alerts (Watch Duty, Frontline Wildfire Tracker, Firespot, Fire Notification, etc.) to stay informed of developing emergencies.

Effective emergency messages, regardless of the medium used to share the information, should include the following information:

- Source - The local authority issuing the message.
- Hazard - The nature of threat, such as a wildfire.
- Location - Where the hazard is impacting the community.
- Time - When recipients should take action.
- Guidance - Specific action to be taken, such as prepare to evacuate, evacuate, avoid a specific route when evacuating, etc.

A complete message with those five types of information, in that order, is most effective in influencing a recipient's understanding, belief, and decision making to take appropriate action. Incomplete messages that are not well understood can delay an evacuation as recipients seek additional information [181], [182], [183].

Written or verbal messages in languages other than English are important to reach multiple demographics, especially vulnerable populations and visitors. If critical infrastructure including cell towers, telephone system, and electricity are compromised by wildfire or subject to a Public Safety Power Shutoff / Public Power Shutoff, reliance on electronic messaging systems will result in incomplete notification of the public [154], [155].

Emergency notification, communication, and messaging are often issued by multiple local, state, federal, and tribal agencies and organizations, and the various entities may each have different preferred communication methods, protocols, procedures, terminology to describe hazard and actions to take, and infrastructure to disseminate message (e.g., social media, TV, radio, cellular and broadcast towers, reverse 911 calls, door-to-door notification, vehicle-mounted public address system, emergency sirens) [117].Use of the Incident Command System (ICS) / National Incident Management System (NIMS) to coordinate notification efforts is encouraged to prevent miscommunication, conflicting information/recommendations, and confusion by the public [184].

There are few codes, standards, and/or guidance documents for wildfire or post-wildfire resiliency for communications systems. As most critical infrastructure is designed and managed at city and regional scales, most developers, contractors, engineers, and planners have little influence over the wildfire safety provisions for those large-scale systems [130].

Key Terminology

- **Dead Zone:** An area where cell phones cannot transmit to a mobile site, base station, or repeater, typically because the signal between the cell phone and mobile site antenna is blocked due to terrain, vegetation, or distance.

- **Notification Systems:** An emergency notification system is the technical system(s) or platform that facilitates the rapid dissemination of emergency messages to targeted audiences through multiple communication channels. These channels may include voice calls, emergency alert systems (EAS), SMS, reverse 911, social media, desktop alerts, digital signage, etc.

- **Early Warning System:** This integrated system combines hazard monitoring, forecasting, risk assessment, communication, and preparedness efforts, enabling various groups (like individuals, communities, and governments) to act promptly and lessen potential harm before hazardous events occur [185].

- **Emergency Alert System (EAS):** “The EAS is a national public warning system used by state and local authorities to deliver important emergency information to affected communities. Participants include radio and television broadcasters, cable systems, satellite radio and television providers, and wireline video providers” [186].

- **Wireless Emergency Alerts (WEA):** “WEA is a public safety system that allows customers who own compatible mobile devices to receive geographically targeted, text-like messages alerting them of imminent threats to safety in their area. WEA enables government officials to target emergency alerts to specific geographic areas… Authorized public safety officials send WEA alerts through FEMA’s Integrated Public Alert and Warning System (IPAWS) to participating wireless carriers, which then push the alerts to compatible mobile devices in the affected area.” WEA alerts are limited to 360 characters and issued in English or Spanish [187].

- **Public Safety Power Shutoffs (PSPS) / Public Power Shutoffs (PPS):** Power is temporarily turned off to reduce the risk of inadvertent fire ignition by electric infrastructure [172].

Fire Test Standards

None identified at time of publication.

Referenced Codes and Standards

Planning codes and standards will vary depending on location and adoption in individual jurisdictions.

- Check local, county, and state amendments for any additional requirements.
- Check local general plan, multi-hazard mitigation plan, or zoning documents for any additional requirements.
- International Residential Code (if applicable - check for wildfire amendments).

Examples of building codes and standards:

- *2022 NFPA 1140 Standard for Wildland Fire Protection* - Chapter 17 Community Safety and Emergency Preparedness
- *2024 NFPA 1660, Standard for Emergency, Continuity, and Crisis Management: Preparedness, Response, and Recovery*
- *2025 NFPA 72, National Fire Alarm and Signaling Cod* - Chapter 24 Emergency Communication System (ECS)
- *National Incident Management System (NIMS) / Incident Command System (ICS)*

Typical Design, Vulnerability, and Mitigation Considerations

Table 48. Typical notification and communication infrastructure challenges and their potential mitigations.

Typical Challenges	Vulnerability	Potential Mitigations
Placement of Infrastructure Adjacent to Hazardous Topographic Features	• Because of the nature of how communication towers work, they are often placed on hilltops or ridgelines to maximize line of site and, thus, service distance (Figure 3.44). These topographic features that improve service of communication infrastructure often coincide with higher wildfire hazard.	• Consider hazard in addition to other priorities when placing communication infrastructure. Undertake vegetation treatment and infrastructure hardening when infrastructure must be placed in high hazard areas (see following items).
Vegetation Contact with Communication Infrastructure	• Communications infrastructure (towers, poles and lines) is often surrounded by vegetation, which can act as fuel during a wildfire. Type, location, and maintenance of vegetation all impact wildfire risk. • In some situations, such as when multiple entities have equipment on the same tower, the party responsible for vegetation management in the right-of-way of communication infrastructure might be different from the party responsible for the communications infrastructure itself.	• Provide a minimum of 30' of hardscaping or brush clearance around communication towers and associated equipment. This may need to be increased depending on the topography, vegetation type, and local climate/weather. • Although there is not specific guidance for clearance under communications lines, guidance can be borrowed from electrical utilities. Trigger trimming requirements when vegetation is 4' from the line and trim to 6' clearance, to allow for growth in between trimming cycles. • Consult with local fire authorities for any local requirements, guidance, and best practices. Where no local guidance is provided, consult *NFPA 1*, *NFPA 1140*, or *IWUIC* for vegetation management guidance.
Vulnerability of Communication Infrastructure Construction	• Communication infrastructure is often vulnerable to damage or destruction during a wildfire event due to its construction, which is often of combustible materials. Failure of these materials could cause the communication infrastructure to cease from functioning properly.	• Construct new infrastructure, or retrofit existing infrastructure, to be of noncombustible materials. Where the use of noncombustible materials is not possible, use ignition-resistant (refer to *2022 California Building Code* Section 704A) materials.

General Mitigation Strategies

- There may be multiple entities responsible for managing communication infrastructure, and communication infrastructure may serve multiple jurisdictions. Coordinate with all responsible parties regarding wildfire concerns and mitigation. Infrastructure should be inventoried and assessed to determine vulnerability. Mitigation strategies, such as the removal of hazardous vegetation, may be part of an existing CWPP or HMP. If a critical infrastructure plan exists separately, planners should seek connections between these plans [109].

