Pathways to Fire Spread in the Wildland Urban Interface (WUI)

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Presented by:
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• Wildland-Urban Interface Problem
• Exposure Conditions
  — *Firebrands, radiant heating, direct flame contact*
• Response of Components and Systems
  — *Roofing, gutters, eaves, fences, etc.*
• Mitigation Strategies
  — *Codes and standards, zone concept, risk mapping.*
• Gap Analysis
  — *Future recommendations*
Cocos Fire, San Marcos, CA 2014

WILDLAND-URBAN INTERFACE PROBLEM
Why Big, Intense Wildfires Are the New Normal

Climate change, untamed vegetation, and development have created a new wildfire landscape.
WUI Disaster Sequence

**Conditions**

- Severe wildfire potential
- Extreme fuels, weather, & topography

**Consequence**

- Fighting resources overwhelmed by wildfire & igniting homes

**Extreme burning conditions**

- High intensities & growth rates

**Residential fires**

- Highly ignitable homes, numerous ignitions

- Given ignitions
- Given homes

While the number of wildfires is somewhat steady (solid blue), the size and intensity of these fires (dashed black) is drastically increasing. (Right) Federal firefighting costs are similarly increasing.

National Interagency Fire Center. www.nifc.gov/nicc
Structures Lost to Wildfire (1999-2011)

Compiled and mapped by the Fire Modeling Institute; Fire, Fuel, and Smoke Program; Rocky Mountain Research Station; Missoula, MT; 4/5/2012

National Interagency Fire Center. www.nifc.gov/nicc
What causes a home to ignite during a WUI fire?

EXPOSURE CONDITIONS

Destroyed neighborhood after 2007 San Diego Wildfires
Photo by Sandy Huffaker / Getty Images
1. **Radiation**
   
   – Originally thought to be responsible for most/all ignitions

![Diagram showing radiation, height of flames, and separation distance.](image-url)
Panels 40 m (130 ft) away could not ignite, even from the most intense fires.

If fuels are cleared away from a structure, it is very difficult to ignite by radiation!

- Panels 40 m (130 ft) away could not ignite, even from the most intense fires.

3 Exposure Conditions

1. Radiation
   – Originally thought to be responsible for most/all ignitions

2. Direct Flame Contact
   – Smaller flames from nearby sources ignite portions of home
Direct Flame Contact

• Flames must directly contact long enough to cause ignition

• Typically, does not occur from the main fire front
  – Unless extreme conditions present
  – Often secondary source: nearby burning material (mulch, wood pile, etc.)

• Traditional wildfire literature describes flame lengths and ROS of vegetative fuels under various ambient conditions

• Existing fire models cannot determine effectiveness or size of a needed fuel break.

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2. **Direct Flame Contact**
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3. **Embers or Firebrands**
   - Small burning pieces which ignite a structure or nearby fuels
3 Exposure Conditions

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Firebrands
• Least understood of ignition pathways

• Typically broken into 3 processes
  – Production/Generation
  – Lofting/Transport
    • In 2007 NIST study in San Diego, firebrands arrived 1 hour before arrival of the flame front
    • Travelled up to 9 km igniting properties over the following 9 hours.
  – Ignition/Deposition

• Of the three, Production and Ignition are least understood

Maranghides, A., McNamara, D., Mell, W., Trook, J., Toman, B., 2013. A case study of a community affected by the Witch and Guejito fires: report #2
Firebrand Reproduction for Testing

A typical experiment with the NIST Dragon in BRI’s FRWTF

“Ember storm” produced in the IBHS research facility

Vinyl gutters and mulch and debris ignite and burn at a test in the IBHS research center.

RESPONSE OF COMPONENTS AND SYSTEMS
• Often most susceptible component to firebrand attack
  – 1990 Santa Barbara Paint fire, 70% of houses with nonflammable roofs survived, 19% with flammable roofs survived.
  – 2007 San Diego Wildfires, 100% of exposed wood shake destroyed, 24% of exposed Spanish tile roofs destroyed (in studied community)
• Fire Ratings on Roofs
  – ASTM E-108, UL 790, NFPA 276
  – Evaluates resistance to spread into attic, spread onto roof covering, generating burning firebrands
  – Class A,B,C
  – “Brand” test may not be appropriate – no accumulation

Maranghides, A., McNamara, D., Mell, W., Trook, J., Toman, B., 2013. A case study of a community affected by the Witch and Guejito fires : report #2
• Even Class A roofs found to ignite (Manzello et al.)
  – “Brand” test may not be appropriate – no accumulation

