Preventing DISASTER

Home Ignitability in the Wildland–Urban Interface

Wildland-urban interface (W-UI) fires are a significant concern for federal, state, and local land management and fire agencies. Research using modeling, experiments, and W-UI case studies indicates that home ignitability during wildland fires depends on the characteristics of the home and its immediate surroundings. These findings have implications for hazard assessment and risk mapping, effective mitigations, and identification of appropriate responsibility for reducing the potential far home lass caused by W-UI fires,

By Jack D. Cohen

Once largely considered a California problem, residential fire losses associated with wildland fires gained national attention in 1985 when 1,400 homes were destroyed nationwide (Laughlin and Page 1987). The wildland fire threat to homes is increasing and is commonly referred to as the wildland—urban interface (W-UI) fire problem. Since 1990, W-UI fires have threatened and destroyed homes in Alaska, Arizona, California, Colorado, Florida, Michigan, New Mexico, New York, and Washington. Extensive or severe fires in Yellowstone in 1988, Oakland in 1991, and Florida in 1998 attracted much media coverage and focused national attention on wildland fire threats to people and property

Federal, state, and local land management and fire agencies must directly and indirectly protect homes from wildfire within and adjacent to wildlands. Davis (1990) indicated that since the mid-1940s, a major population increase has occurred in or adjacent to forests and woodland areas. Increasing residential presence near fire-prone wildlands has prompted agencies to take actions to reduce W-UI fire losses.

When an apparently all-encompassing, seemingly unstoppable W-UI fire occurs, the rapid involvement of many homes over a wide area produces a surreal impression; some homes survive amid the complete destruction of surrounding residences. After the 1993 Laguna Hills fire, some termed this seemingly inexplicable juxtaposition a “miracle.’ Miracles aside, the characteristics of the surviving home and its immediate surroundings greatly influenced its survival.

Wildland fire and home ignition research indicates that a home’s exterior and site characteristics significantly influence its ignitability and thus its chances for survival. Considering home and site characteristics when designing, building, siting, and maintaining a home can reduce W-UI fire losses.

W-UI Fire Loss Characteristics

W-UI residential fire losses differ from typical residential fire losses. Whereas residential fires usually involve one structure with a partial loss, W-UI fires can result in hundreds of totally destroyed homes. Particularly during severe W-UI fires, numerous homes can ignite in a very short time. The usual result is that a home either survives or is totally destroyed; only a few structures incur partial damage (Foote 1994).