- Public alerts using verbal instructions are limited in efficacy outdoors because the intelligible range of voice messages is limited by reverberation with buildings or vegetation, and limited placement of speakers [117]. Reliance solely on audible alerts excludes those with hearing loss [188].

- Where possible, and particularly in high hazard areas, provide redundancy of infrastructure to reduce the possibility that communication channels will be lost during a wildfire event.

- As part of evacuation planning (See Section 3.2.3 *Means of Egress and Evacuation Planning*), develop a notification plan using resilient, multi-modal notification systems. Evacuation terminology and nomenclature can vary between organizations and locations. Work with response partner organizations prior to an incident, to better understand various notification capabilities, terminology, and notification processes to avoid miscommunication of important information to the public during an event. Educate the community on appropriate elements of the notification plan, potential actions to take upon receipt of notifications, availability of public shelters outside the evacuation area, etc [182], [183].

- Operational phrases or jargon are often not well understood by the public (evacuation warning vs evacuation order, Level 1 vs Level 2, Temporary Refuge Area, etc). If operational phrases must be used, also use plain-language description of actions to take. While community members may be educated about the operational phrases' meanings, visitors who receive the messages but may not understand the terminology [183].

Training Programs

- National Fire Protection Association (NFPA):
  - Certified Wildfire Mitigation Specialist Training - https://www.nfpa.org/for-professionals/certification/cwms#who-it's-for
- Federal Emergency Management Agency (FEMA) Emergency Management Institute (EMI):
  - Public Information Awareness Basics - IS-29 Public Information Officers Awareness and E0105 Public Information Basics https://training.fema.gov/programs/public-information-officer/basic/
  - Advanced Public Information Officer - E0388 Advanced Public Information Officer https://training.fema.gov/programs/public-information-officer/advanced/
  - Executive Public Information Officer - E0389 Executive Public Information Leadership https://training.fema.gov/programs/public-information-officer/executive/
  - E/L 969: All-Hazards Position Specific Communications Unit Leader
- Santa Clara County Fire Safe Council
  - Lost in Translation: Rethinking Wildfire Emergency Messaging Webinar (April 2025) https://zoom.us/clips/share/l3tPVz7mRoK9gnTJX35-2g
- Society of Fire Protection Engineers Foundation: https://www.sfpe.org/foundation/wildland-urban-interface/wui-initiatives
  - Advanced Engineering Science for the Fire Service: Advanced Training Topics in WUI Fire Risk Assessment & Mitigation

Gaps in Knowledge

- Codes, standards, and guidance for placement, hardening, and vegetation maintenance around communications infrastructure are limited.

- Little to no guidance exists for infrastructure specific to communications.

- Best practice guidance for functional operations, including coordination of public notification systems, emergency communication and messaging between agencies that have adjoining or overlapping jurisdictions, is lacking in both theory and practice. As part of emergency planning, for wildfires and other hazards, an approach for coordination between plans and different technologies/programs used by agencies should be formulated.

- Research on emergency alert fatigue, why people opt out of receiving emergency alert messages, and the potential use of emergency sirens for a wildfire, are areas for future research.

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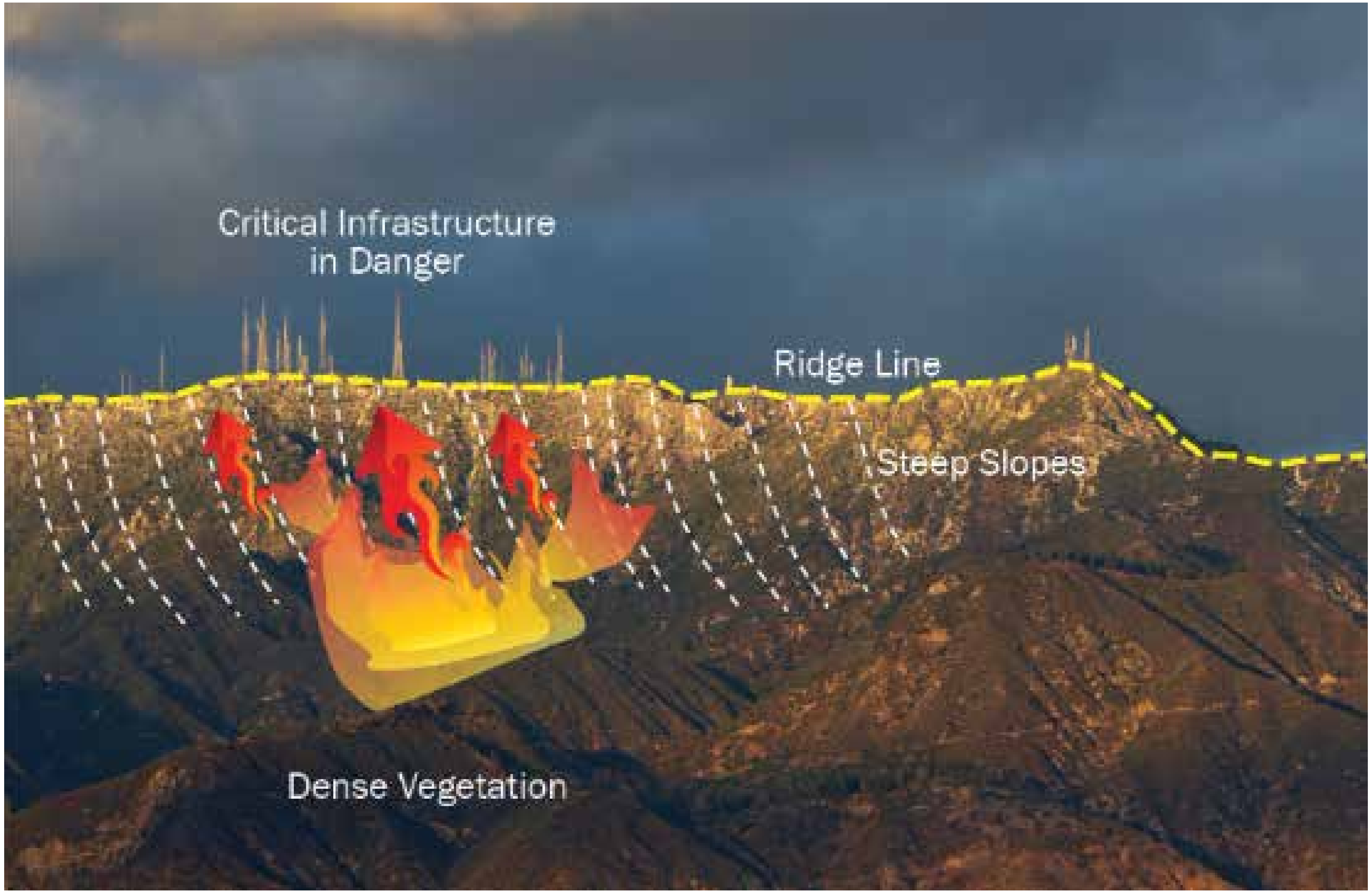