  – Tile roofs
    • With tar paper and bird stops removed – OSB would ignite
    • Smoldering sometimes occurred with proper bird stop/tar paper installation
    • If needles and leaves are deposited under the tiles, ceramic tile roofing assemblies were ignitable under all conditions considered
    • Flat tile terracotta roofing assembly performed best (interlocking design)

  – Asphalt roof
    • Assemblies (OSB, tar paper, and asphalt shingles) failed to ignited under firebrand exposure in 60° and 90° valleys
    • Asphalt shingles did melt, but no ignition was observed

  – A potential cost-effective mitigation strategy would be to use a continuous underlayment of firebrand-resistant sarking

Debris collected in gutters can be ignited by firebrands
   – Thought to be a significant cause of ignitions in the Grass Valley Fire
PVC gutter tests showed ignition & melting of gutter, but only smoldering of asphalt roof assembly
   – Pine needles placed in gutter as litter
IBHS large-scale tests of gutter ignitions
   – Vinyl gutter caught fire with litter inside, but gutter melted off after ignition
   – Metal gutter: house caught fire through flame contact to fascia and roof sheathing

**Must find ways to keep litter off roof/gutter**

*IBHS, [http://www.disastersafety.org](http://www.disastersafety.org).*
• Mulch, woody vegetation, wood piles and other flammable debris should not be stored near a structure
  – Ignite by direct flame contact or firebrands and ignite the home

• Mulch Ignition & Flaming Tests
  – Manzello et al. (2006b) mulches including shredded hardwood, pine straw and dried cut grass.
    • Ignition dependent on **number or flux of brands** (one insufficient)
  – Steward (2003) tested 13 different mulches
    • When igniting with a torch, all mulches eventually ignited, but with ground rubber and pine needles igniting significantly faster than other mulches.
  – Quarles and Smith (2004) measured some relative flammability properties for 8 mulches in 8 foot (2.5 m) diameter plots
    • Except for composted wood chips, all exhibited flaming combustion

Eaves and Vents

- Eaves and vents have been recognized to be significant sources of ignition for homes in the WUI.
- Most homes have these vents both for thermal efficiency and to minimize the chance of moisture buildup.

It is common to have at least one outlet vent type:
- Gable
- Ridge
- Soffit

A schematic of vents used to ventilate an attic space

www.finehombuilding.com
Mesh Sizes

- Reducing mesh size - primary strategy to reduce ignitions
- Firebrands still don’t quench with mesh
  - Continues to burn until it passes through opening
  - Even as small as 1 mm
  - Smaller mesh reduces prob. of ignition
  - Larger mesh sizes ignite more quickly
- Eave vents had less accumulation than gable or foundation vents in NIST Dragon
  - Horizontal vent created recirculating flow that did not carry firebrands as well

*Firebrand penetration ratio as a function of mesh opening size*

Ember Penetration Test

• New standard: ASTM E2886, Standard Test Method for Evaluating the Ability of Exterior Vents to Resist the Entry of Embers and Direct Flame Impingement

• Ember exclusion/intrusion test and a flame intrusion test

• Different than previous tests performed with NIST Dragon
  – Embers fall through vertical shaft and through a vent onto a cotton target
  – Considered a worst-case scenario, therefore used in test standard
  – Compared to NIST Dragon tests performed horizontally in a large-scale fire wind tunnel

In investigation of the 2007 Witch Creek and Guejito fires, 45% of homes with attached wood fences were destroyed

- Wooden trellises and other yard structures were also burned
- Post-fire studies on the Waldo Canyon Fire in Colorado determined wood fences were vulnerable to ignition from firebrand showers

No experimental verification of this ignition mechanism

NIST is currently performing research on this topic

Obvious to keep all flammable materials away from home

- *Separation distances required needs research*

Maranghides, A., McNamara, D., Mell, W., Trook, J., Toman, B., 2013. NIST report #2
Decks, Porches and Patios

• Decks significant source of ignition in 2007 San Diego Fires
  – Wooded slopes with overhanging decks created a large hazard
  – Combustibles under deck major hazard
    • Direct flame impingement from small surface fire observed
    • Angora fire: surroundings had small or no fire, but decks ignited homes

• Deck material tested for flame spread properties and ignition potential from direct flame contact, but not firebrands or the potential radiant energy production from the deck to ignite the adjacent structure

• Manzello and Suzuki tested deck sections in re-entrant corner

• Decks need better national tests (CA has CBC 12-7A-4)