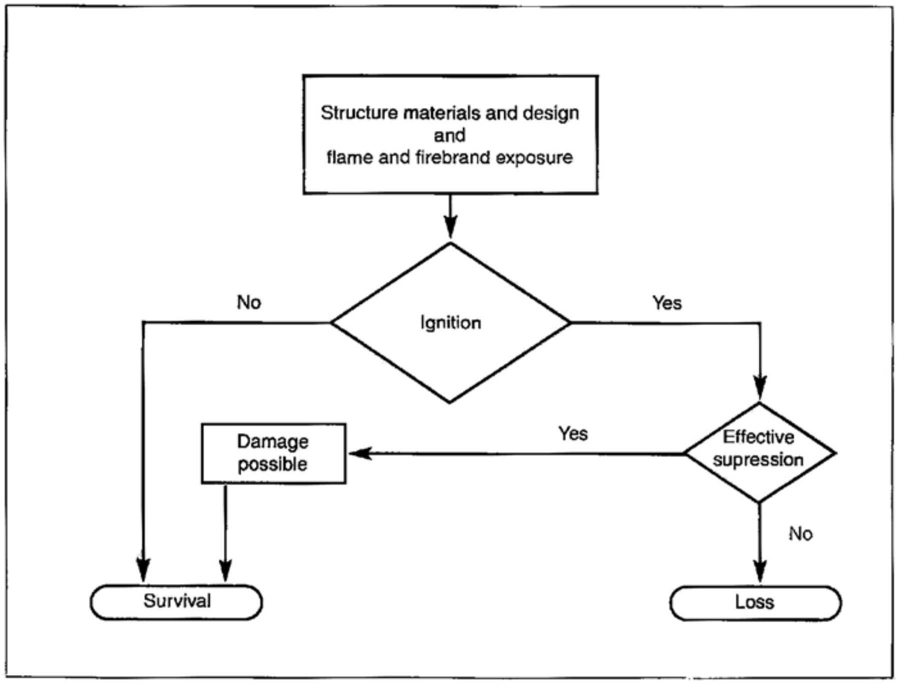


***Figure 1*. The structure survival process**

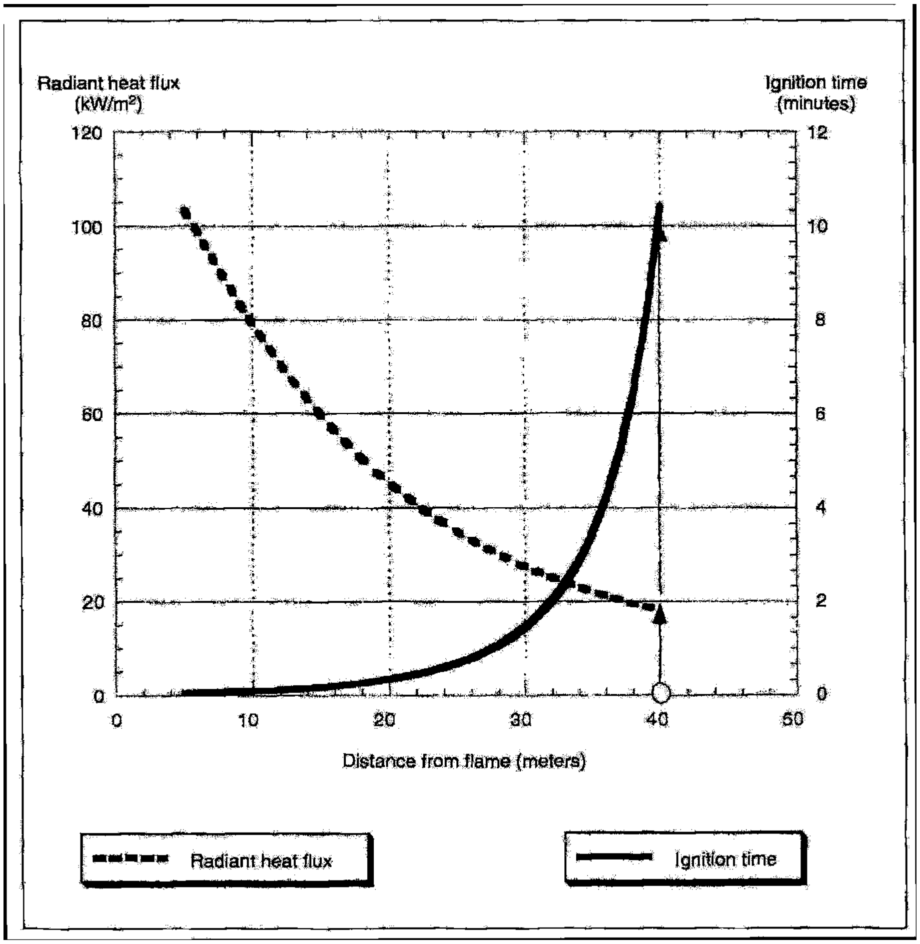


***Figure* 2.The incident radiant heat flux is shown as a function of a wall's distance from a flame 20 meters high by 50 meters wide, uniform, constant, 1,200 K, black-body. The minimum time required for a piloted wood ignition is shown given the corresponding heat flux at that distance.**

The W-UI Fire commonly originates in wildland fuels. During dry, windy conditions in areas with continuous fine fuels, a wildland fire can spread rapidly, outpacing the initial attack of firefighters. If residences arc nearby, a wildland fire can expose numerous homes to flames and lofted burning embers, or firebrands.