Figure 3.44. Communications infrastructure is often put on hilltops or ridgelines, at the top of steep slopes, where it may be in a wildfire hazard area. Image adapted from FEMA Marshall Fire MAT, Best Practices for Wildfire Resilient Subdivision Planning, FEMA, 2023. https://www.fema.gov/

OTHER TOPICS

NEIGHBORHOOD AND COMMUNITY-SCALE

3.6.1 MULTI-HAZARD CONSIDERATIONS

Main Concern(s)

The location of a neighborhood in relation to surrounding vegetation and terrain influences not only wildfire hazard, but also other hazards. A key challenge is that other hazards may compound wildfire issues or that wildfire-focused mitigations may exacerbate other hazards (or vice versa). Other hazards which interact with wildfire may include drought, lightning, high wind, extreme heat, flood, and landslide.

Communities should use a multi-disciplinary approach to hazard mitigation to reduce wildfire loss exacerbated by other hazards and address hazards that could develop post-wildfire, such as flooding and debris flows. Planners, developers, and land managers pursuing a multi-disciplinary approach to wildfire mitigation should consider the following:

- Natural hazard events can impact key fire hazard conditions (i.e., topography, fuel, and weather) that may make wildfires more likely to ignite and spread (Figure 3.45).
- Wildfires can increase the likelihood and severity of secondary hazard events, such as flooding and debris flows (Figure 3.46).
- Development strategies in the wildland-urban interface may not adequately address mitigation best practices or may inadvertently exacerbate the effects of multi-hazard events.
- Wildfire mitigation requires a multi-disciplinary approach that collectively addresses the impact of natural hazards on wildfire risk through effective land management and building techniques.

Hazardous topographic and fuel conditions, combined with extreme climate conditions and an ignition source combine to influence the probability, intensity, and severity of wildfire behavior. Natural hazards events can also influence these fire hazard conditions to increase the probability and likely severity of a wildfire. In wildfire-prone areas, post-fire conditions can also increase the risk of secondary natural hazards, or "cascading effects," such as floods and landslides downslope of burn boundaries (Figure 3.46).

Key Terminology

- **Debris Flow:** Fast-moving, deadly landslides. They are powerful mixtures of mud, rocks, boulders, entire trees - and sometimes, homes or vehicles [189].
- **Drought:** A deficiency of precipitation experienced over an extended period of time, typically a season or longer [190].
- **Extreme Heat:** A period of high heat and humidity with temperatures above 90 degrees for at least two to three days [191]. Extreme heat often results in the highest number of annual deaths attributed to weather-related hazards.
- **Flooding:** Flooding is the temporary condition of partial or complete inundation of normally dry land [192]. Flash flooding is usually a result of heavy localized precipitation falling in a short time period. Post-wildfire landscapes may be especially susceptible to flash flooding due to changes in soil chemistry (Figure 3.46).

- **High Winds:** Damaging winds exceeding 50-60 miles per hour can occur during tornadoes, severe thunderstorms, winter storms, or coastal storms [193]. These winds can have severe impacts on buildings, pulling off the roof covering, roof deck, or wall siding and pushing or pulling off the windows [194].

- **Secondary Hazard:** Secondary hazard events are triggered by a primary hazard event and may extend the impacts of the initial hazard event. Secondary hazards can occur immediately following the initial event or up to a few years following an event. Depending on specifics, such as extent and timing, secondary hazards may extend losses and damages, complicate the recovery process, and/or introduce new challenges.

Fire Test Standards

None identified at time of publication.

Referenced Codes and Standards

Planning codes and standards will vary depending on location and adoption in individual jurisdictions.

- Check local, county, and state amendments for any additional requirements.
- Check local general plan, multi-hazard mitigation plan, or zoning documents for any additional requirements.
- International Residential Code (if applicable - check for wildfire amendments).
- Refer to local Multi-Hazard Mitigation Plan for tailored guidance.

Typical Design, Vulnerability, and Mitigation Considerations

Table 49. Typical multi-hazard challenges and their potential mitigations.

Typical Challenges	Vulnerability	Potential Mitigations
Drought	• Drought has been shown to interact often with other factors, (e.g., vegetation density and condition, topography, fire weather, management activities) to affect fire intensity, severity, extent, and frequency [195]. When drought occurs, both live and dead vegetation can dry out and become more flammable, increasing the probability of ignition and the rate a fire can spread.	• Vegetation management planning inside developments should consider and account for potential droughts. Where a development is adjacent to unmanaged vegetated areas, additional separation distances or other mitigations should be undertaken.
High Winds	• High winds influence wildfire behavior, spread embers, and breach building envelopes (via both wind-carried debris & wind gusts), and can dry out vegetation quickly.	• Consider high winds when making construction and building maintenance decisions (e.g., roof material, installation and maintenance).

Extreme Heat	• Extreme heat can exacerbate drought conditions, lower soil and live fuel moisture, and reduce natural water sources, which impact likelihood of wildfire ignition and spread, as well as reduce available firefighting resources. • Additionally, extreme heat increases the vulnerability of people exposed to it. Public Safety Power Shutoffs (PSPS), which may occur during extreme heat and high wind conditions, to reduce the likelihood of wildfire ignition, can increase the impacts of heat on socially vulnerable individuals particularly those already at risk due to health concerns or older age.	• Designate public cooling areas and explore the use of microgrids or other alternative power systems. Incorporate consideration of extreme heat conditions in emergency management planning. • Emergency power sources can mitigate the impacts of a PSPS, but the fuel source for emergency power must be independent of a potential shutoff as well.
Flood, Landslide & Debris Flow	• Floods, landslides, and/or debris flows are one of the most common post-wildfire secondary hazards. Because of vegetation removal and impacts on soil chemistry, wildfire can significantly impact the hydrologic response of a watershed (USGS). When rainfall occurs following a wildfire, landslides and debris flows can further impact communities and individuals within the burn scar.	• Incorporate debris flow mitigation techniques in wildfire preparations and planning. • Incorporate erosion control post-wildfire as part of revegetation. This may include ground roughening, native species, mulching, erosion control mats. • Erect erosion barriers - contour log felling/log erosion barrier, silt fences, fiber rolls/straw wattles. • Undertake channel treatments - control water and sediment movement in channels to reduce flood/landslide risks, diversion, dams, stream bank armoring, debris dams/basins. • Implement slope stabilization and erosion control - prioritize efforts on slopes of recharge areas for streams that lead to developed areas or impact water supply.