Mell, W., Maranghides, A., 2009. NIST Technical Note 1635
Sidings, Windows and Glazing

- Ignition of materials on exterior walls major concern
  - Siding often ignites due to direct flame contact or radiant heat
- Under wind-driven conditions, **re-entrant corners** lead to the formation of a small recirculation zone which can attach the flame close to a wall (essentially mimicking a fire whirl) and lead to a higher vulnerability to ignition.
- Siding treatments have been studied using NIST Dragon
  - Vinyl siding: firebrands melted through siding
  - Polypropylene siding: melted, did not ignite
  - In actual wildfire: winds can be above 20 m/s
  - Test illustrates potential hazards

*Wildfire Home Assessment and Checklist. http://www.disastersafety.org*


Sidings, Windows and Glazing

- Firebrand accumulation around glazing assemblies possible mechanism for window breakage
  - Contributor to fire penetration into a structure?
  - Embers could accumulate in the framing of a double hung assembly, more so in a vertical wall assembly, but none sustained sufficient damage to break the glass or penetrate the structure
- Windows tested for radiant exposure
  - Glass is the most vulnerable part of a window
    - Dual-pane tempered glass did not fail even with a 25 min exposure 35kW/m²
    - Conclusion supports code, such as NFPA 1144 5.7.2 which requires the use of tempered or other fire-resistant glass (NFPA, 2013).
- Plastic Skylights – highlighted as risk
  - While obvious, no data available to back up the assessment

• Siding ignition from ICFME proposed 2 story structures spaced about 39 feet apart (*based on radiant heat fluxes*)

• Large-scale experiments at NIST (*only in literature*)
  – Fire spread to buildings clad with combustible material vs. non-combustible (fire-rated gypsum wallboard)
  – Spread rate was significantly slowed with non-combustible cladding (1-hour fire rated assembly, spaced 6 ft (1.8 m))
  – Most significant spread from flames exiting/entering broken windows
  – Heat fluxes on adjacent wall peaked between 60 - 110 kW/m² at the top of the wall
  – A 1-hour fire-rated wall could increase protection for closely spaced homes, but complete hardening of a home will require other protection methods (Quarles et al., 2012).

• **More testing needed**

Community Planning

• Waldo Canyon fire
  – 12 -20 ft (3 -6 m) spacing where home-to-home ignition occurred

• Witch and Guejito Fires
  – Correlation found between vegetation near a home and number of structures destroyed
  – Spread within community primarily governed by structure-to-structure spread

• Syphard studied effect of land use planning (California)
  – Areas with low structure density or isolated clusters (separation of 100m or more) more likely to burn (more than high density).
  – The most important location-dependent variable found was historical fire frequency, which corresponded with wind corridors.
  – Structures on edge of community or steep slopes also susceptible

Maranghides, A., McNamara, D., Mell, W., Trook, J., Toman, B., 2013. NIST report #2
MITIGATION STRATEGIES
Some Available Codes and Standards

• **NFPA 1141**: Standard for fire protection infrastructure for land development in wildland, rural, and suburban areas
• **NFPA 1142**: Standard on water supplies for suburban and rural firefighting
• **NFPA 1143**: Standard for wildland fire management
• **NFPA 1144**: Standard for reducing structure ignition hazards from wildland fire
• **ICC International Wildland-Urban Interface Code**
• **California Building Code Chapter 7A**: Materials and Construction Methods for Exterior Wildfire Exposure

• Designed for AHJ's, planners, developers and communities
## Appendix C

### Fire Hazard Severity Form

The provisions contained in this appendix are not mandatory unless specifically referenced in the adopting ordinance.

When adopted, this appendix is to be used in place of Table 301.4.1 to determine the fire hazard severity.

### Field Shanahan Focus on primary roads 1, 3, 5
One road 5

### 2. Width of Primary Road
30 feet or more 1, 3
Less than 30 feet 5

### 3. Accessibility
Road grade 5 or less 1, 3
Road grade more than 5% 5

### 4. Secondary Road Terraces
Long road, end elevation with an outside turning radius of 9 feet or greater 1, 3
End of road 5
Road bed more than 20% or less in length 3
Road bed more than 20% or less in length 5