A rapidly spreading wildland fire coupled with highly ignitable homes can cause many homes to burn simultaneously. This multistructure involvement can overwhelm fire protection Capabilities and, in effect, result in unprotected residences. Severe W-UI fires can destroy whole neighborhoods in a few hours—much faster than the response time and suppression capabilities of even the best—equipped and staffed firefighting agencies. For example, 479 homes were destroyed during the 1990 Painted Cave fire in Santa Barbara, most of them within two hours of the initial fire report. The 1993 Laguna Hills fire in southern California ignited and burned nearly all of the 366 homes destroyed in less than five hours.

Whether a home survives depends initially on whether it ignites; if ignitions with continued burning occur, survival then depends on effective fire suppression. *Figure 1* shows that home survival begins with attention to the factors that influence ignition. These factors determine home ignitability and include the structure's exterior materials and design combined with its exposure to flames and firebrands. The lower the home ignitability the lower the chance of incurring an effective ignition.

Ignition: A local Process

Ignition and spread of fire, whether on structures or in wildland vegetation, is a combustion process. Fire spreads as a continuing ignition process whether from the propagation of flames or from the spot ignitions of firebrands. Unlike a flash flood or an avalanche, in which a mass engulfs objects in its path, fire spreads because the requirements for combustion are satisfied at locations along the path. The basic requirements for combustion—the fire triangle—are fuel, heat, and oxygen. An insufficiency of any one of the three components, which can occur over a relatively short distance, will prevent a specific location from burning. "Green islands" that remain after the passage of a severe, stand-replacement fire demonstrate this phenomenon. Commonly one can find a green, living tree canopy very close to a completely consumed canopy.

The requirements for combustion equally apply to the W-UI fire situation. In the wildland fire context, fire managers commonly refer to vegetation as fuel. However, for the specific context of W-UI residential fire losses, a house becomes the fuel. Heat is supplied by the flames of adjacent burning materials that could include firewood piles, dead and live vegetation, and neighboring structures. Firebrands from upwind fires also supply heat when they collect on a house and adjacent flammable materials. The atmosphere amply supplies the third necessary component, oxygen.

A wildland fire cannot spread to homes unless the homes and their adjacent surroundings meet those combustion requirements. The home ignitability determines whether these requirements are met, regardless of how intensely or fast—spreading distant fires are burning. To use an extreme example, a concrete bunker would not ignite during any wildland fire situation. At the other extreme, some highly ignitable homes have ignited without flames having spread to them. These homes directly ignited from firebrands.

Firebrands are a significant ignition source during W-UI fires, particularly when flammable roofs are involved. Foote (1994) found a significant difference in home survival solely based on roof flammability. Homes with nonflammable roofs had a 70 percent survival rate compared with 19 percent for homes with flammable roofs. Davis (1990) reported similar results related to roof flammability.

Reducing W-UI fire losses in the context of home ignitability involves mitigating the fuel and heat components sufficiently to prevent ignitions. However, the question of sufficiency (or efficiency) remains: How much, or perhaps more appropriately, how little fuel and heat reduction must be done to effectively reduce home ignitions? To answer this question, we must first quantify the heat source in terms of the fuel's ignition requirements; specifically, how close can flames be to a home's wood exterior before an ignition occurs?

Research Insights

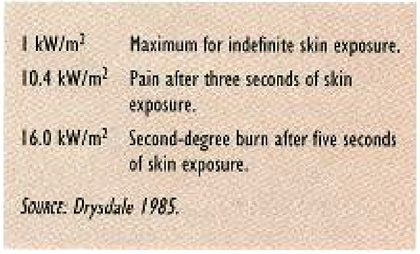
Diverse research approaches are providing clues for assessing the fuel and heat requirements for residential ignitions. Structure ignition modeling, fire experiments, and W-UI fire case studies indicate that the fuel and heat required for home ignitions only involve the structure and its immediate surroundings—the home ignitability context.

Modeling. The Structure Ignition Assessment Model (SIAM) (Cohen 1995) is currently being developed to asses the potential for structure ignitions from flame exposure and firebrands during W-UI fires. One function of SIAM is to calculate the total heat transferred, both radiation and convection, to a structure for varying flame sizes and from varying distances. From the calculated heat transfer, SIAM calculates the amount of heat over time that common exterior wood products can sustain before the occurrence of a piloted ignition (Tran et al. 1992).