General Mitigation Strategies

- While planning new developments, evaluating existing developments, and/or undertaking emergency management planning related to wildfire, incorporate consideration of multi-hazard and secondary hazard concerns. Additional or more involved mitigations may be appropriate to reduce likelihood and impacts of multiple hazards.

- Where possible, locate development away from hazardous vegetation and high hazard topographies (avoidance).

- Where secondary hazards are a concern, increase setbacks from hazardous vegetation and treat fuels.

- Expanding existing local ordinances for water conservation to include fire protection requirements can help align multiple landscaping objectives, such as water conservation and management of hazardous vegetation for fire risk reduction.

- When designing hazardous fuel mitigations, consider not only current conditions, but potential future conditions (e.g., under drought, long term climate change) and adjust plans accordingly, as appropriate. Where in areas of drought or subject to especially high winds, consider going beyond minimum requirements.

Training Programs

- Federal Emergency Management Agency (FEMA) Emergency Management Institute (EMI):
  - IS-362.A: Multi-Hazard Emergency Planning for Schools https://training.fema.gov/is/courseoverview.aspx?code=is-362.a&lang=en and https://training.fema.gov/programs/emischool/el361toolkit/siteindex.htm
- American Planning Association (APA) Hazard Mitigation & Disaster Recovery Planning Division: https://hazards.planning.org/

Gaps in Knowledge

- Where hazard-specific codes and standards exist, they are typically focused on a single hazard and do not consider multiple hazards. Location-specific hazard analysis to understand what hazards are relevant and how they are likely to interact for a neighborhood or community can help determine appropriate planning and mitigations in the absence of local guidance or requirements.
- How different hazards interact will continue to evolve over time with climate change impacts. How these interactions are likely to change is not well understood. Any local planning should consider future changes as well as the current state conditions.

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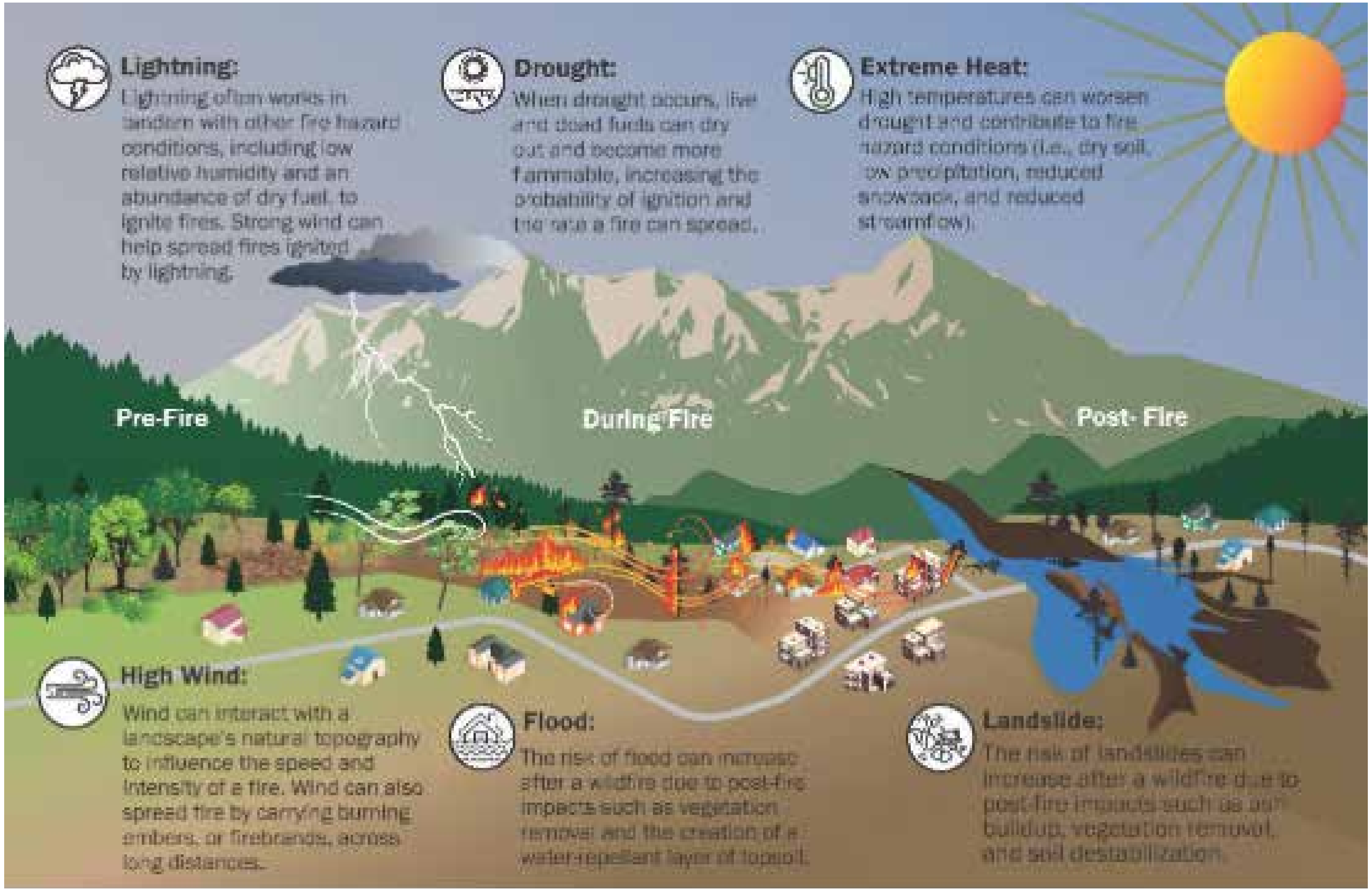

Figure 3.45. Hazards that may interact, influence, or be influenced by wildfires and wildfire hazard. Image adapted from FEMA Marshall Fire MAT, Best Practices for Wildfire Resilient Subdivision Planning, FEMA, 2023. https://www.fema.gov/