### 5. Street Signs
Present 1, 3
Not present 5

### B. Vegetation (R芙VCC Definitions)
1. Fuel Type
Light 1, 3, 5
Moderate 5
Heavy 10

2. Defensible Space
50% or more of site 1
50% or less, but less than 30% of site 5
Less than 30% of site 20

### C. Topography
5% or less 1
More than 5%, but less than 20% 1
20% or more, but less than 30% 1
30% or more 10

### D. Roofing Material
Class A Roof Material 1
Class B Roof Material 5
Non-rust 10

### E. Fire Protection—Water Source
Sufficient water source within 1000 feet 1
Water source farther than 1000 feet or off site 3
Water source farther than 1000 feet, and 45o or less, rounded trip 7
Water source farther than 45 feet, rounded trip 13

### F. Existing Building Construction Materials
Noncombustible roof/shingles/roof deck 1
Noncombustible roof/shingles/roof deck 5
Combustible siding and deck 13

### G. Utilities (gas and/or electric)
All underground 1
All aboveground 1

### H. Utilities (gas and/or electric)
All underground 1
All aboveground 1

### I. Test for Subdivision
Moderate Repeat 49
High Repeat 49
Extreme Repeat 75

### Home Ignition Zone Assessment Mitigation Guide

#### Property Ignition Zone Assessment Mitigation Guide

<table>
<thead>
<tr>
<th>ASSESSMENT ITEMS</th>
<th>MITIGATION RECOMMENDATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. OVERVIEW OF SURROUNDINGS:</td>
<td></td>
</tr>
<tr>
<td>How is the structure positioned in relationship to severe fire behavior?</td>
<td></td>
</tr>
<tr>
<td>Type of construction:</td>
<td></td>
</tr>
<tr>
<td>Inspect the roof – remove combustible! Shingles on eaves?</td>
<td></td>
</tr>
<tr>
<td>Shingles flat with no gaps?</td>
<td></td>
</tr>
<tr>
<td>Gutters – present? Noncombustible?</td>
<td></td>
</tr>
<tr>
<td>Oven on roof, gutters, and eaves?</td>
<td></td>
</tr>
</tbody>
</table>

**PROPERTY**

- **Cedar Shake**
  - Location of home exposed
  - Defensible space
  - 10 ft
  - 20 ft
  - 30 ft

**Know Your Space**

*Get a free home inspection to help determine what parts of your home are most vulnerable during a wildfire. Find more information here.*

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Defensible Space

• NIST investigation of the Witch Creek and Guejito Fires

<table>
<thead>
<tr>
<th>Zone</th>
<th>Destroyed Structures With Wildland Vegetation</th>
<th>Destroyed Structures Without Wildland Vegetation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 30 ft from the structure</td>
<td>67%</td>
<td>32%</td>
</tr>
<tr>
<td>30 – 100 ft from the structure</td>
<td>59%</td>
<td>27%</td>
</tr>
<tr>
<td>100 – 200 ft from the structure</td>
<td>54%</td>
<td>27%</td>
</tr>
<tr>
<td>Beyond 200 ft</td>
<td>64%</td>
<td>17%</td>
</tr>
</tbody>
</table>

Percent structure destroyed with and without wildland vegetation

• Many Firewise recommendations effective in reducing ignition
• Firewise does not explicitly recognize the hazard that an untreated property can have on an adjacent properties
  • e.g. homeowners pushed fuel piles away from their homes, but in effect pushed closer to neighbor’s house
• Recent study: structures were more likely to survive a fire with defensible space immediately adjacent to them

Maranghides, A., McNamara, D., Mell, W., Trook, J., Toman, B., 2013. NIST Report #2
Fuel Treatments

• Physically altering vegetation (e.g. removing, thinning, pruning, mastication, etc.)
  – Reduce intensity of fire (flame length, ROS)
  – Remove ladder fuels & space fuels to prevent crowing in tree canopy
  – Mechanical treatments: (hand/machine, chipping/pile burning or grazing) or prescribed burning
  – Continued maintenance important to retain effectiveness.