Piloted ignition When wood is sufficiently heated, it decomposes to release combustible volatiles. At a sufficient volatile—air mixture, a small flame or hot spark can ignite it to produce flaming; thus, a piloted ignition.

Based on severe-case assumptions of flame radiation and exposure time, SIAM calculations indicate that wildland flame fronts comparable to crowning and torching trees (flames 20 meters high and 50 meters wide) will not ignite wood surfaces at distances greater than 40 meters (Cohen and Butler, in press). *Figure 2* shows the radiant heat a wall would receive from flames depending on its distance from the fire. The incident radiant heat flux, defined as the rate of radiant energy per unit area received at an exposed surface, decreases as the distance increases.

Figure 2 also shows that the time required for ignition depends on the distance to a flame of a given size. At 40 meters the radiant heat transfer is less than 20 kilowatts per square meter *(kW/m^2)*, which translates to a minimum piloted ignition time of more than 10 minutes.



1 kW/m^2	Maximum for indefinite skin exposure.
10.4 kW/m^2	Pain after three seconds of skin exposure.
16.0 kW/m^2	Second-degree burn after five seconds of skin exposure.

Source: Drysdale 1985.

Ten minutes, however, is significantly longer than the burning time of wildland flame fronts at a location. Large flames of wildland fires typically depend on fine dead and live vegetation, which limits the intense burning duration at a specific location to less than a few minutes. Recent crown fire experiments have demonstrated a location-specific burning duration of 50 to 70 seconds.

Experiments. Field studies conducted during the International Crown Fire Modelling Experiment (Alexander et al. 1998) provide data for comparisons with SIAM model estimates. Total heat transfer (radiation and convection) and ignition data were obtained from heat flux sensors placed in wooden wall sections.

The instrumented walls were located on flat, cleared terrain at 10, 20, and 30 meters downwind from the edge of the forested plots. The wall section at 10 meters was 2.44 meters wide and 2.44 meters high with a 1.22-meter eave and roof section (*fig. 3a)*. Exterior plywood (T-1-11) covered the wall with oriented-strand board covering the roof section and the eave soffit. Trim boards were solid wood with wood fiber composition board on the cave fascia. None of the materials were treated with fire retardant.

(a) 10-meter wood wall section before the crown fire. **(b) Experimental crown fire.**

Figure 3. **International Crown Fire Modelling Experiment.**

The forest was variably composed of an overstory of jack pine *(Pinus banksiana)* about 14 meters high with an understory of black spruce *(Picea mariana).* The spreading crown fire produced flames approximately 20 meters high. *Figures 3b and 3c* show examples of the experimental crown fire.

Five burns were conducted where wall sections were exposed to a spreading crown fire. As the crown fires reached the downwind edge of the plot, turbulent flames extended into the clearing beyond the forest edge. In two of the five burns, flames extended beyond 10 meters to make contact with the 10-meter wall section. When flame contact occurred, the 10-meter walls ignited; however, without flame contact, only scorch occurred, as shown in *figure 3d.* The wooden panels at 20 meters experienced light scorch when flames extended beyond 10 meters from the experimental plot, and no scorch from the other burns. The 30-meter wall section had no scorch from any of the crown fires.

Figure 4 displays the average total incident heat flux (radiation and convection combined) corresponding to the wall at 10 meters *(fig. 3d)* and the crown fire shown in figures *3b and 3c.* The average total incident heat flux is calculated from two sensors placed 1 meter apart in the wall. The amount of heat received by the wall increased as the flame front approached and decreased as the fine vegetation was consumed. The initial heat flux "spike" was caused by a nonuniform crowning flame front.