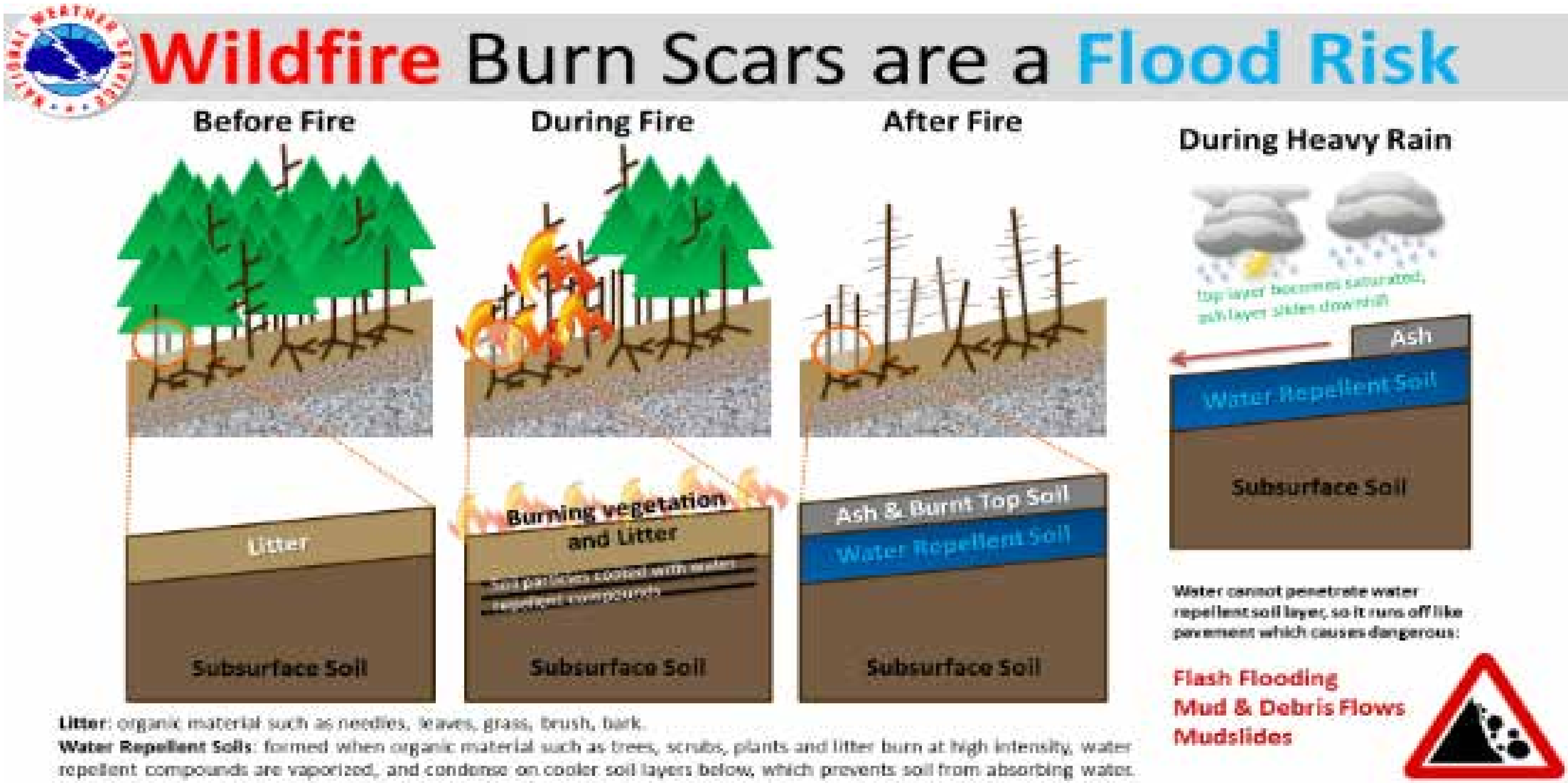

Figure 3.46. Areas previously impacted by wildfire are at heightened risk of flooding and/or debris flows. Image courtesy of National Weather Service. https://www.weather.gov/

3.6.2 INDUSTRIAL AND HAZARDOUS LAND USES

Main Concern(s)

Under certain conditions, hazardous and industrial land uses (e.g, power plants, lumberyards, sawmills, warehouses with hazardous materials, outdoor shooting ranges, photovoltaic (PV) farms) can be sources of ignition, increase fire behavior, or prompt other environmental threats if they burn [196]. These land uses may require additional review and conditions prior to their approval to ensure appropriate mitigation occurs as part of their siting process and long-term maintenance [109].

Key Terminology

- **Hazardous Land Use:** A land use that presents a significantly elevated potential for the ignition, prolonged duration, or increased intensity of a wildfire due to the presence of flammable materials, liquids, or gasses, or other features that initiate or sustain combustion, such as power-generation and distribution facilities; wood processing or storage sites; flammable gas or liquids processing or storage sites; or shooting range [164].

- **Industrial Land Use:** A land use that allows for the manufacturing, packaging, or storage of industrial products, e.g., factories, power plants, warehouses, storage facilities, etc. [132].

Fire Test Standards

None identified at time of publication.

Referenced Codes and Standards

Planning codes and standards will vary depending on location and adoption in individual jurisdictions.

- Check local, county, and state amendments for any additional requirements.
- Check local general plan, multi-hazard mitigation plan, or zoning documents for any additional requirements.

Examples of Building Codes and Standards:

- *IWUIC 202* - Appendix A: General Requirements, Section A104A, Ignition Source Control
  - ***Note:*** *For jurisdictions where the 2024 IWUIC is adopted, requirements contained in Appendix A do not apply unless specifically adopted.*
- Check local, county, and state codes and regulations for any additional requirements.

Typical Design, Vulnerability, and Mitigation Considerations

Table 50. Typical challenges of industrial and hazardous land use and their vulnerabilities and potential mitigations.

Typical Challenges	Vulnerability	Potential Mitigations
Hazardous and Industrial Land Uses	• Hazardous land uses may pose additional threats to nearby residential neighborhoods or other development by serving as a potential source of ignition for a wildfire (e.g., outdoor shooting range), prolonging the duration or intensity of a wildfire (e.g., such as when a wildfire is burning a sawmill), serving as a source for increased production of embers (lumberyard), or exposing emergency responders to additional dangers making response and suppression difficult [136]. Other hazardous land uses may include incinerators, outdoor fireplaces, permanent barbecues and grills.	• Locate hazardous land uses away from residential uses to minimize risk of increased exposure [136]. Minimum distances should be established in consultation with the local fire authority. • Require additional mitigation measures for any land uses that could potentially exacerbate risk (e.g., storage of combustible materials, fuel storage facilities) and which cannot be restricted [109]. Mitigations may include increasing setbacks and defensible space areas, including additional construction provisions, managing hazardous vegetation in and near the site, requiring secondary emergency water supplies and emergency power, or increasing exterior wall fire resistance rating (e.g., 1-hour to 2-hour) [130], [136]. Where the exterior wall is rated, the openings (i.e., vents, windows, etc.), under eave, and projections should also be protected.

General Mitigation Strategies

- Ensure local land management planning addresses hazardous and industrial land uses that may potentially ignite a wildfire, prolong its duration, or increase its intensity [136]. This process should include identifying and locating future industrial and hazardous land uses away from residential land uses and other areas to reduce risk to people and property in the event of a wildfire ignition or occurrence.