• General consensus on effectiveness of lowering fire intensity
  – Shown in 2007 Angora Fire

• Southern California study
  – Did not stop fires on own, but improved firefighter access & effectiveness

*Fuel treatment area which met the full force of a crowning head fire. It transitioned to a lower intensity surface fire at the fuel treatment area.*

Risk Assessment Methodologies

- Risk-based approach can reduce losses by efficiency
  - Mitigation, structure hardening, suppression, evacuation, etc.
  - Still need more input data, but early results may help
  - CA – FRAP program (highlight WUI areas)
  - USFS – WFDSS, used for operational firefighting decision making

Conceptual model highlighting means-based objectives and actions for reducing the risk of home loss as a result of wildfire. The risk of home loss is jointly determined by the probability of home exposure to wildfire and the susceptibility of home to wildfire

Wetting/Covering Agents

• Exterior sprinklers, gel and foam agents, exterior blankets, etc.
  – Some mentioned in 2012 ICC WUI Code
  – Most not evaluated in actual-scale WUI event
• Bench-scale tests focus on radiant heating
  – Unrealistic conditions (flame contact, firebrands)
• Some gel and foam coatings delay ignition
  – Benefit is short term (hours after application)
  – Note the benefit is short term (hours) and it *must not blow off!*
    *(typical hot, dry, windy conditions)*
• Only 1 published study on exterior sprinklers
  – All but one structure with a working sprinkler system survived a fire
  – Does not *PROVE* this works – no record of individual exposure conditions
  – *Water availability issues if implemented at large scale*

GAP ANALYSIS

Rim Fire
Yosemite, CA
112 Buildings Destroyed
257,314 Acres Burned
2013
Identified Gaps

• Quantification of Risk and Hazard
  – Pre- and Post-Fire Data Collection
  – Testing of Firebrands
  – Understanding of Ember Fundamentals
  – Understanding of Wildland Fire Fundamentals
  – Structural Ignition

• Practical and Specific Issues
  – Fuel Management, Defensible Space and Community Planning
  – Test Standards and Design of WUI Materials
  – Effectiveness of Mitigation Strategies
  – Impact of Wildland Fires on Health and Environment
  – Firefighting Techniques
  – Identification of Educational Needs
Most all studies fail to **quantify** effects in a repeatable manner
- Difficult to create test standards or regulations without a scale
- Performance-based design difficult without know-how
- Basic knowledge still lacking on HOW to quantify (e.g., ember flux?)

Available knowledge focused on wildland fire behavior (fuel, slope topography) and density of structures

Quantitative values needed for **risk analysis and models**

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**Proposed scale for WUI exposure from wildland fuels by Maranghides and Mell (2013)**

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Pre and Post-Fire Data Collection

• Data could greatly enhance our current understanding of how WUI fires spread to help better address the problem
  – Identify risks
  – Build statistical/risk models

• Some guidelines and tools for WUI data collection have been proposed by workshops

• More verification of Mitigation Strategies
  – Some Firewise recommendations validated after Witch & Guejito fire
  – *Implementation of home fire sprinklers*, which is offered to decrease home separation distance from 30 ft to 15 ft in NFPA 1141 have no data in the literature to support them.
  – What if power/water goes out during WUI fire – need for resilience

Understanding Firebrads

• Firebrads least understood component of WUI fires
  – More knowledge needed on generation & ignition
  – Testing needed on different fuels under more extreme conditions

• Firebrand tests on structural components
  – Most tests on fuel beds, not structural components
  – Higher velocities and flux of firebrands needed
  – Interaction of multiple building components
  – Re-entrant corners (worst case?)

• With more knowledge – can build materials & assemblies that resist ignition and deposition of brands

• Fundamental knowledge will enable scale model testing and development of new solutions & test standards
• Very little work has been done to develop strategies to design a WUI community
• No publication was found in which a strategy was proposed to aid in the design of a WUI community
  – Most aimed at homeowner maintenance
  – Codes say what you can’t do – but what can we do?
• Greenbelts, parks, walking/bike paths or other defensible spaces may be particularly effective design strategies, however no guidance appears available for their use
• Two sides to WUI home protection: engineering and maintenance
  – Just like inside a structure, education and enforcement are needed to ensure proper function
  – Continue community-wide programs such as Firewise
Test Standards and Design of Components

• Measure ignition and fire resistance
  – Must be coupled to exposure, which needs further study
  – Still need to fundamentally know how items ignite!
  – Can we engineer a solution for debris?

• Specific tests needing development/improvement
  – Roof tests: Class A rated by UL 790, ASTM-E108 or NFPA 276 have failed wind-tunnel firebrand shower tests (Manzello et al., 2013)
  – Gutters and other roofing products - to keep debris accumulation minimal or nonexistent
  – Fences and sidings: little known, research first
  – Mulch: test standards proposed (Beyler et al, 2014), but still need to look at ability of these mulches to ignite homes.
  – Decks/Porches: need better national tests (CA has CBC 12-7A-4.)
  – Sprinklers: on home outside or inside. Need tests for coatings, first we need to understand more!
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Read our Report: ter.ps/wuireport