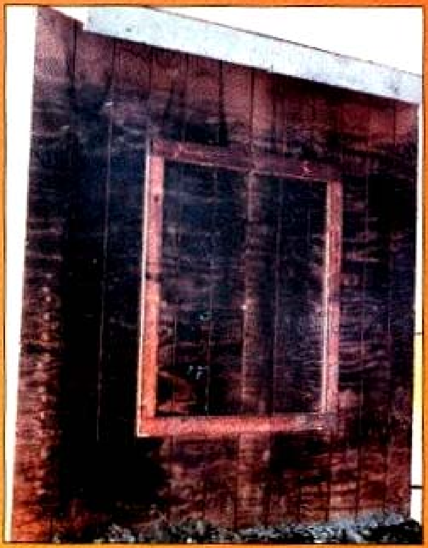
The flux-time integral shown in *figure 4* indicates whether sufficient heating has occurred to pilot-ignite wood (Tran et al. 992). SIAM uses the flux-time integral for calculating ignition potential, a correlation of the incident heat flux and the time required for piloted wood ignition.

The flux-time correlation identifies two principal ignition criteria: (1) A minimum heat flux of 13 kW/m^2 must occur before a piloted ignition can occur for any exposure time, and (2) piloted ignition depends on attaining a critical heating dosage level (heat transfer and its duration). These criteria are graphed in *figure 4.* The flux-time integral only increases for incident heat fluxes greater than the minimum of 13 kW/m^2, and the flux-time integral threshold value of 11,500 is shown as the ignition threshold. As seen in the figure, the flux-time integral does not reach the ignition threshold, indicating an exposure insufficient for ignition and corresponding to no actual occurrence of a wall ignition. Therefore, a home at some distance from a large flame front, such as a crown fire, may not receive sufficient energy to meet the minimum for ignition over any time period. In addition, a home closer to a large flame front can receive a high heat flux (for example, 46 kW/m^2 as shown in *figure 4*), but without the necessary duration to meet the threshold for ignition.

The flux-time integral plot indicates the duration of the heat transfer relevant to ignition. The heat transfer duration relevant to ignition combines the heat transfer from the approaching crown fire plus the burning time of the fire after it has reached the end of the plot. The observed time required for the flux-time integral to increase from zero to its maximum value corresponds to the heat transfer duration significant for ignition. *Figure 4* indicates a duration of 65 seconds (flux-time plot from 75 seconds to 140 seconds).

Case studies. Case studies of actual W-UI fires provide an independent comparison with SIAM and the crown

(c) Experimental crown fire.



(d) After crown fire exposure the wall scorched but did not ignite. Note the lack of wall scorch under the eave because of the radiation "shading" from the eave.

fire experiments. The actual fires incorporate a wide range of fire exposures. The case studies chosen examine significant factors related to home survival for two fires that destroyed hundreds of structures. The Bel Air fire resulted in 484 homes destroyed (Howard et al. 1973) and the Painted Cave fire destroyed 479 homes (Foote 1994).

Analyses of both fires indicate that home ignitions depend on the characteristics of a structure and its immediate surroundings. Howard et al. (1973) observed 86 percent survival for homes with nonflammable roofs and a clearance of 10 meters or more.

Dicussion

A comparison of the SIAM model calculations in *figure 2* with the observed heat flux from the experimental crown fire in *figure 4* indicated that the model overestimates the heat flux. The model calculation at 10 meters reveals a radiant heat flux of 70 kW/m^2, which exceeds the highest total heat flux of 46 kW/m^2 observed at the 10-meter wall section in *figure 4*. SIAM calculations