- Apply mitigation measures to existing and future hazardous and industrial land uses, which may include construction provisions, setbacks or separations from other land uses, fire protection, hazard management (including vegetation management) plans, or other conditions [136].

- For residential areas in proximity to hazardous and industrial land uses, encourage or require additional mitigation measures (as identified in this handbook) to reduce potential exposure from embers and fire exposures.

Training Progrmas

None identified at time of publication.

Gaps in Knowledge

There is limited information about the impacts of wildland fires on industrial or hazardous land uses and potential risk mitigations.

Other References

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3.6.3 VULNERABLE LAND USES, TEMPORARY LAND USES

Main Concern(s)

Other land uses may require additional considerations either during the planning and approval phases of the proposed activity or during ongoing maintenance. These include vulnerable land uses, temporary land uses, or other land uses where there is the potential for vulnerable populations, large groups or gatherings of people, or other conditions to occur during a wildfire event that require special consideration for fire protection response and the safe movement or sheltering of people [109].

Key Terminology

- **Vulnerable Land Use:** Types of land use occupied by vulnerable populations (e.g., schools, hospitals, care homes) [136].
- **Temporary Land Use:** Types of land use that are seasonal or transient in nature (outdoor festivals, farm stand, holiday tree farms) [197].

Fire Test Standards

None identified at time of publication.

Referenced Codes and Standards

Requirements for temporary and vulnerable land uses are tied to applicable state and local government regulations. Consult local regulations (development codes, subdivision regulations, zoning ordinances) to determine if your jurisdiction has adopted requirements and whether there are any specified conditions of approval in place.

- *IWUIC 2024* Appendix A: General Requirements, Section A104A—Ignition Source Ignition Source Control
  - ***Note:*** *For jurisdictions where the 2024 IWUIC is adopted, requirements contained in Appendix A do not apply unless specifically adopted.*

Typical Design, Vulnerability, and Mitigation Considerations

Table 51. Typical challenges of temporary, vulnerable, and special land uses, and their vulnerabilities and potential mitigations.

Typical Challenges	Vulnerability	Potential Mitigations
Temporary Land Uses	• Some temporary land uses may be hazardous if they are a potential ignition source, such as fireworks stands, fireworks display or other temporary displays. • Some temporary land uses may allow large groups of people or outdoor mass gatherings, such as festivals and outdoor concerts. When these gatherings occur in high hazard locations, it is important to consider the potential risk during a wildfire event.	• Assess temporary land uses (e.g., for fireworks, outdoor mass gatherings) to determine their potential hazard and exposure level based on their proposed location, type of activity, number of persons, and other factors, and recommend appropriate mitigation measures as a condition of approval [136]. • Require temporary festival areas or similar venues to maintain on-site fire protection equipment.
Vulnerable Land Uses	• Vulnerable land uses such as nursing homes, critical care facilities, hospitals, centers for persons with disabilities and similar land uses require additional evaluation and consideration for how the population and associated structure(s) will be affected during a wildfire emergency. For example, dependency on power or water supply for medical needs and limited mobility should be considered under a wildfire scenario.	• When siting new development, locate vulnerable land uses outside of high wildfire hazard areas. • If siting within a wildfire hazard area is unavoidable (or for existing uses), assess vulnerable land uses for how the population may be impacted and implement additional measures, which may include: an enhanced evacuation plan, options to shelter in place or provide a temporary area of refuge, provide backup power supply requirements (with independent fuel source that cannot be turned off as a result of wildfire risk), additional access and water supply requirements, increased fuel modification and structure hardening, or changes to the occupancy or use of the facility if sufficient mitigation cannot be achieved. • Consider additional conditions and mitigations when land use planning decisions may place populations with access and functional needs, such as farm workers, non-English speaking, and limited mobility, at additional risk to wildfire.
Special Uses	• Some special uses may be hazardous if they are a potential ignition source, such as campgrounds where outdoor burning activities may occur, or where a wildland fire may be a threat to the area.	• Require campgrounds to manage hazardous vegetation and maintain an emergency response plan to be approved by a local fire authority [198]. • Enforce seasonal or drought condition open-air burn bans to prevent wildland fire ignitions. • Require additional development review and approval for special uses in wildfire hazard areas for special uses when the presence of large animals or livestock may require additional planning considerations during an evacuation.

General Mitigation Strategies

- Apply special standards and conditions to specific uses when additional mitigation for wildfire is required and achievable.

Training Programs

None identified at time of publication.

Gaps in Knowledge

There is limited research or analysis of human behavior or evacuation of populations from schools, healthcare or medical facilities, or other vulnerable land uses during a wildfire event.

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EXAMPLES OF NEIGHBORHOOD- AND COMMMUNITY-SCALE PROGRAMS

NEIGHBORHOOD AND COMMUNITY-SCALE

3.7.1 NATIONWIDE, STATE, AND LOCAL PROGRAMS

Examples of Neighborhood- and Community-Scale Programs

Social science research indicates that an effective way to engage homeowners in mitigating wildfire risk on their properties is through interactive methods, including on-site learning opportunities [11], [12]. To advance this mitigation strategy, several federal, state, and local level programs exist to assist property-owners, neighborhoods, and communities in mitigating wildfire risks. The following are examples of nationwide, state, and local programs.

National and State Programs - A number of formal programs encourage communities to engage in community education and risk mitigation.

- **Ready-Set-Go -** Ready? Set? Go! is a public education program/campaign for wildfire awareness that is managed by the International Association of Fire Chiefs (IAFC), used by CAL FIRE and adopted by local jurisdictions to provide citizens with critical information on creating defensible space around their home, retrofitting their home with fire-resistant materials, preparing to safely evacuate well ahead of a wildfire, and taking the evacuation steps necessary to give citizens the best chance of surviving a wildfire. Learn more at
  - IAFC website: https://www.iafc.org/topics-and-tools/resources/resource/ready-set-go-program
  - CAL FIRE website: https://readyforwildfire.org/Prepare-For-Wildfire/

- **Fire Adapted Communities Learning Network (FAC Net)** - FAC Net is the result of a partnership between the Watershed Research and Training Center, The Nature Conservancy, the USDA Forest Service, and the Department of the Interior. This is a national network of wildfire resilience practitioners focused on building wildfire resilience capacity in fire-prone communities by supporting and connecting individuals and communities working on wildfire resilience. FAC Net provides resources, tools, and connections to increase resilience in "Fire Adapted Communities." Learn more at https://fireadaptednetwork.org/

FIRE ADAPTED COMMUNITIES LEARNING NETWORK

- **Community Planning Assistance for Wildfires (CPAW)** - The Community Planning Assistance for Wildfire (CPAW) program works with communities across the United States to reduce wildfire risk through improved land use planning. CPAW provides communities with multi-disciplinary teams, which include land use planners, foresters, researchers, and policy analysts. Teams collaborate with communities to develop site-specific planning recommendations. All services provided through CPAW are grant funded and come at no cost to the community. Communities are selected through a competitive grant process and generally receive assistance over the course of one year. Participation in the program is voluntary and must be requested by local governments. Learn more at https://cpaw.headwaterseconomics.org/

- **Fire Safe Councils (CA)** - Fire safe councils (FSCs) are grassroots, community-based organizations in California with the objective of making communities less vulnerable to catastrophic wildfire. Fire safe councils work towards this goal through education programs and mitigation projects such as fuel breaks, chipper days, home assessments, etc.

FSCs usually include representatives from: Fire agencies, including federal (U.S. Forest Service, Bureau of Land Management), state (CAL FIRE), and/or local fire protection districts

- City and/or county government
- Businesses, especially insurance
- Other agencies, such as Resource Conservation Districts
- Members of the public

All FSCs are independent entities. Some are organized as non-profit 501(c)(3) corporations, while others operate under a memorandum of understanding with a county, city, and/or local fire protection district, and some have no formal structure at all. FSCs also vary in scope. The area of interest for fire safe councils ranges from the Homeowner's Association of a subdivision up to county-wide. Additionally, in some areas, several FSCs have joined together in regional association. While some FSCs have paid staff, such as an Executive Director, and may have grant funding for fuel reduction projects, all FSCs rely heavily on volunteers for much of their work. Learn more at https://cafiresafecouncil.org/

- **FireSafe Montana** - FireSafe Montana is a private, non-profit organization coordinating and supporting a statewide coalition of diverse interests working together to help Montanans make their homes, neighborhoods, and communities fire safe. This program assists in the development of local Fire Safe Councils across the state. These councils are key to raising public awareness of local wildland fire threats and issues, motivating residents to take positive action, and providing access to the expertise and resources homeowners need to get the job done. FireSafe Montana also provides public information programs and materials, a website, a newsletter, and special events, as well as its active involvement in federal, state, and local fire mitigation efforts. Learn more at https://firesafemt.org/

- **Fire Risk Reduction Community List (FRRCL)** - The list is maintained by the California Board of Forestry and Fire Protection and updated every two years. It is "a list of local agencies located in a state responsibility area or a very high fire hazard severity zone...that meet best practices for local fire planning." Communities on the Fire Risk Reduction Community List are prioritized for California's Wildfire Prevention Grants and home and business owners in FRRCL communities receive insurance discounts. Learn more at https://bof.fire.ca.gov/projects-and-programs/fire-risk-reduction-community-list/

Local Community Programs - Numerous local level governments and/or civil society groups create local voluntary programs to help support wildfire regulations, community awareness and education, grass-roots wildfire resilience assessments, and home hardening workshops, brush clearing programs, etc. The following is a sample list of local community programs and/or community groups that provide bottom-up wildfire resilience initiatives.

- **Wildfire Partners, Boulder County Colorado** - Since 2014, Boulder County has administered its Wildfire Partners program. The program trains wildfire mitigation specialists to identify local vulnerabilities on structures, landscaping, and other property features. Mitigation specialists conduct one-on-one assessments with homeowners to advise them on mitigation actions and provide them with a customized report. Once all required mitigation is achieved by the homeowner, a specialist will inspect the property and issue a certificate. Certificates have successfully been used by some homeowners to obtain insurance coverage.

WILDFIRE PARTNERS

Other communities in Colorado, including Eagle County, Larimer County, and fire protection districts in Jefferson County, have also adopted a similar program to successfully conduct local assessments. These performance-based assessment programs provide flexibility to mitigate conditions specific to each home ignition zone and leverage personal interactions to change long-term outcomes. They also incorporate technology to track changes at the parcel scale, enabling a measurable approach to risk reduction. Learn more at

- Boulder County Wildfire Partners Program: https://wildfirepartners.org/
- Eagle County REALFire Program: https://realfire.net/
- Larimer County Wildfire Partner Program: https://www.larimer.gov/wpp
- Elk Creek Wildfire Prepared Program: https://www.wildfireprepared.com

- **Greater Flagstaff Forest Partnership (GFFP), Flagstaff, Arizona** - This program was formed as a collaborative effort to enhance community awareness on issues related to forest health and wildfire impacts. Learn more at https://gffp.org/

- **Ventura County Wildfire Collaborative (VCWC), Ventura County, CA** - A community-driven collaborative comprised of the Ventura County Resource Conservative District, Ventura County Fire Department, four Fire Safe Councils (Ojai Valley, Ventura Regional, Bell Canyon, Oak Park), industry and academic partners that work together to coordinate resources, advise local and state agencies, work with the community, and secure funding to help prevent, prepare for, respond to, and recover from wildfires. Learn more at https://vcrcd.org/vcwc/

- **Community Wildfire Planning Center (CWPC), Littleton, CO** - CWPC is a national non-profit organization that provides WUI planning expertise, resources, trainings, tools, and technical assistance to help communities reduce wildfire risk. CWPC works with federal, state, and local government agencies, including fire and planning departments, as well as non-profit organizations and others. Resources include its "WUI Planning Hub" which offers a collection of state and national resources related to land use planning across the U.S., such as links to the California WUI Planning Guide, Community Wildfire Protection Plan Toolkit, resources from the American Planning Association, and more. Learn more at https://www.communitywildfire.org/

- **Marin Wildfire Prevention Authority, Marin County, CA** - This community-based organization in Northern California leads the development of fire adapted communities based on priorities set in their Community Wildfire Protection Plan (CWPP), including vegetation management; detection, alert and evacuation; grants; public outreach and education; and defensible space and home hardening. The organization's efforts are supported and funded by Marin Couty voters through Measure C (passed in 2020), which provides a tax-based fund for the next 10 years to "plan, finance, implement, manage, own, and operate a multi-jurisdictional agency to prevent and mitigate wildfires in Marin County." Learn more at https://www.marinwildfire.org/

MARIN WILDFIRE PREVENTION AUTHORITY

- **Homeowners and Road Associations** - Various neighborhood groups develop local community education programs, home ignition zone assessments, neighborhood wood chipping events, and other neighborhood-level wildfire resilience initiatives.

    - An example of an HOA's neighborhood-scale vegetation management is in Incline Village, Nevada. The Incline Fire Smart Community Pilot in the Tyrolian Village Homeowner Association neighborhood of 60 acres and 228 homes, analyzed the baseline risk and treatments requirements at both the parcel and community level using computer models. Targeted fuel reduction treatments began on 35 acres to supplement previous mitigation efforts (tree thinning) by the HOA and parcel-level efforts. Post-treatment analysis quantifies how risk was reduced by vegetation treatment. The HOA committed to long-term mitigation and maintenance, intending to develop a shareable model for other WUI communities [199].