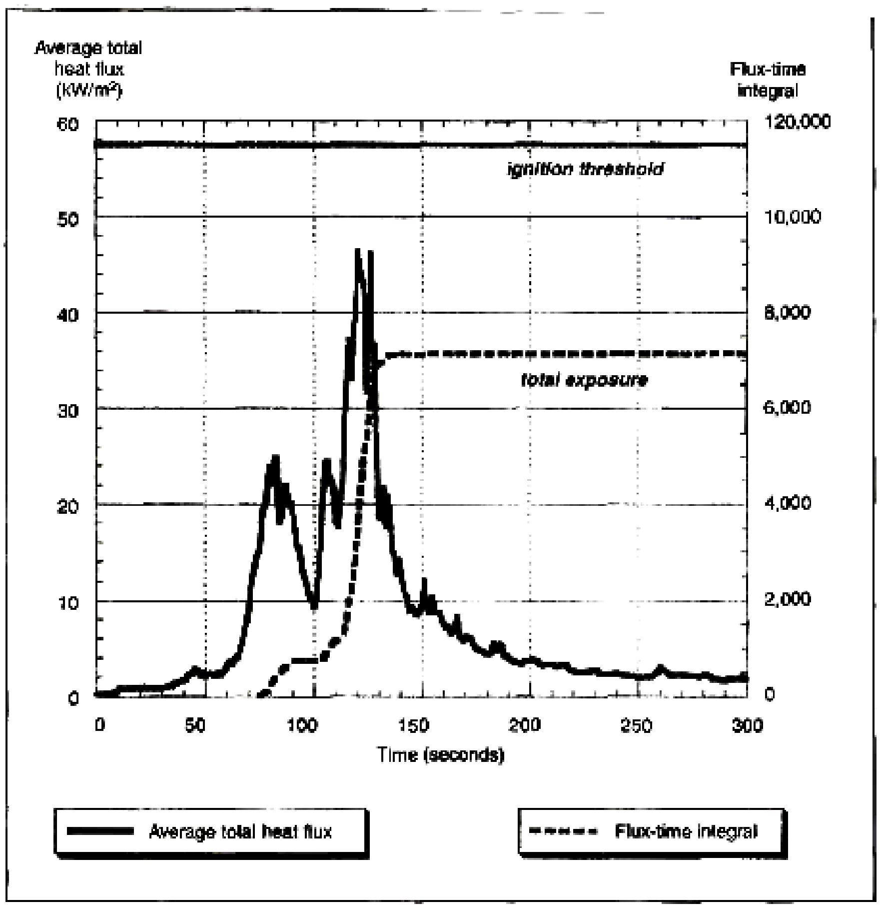


Figure 4. Actual average total incident heat flux and flux-time integral for the crown fire and 10-meter wall section shown in figure 3.

overestimate the heat transfer because the severe-case assumptions designate a homogeneous, black-body radiating flame front. Real flame fronts do not meet these assumptions and produce a significantly smaller radiant heat flux by comparison. For a given flame front, the SIAM calculations represent an extreme-case estimate of radiant heat transfer, and thus an extreme-case estimate of ignition potential.

Given the duration of the experimental heat flux (65 seconds), we can calculate the heat flux and corresponding distance required for ignition. At 65 seconds, the ignition time graph (*fig. 2)* indicates ignition at a flame distance of less than 30 meters. If the heat flux duration is extended by a factor of five to 325 seconds, the flame distance for ignition is less than 40 meters. By comparison, the 10-meter wall sections in the crown fire experiment did not ignite without flame contact and all burns produced little or no scorch to wall sections at 20 and 30 meters. The W-UI fire case studies indicated approximately 90 percent survival with a vegetation clearance on the order of 10 to 20 meters for homes with nonflammable roofs. Thus, the case studies support the general flame-to-structure distance range of 10 to 40 meters as found through modeling and experiments.

However, firebrands can also cause homes to ignite during wildland fires. Although firebrands capable of ignition can originate from a fire several kilometers away, homes can only be threatened if the firebrands ignite the home directly or ignite adjacent flammable materials that then ignite the home.

Analyses of potential home ignitions using modeling, experiments, and case studies did not explicitly address firebrand ignitions. However, firebrand ignitions were implicitly considered because of the firebrand exposures that occurred during the crown fire experiments and the case studies. The experimental crown fires provided a firebrand exposure that resulted in spot ignitions in the dead wood and duff around the wall sections hut not directly on the walls. In the case studies, firebrand ignitions occurred throughout the areas affected by the Bel Air and Painted Cave fires. The high survival rate for homes with nonflammable roofs and 10- to 20-meter vegetation clearances included fire-brands as an ignition factor, thus indicating that firebrand ignitions also depend on the ignition characteristics of the home and the adjacent flammable materials.