Research Organizations - Several organizations are involved in research and analysis at the national, state, or local level to improve our understanding of the community-level impact of WUI fires. A few examples of their community risk mitigation projects are highlighted below as suggestions for further reading:

- **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)** - These entities collaborated on a *Hazard Mitigation Methodology (HMM)* [200]. The HMM builds on the WUI case studies NIST conducted over the previous decade, as well as the extensive fire research conducted by NIST and IBHS regarding structure separation distance and fire spread. The foundational document of the HMM defines seven WUI types based on structure separation distance, typical parcel size, housing density (in structures per acre), WUI type (interface vs intermix), and distance to the wildland (perimeter vs interior of the community). Though the HMM was developed for existing communities to evaluate parcel layouts, housing density, and separation distances to identify potential for fire and ember spread, it can also be used by communities under development [20]. The goal of the HMM is for communities to identify opportunities to mitigate risks associated with fire spread from property-to-property and structure-to-structure. Learn more at https://www.nist.gov/el/fire-research-division-73300/resources/hazard-mitigation-methodology-hmm

- **National Institute of Standards and Technology (NIST)** - Over the past two decades, NIST has conducted a number of case studies of WUI fires in California, Texas, and Colorado. The most significant case study effort to date is a multi-report analysis of the 2018 Camp Fire in Paradise, California [201], [202]. The observations and lessons learned from the various case studies resulted in additional community engagement and education tools:
  - *WUI Fire Hazard Evaluation Framework*. The *WUI Fire Hazard Evaluation Framework* intends to assist communities in identifying hazards unique to their area by collecting and analyzing information on population, notification and evacuation, community infrastructure, and firefighting response resources and capabilities. Some of the required information for the Framework is similar to that collected for Community Wildfire Protection Plans (CWPPs) and addressed in this handbook, but the Framework allows community comparisons to identify strengths and areas with room for improvement. The *WUI Fire Hazard Evaluation Framework* suggests that some of the collected data could be incorporated into in-vehicle mobile data systems for first responders to use during a wildland event [202]. Learn more at https://doi.org/10.6028/NIST.TN.2135sup
  - *Evacuation and Sheltering Considerations - Assessment, Planning, and Execution (ESCAPE)* [204]. Using the evacuation lessons learned, NIST developed a 3-hour ESCAPE online educational course, combining the science of WUI fires, discussion of evacuation options, community assessment, and implementation resources. The ESCAPE education tool is available at https://escape.nist.gov/

- **Insurance Institute for Business & Home Safety (IBHS)** - Based on its own fire research and work with other organizations, IBHS developed a *Wildfire Prepared Neighborhood Standard*. The document focuses on neighborhood areas which are at risk due to ember, flame, and radiant heat (neighborhood flame zone), areas at risk due to ember exposure (neighborhood ember zone), and the combustible fuels (vegetation, fences, sheds, etc.) that are pathways for fire spread within the neighborhood. The mitigation requirements address each area's fire risks [205]. Housing developments can be designated as meeting IBHS's *Wildfire Prepared Neighborhood Standard*, which also incorporate IBHS's *Wildfire Prepared Homes* program [206], [207], [208]. Learn more at https://wildfireprepared.org/wp-content/uploads/Wildfire-Prepared-Neighborhood-Standard-2025.pdf

Parcel-Scale Wildland Fire Assessment Checklist

This checklist is a supplemental tool for Fire Departments performing parcel-level WUI risk assessments. To share the results, use the 'Send' button to email the checklist to a recipient. You may add notes to individual questions for context—these will appear in the email. To include images, add them directly to the email before sending.

1. Is the roof covering of Class A material (e.g., cement, slate shingles, clay tiles)?

   ☐ **Yes** ☐ **No** ☐ **Can't determine**

   For more information, see Roof Coverings Handbook Section.

2. Are gutters noncombustible and have gutter guards? Is there any debris accumulation?

   ☐ **Yes** ☐ **No** ☐ **Can't determine**

   For more information, see Gutters Handbook Section.

3. Is the exterior cladding of noncombustible materials?

   ☐ **Yes** ☐ **No** ☐ **Can't determine**

   For more information, see Exterior Wall Covering Handbook Section.

4. Are all vents (i.e., roof vents, soffit vents, inlets/outlets, crawlspace vents) screened and of noncombustible, non-corrosive materials?

   ☐ **Yes** ☐ **No** ☐ **Can't determine**

   For more information, see Roof Vents, Soffit or Under-Eave Vents, Crawl Space / Basement Vents Handbook Sections.

5. Do windows have tempered or double-pane glazing systems?

   ☐ **Yes** ☐ **No** ☐ **Can't determine**

   For more information, see Windows Handbook Section.

6. Are non-structural attachments (i.e., decks, balconies, porches) of noncombustible construction?

   ☐ **Yes** ☐ **No** ☐ **Can't determine**

   For more information, see Architectural Embellishments and Attachments Handbook Section.

7. Does the exterior envelope of the home contain any unprotected gaps at joints and interfaces?

   A. Are there any gaps at the roof edge, wall-to-roof interfaces, or at roof ridges and valleys?

   ☐ **Yes** ☐ **No** ☐ **Can't determine**

   For more information, see Roof Joints & Wall Joints Handbook Sections.

   B. Are there any gaps at window-to-wall, door-to-wall, garage door-to-wall, or wall-to-wall interfaces?

   ☐ **Yes** ☐ **No** ☐ **Can't determine**

   For more information, see Window/Door Joints Handbook Section.

   C. Is there 6" of noncombustible materials at bottom-of-wall (to roof & foundation) joints?

   ☐ **Yes** ☐ **No** ☐ **Can't determine**

   For more information, see Wall Joints Handbook Section.

   D. Are there gaps at the bottom-of-wall joints, particular at the interface of the exterior wall cladding and the foundation?

   ☐ **Yes** ☐ **No** ☐ **Can't determine**

   For more information, see Wall Joints Handbook Section.

8. Is there combustible fencing attached to or within 5 ft of the structure?

   ☐ **Yes** ☐ **No** ☐ **Can't determine**

   For more information, see Fencing Handbook Section.

9. Are combustibles present in Zone 0 (0-5 ft. from structure)?

   ☐ **Yes** ☐ **No** ☐ **Can't determine**

   For more information, see Zones, Spacing, and Landscape Design Handbook Section.

10. Are there community-level hazards present (i.e., limited access/egress, limited firefighting water supplies)?

    ☐ **Yes** ☐ **No** ☐ **Can't determine**

    For more information, see Part 3 of the Handbook.

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