Conclusions

The key to reducing W-UI home fire losses is to reduce home ignitability. SIAM modeling, crown fire experiments, and case studies indicate that a home's structural characteristics and its immediate surroundings determine a home's ignition potential in a W-UI fire. Using the model results as guidance with the concurrence of experiments and case studies, we can conclude that home ignitions are nor likely unless flames and firebrand ignitions occur within 40 meters of the structure. This finding indicates that the spatial scale determining home ignitions corresponds more to specific home and community sites than to the landscape scales of wildland fire management. Thus, the W-UI fire loss problem primarily depends on the home and its immediate site.

Consequently if the community or borne site is not considered in reducing W-UI fire losses, extensive wildland fuel reduction will be required. For highly ignitable homes, effective wildland fire actions must riot only prevent fires from burning to home sites, but also eliminate firebrands that would ignite the home and adjacent flammable materials. To eliminate firebrands, wildland fuel reductions would have to prevent firebrand production from wildland fires for a distance of several kilometers away from homes.

Management Implications

Because home ignitability is limited to a home and its immediate surroundings, fire managers can separate the W-UI structure fire loss problem from other landscape-scale fire management issues. The home and its surrounding 40 meters determine home ignitability, home ignitions depend on home ignitability, and fire losses depend on home ignitions. Thus, the W-UI fire loss problem can be defined as a home ignitability issue largely independent of wildland fuel management issues. This conclusion has significant implications for the actions and responsibilities of homeowners and fire agencies, such as defining and locating potential W-UI fire problems (for example, hazard assessment and mapping), identifying appropriate mitigating actions, and determining who must take responsibility for home ignitability

W-UI fire loss potential. Because home ignitions depend on home ignitability, the behavior of wildland fires beyond the home or community site does not necessarily correspond to W-UI home fire loss potential. Homes with low ignitability can survive high-intensity wildland fires, whereas highly ignitable homes can be destroyed during lower-intensity fires.

This conclusion has implications for identifying and mapping W-UI fire problem areas. Applying the term wildland-urban interface to fire losses might suggest that residential fire threat occurs according to a geographic location. In fact, the wildland fire threat to homes is not a function of *where* it happens related to wildlands, but rather to *how* it happens in terms of home ignitability. Therefore, to reliably map the potential for home losses during wildland fires, home ignitability must be the principal mapping characteristic. The home threat information must correspond to the home ignitability spatial scale, that is, those characteristics of a home and its adjacent she within 40 meters.

Home fire loss mitigation. W-UI home losses can be reduced by focusing efforts on homes and their immediate surroundings. At higher densities where neighboring homes may occupy the immediate surroundings, loss reductions may necessarily involve a community. If homes have a sufficiently low home ignitability, a community exposed to a severe wildfire can survive without major fire destruction. Thus, there is a need to examine the reduction of wildland fuel hazard for the specific objective of home protection. There are various land management reasons for conducting wildland vegetation management. However, when considering the use of wildland fuel hazard reduction specifically for protecting homes, an analysis specific to home ignitability should determine the treatment effectiveness.

Responsibility for home ignitability. If no wildfires or prescribed fires occurred, the wildland fire threat to residential development would not exist. However, our understanding of the fire ecology for most of North America indicates that fire exclusion is neither possible nor desirable. Therefore, homeowners who live in and adjacent to the wildland fire environment most take primary responsibility for ensuring that their homes have sufficiently low home ignitability. Homes should not be considered simply as potential victims of wildland fire, but also as potential participants in the continuation of the fire at their location.

A change needs to take place in the relationship between homeowners and the fire services. Instead of home-related presuppression and fire protection responsibilities residing solely with fire agencies, homeowners must take the principal responsibility for ensuring adequately low home ignitability.

The fire services should become a community partner providing homeowners with technical assistance as well as fire response in a strategy of assisted and managed community self-sufficiency (Cohen and Saveland 1997). For this approach to succeed, it must be shared and implemented equally by homeowners and the fire services.

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Jack D. Cohen (e-mail: jcohen/rmrs_missoula @fs.fed.us) is research physical scientist, USDA Forest Service, Rocky Mountain Research Station, Fire Sciences Laborator, PO Box 8089, Missoula, MT 59808.