



ADDRESSING THE NATION'S WILDFIRE PROBLEM: An S&T Roadmap

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As climate conditions are becoming hotter and drier, wildfires have grown more intense and destructive across much of the U.S. The public safety challenges from wildfires are most acute in the area known as the wildland-urban interface (WUI) where lives and infrastructure are at most risk. Addressing the nation's wildfire problem will invariably involve bridging these two cultures of fire safety and risk (structural and wildland fire fighting) that have traditionally been separate and developing a mix of social and technological innovations and ecosystem services to enable better wildfire mitigation (building codes, design innovations, Artificial Intelligence (AI)-driven risk analysis), fire safety (alerts and warnings), and firefighting practices (automated ignition detection and suppression, enhanced spread modeling, and situational awareness) (Yaella and Orenstein 2021). Pursuing these types of innovations will require a systems-based approach to public safety, recognizing that the WUI brings two distinct cultures of fire risk together in a shared setting.

Scale of the Problem

Over the past several decades, wildfire activity, damages attributed to wildfires, and costs of managing wildfires have increased substantially in the United States (RFF 2021). Wildfires are not a uniquely western U.S. problem; wildfires occur throughout the United States. Data show that more wildfire ignitions occur in eastern states than in the western states, although eastern wildfires tend to be smaller in scale and acreage burned. Additionally, there is no wildfire season. Wildfires are occurring throughout the year and affecting larger areas of the country. In 2020, over 33,000 fires burned approximately 700,000 acres in the east, while almost 26,000 wildfires burned approximately 9.5 million acres in western states (RFF 2021). The 2020 U.S. wildfires also caused \$16.5 billion in damages with indirect costs much higher, encompassing other capital, health, and public safety losses. These trends are exacerbated by climate change and fuel aridity, availability of fuels and ignition sources, population density, and human development. About 32% of all United States houses are located near or on wildland-urban interfaces, putting them at increased risk of adverse, wildfire related events (CRS 2023).

With wildfires increasing in frequency and severity, air quality across the entire country is being impacted. Poor air quality from wildfire smoke can worsen heart and lung conditions, with effects most pronounced among the young, elderly, pregnant women, and individuals already suffering from health issues. The impact of air quality on health extends beyond fire prone regions to almost every American as evidenced by the smoke and particulate haze experienced in Chicago, New York, Washington DC, and Boston in 2021.

The sources of wildfires vary, but are predominantly associated with lightning strikes, human activity, mechanical/electrical sparks, construction, and transportation. Many wildfires occur in the built environment, while others originate within forest lands (Li and Banerjee 2021, Volker et al. 2023). Many wildfires are only detected from 911 callers, or when the size and severity are large enough to be caught by camera and satellite systems. Under the worst fire conditions, fire spotting planes are used to patrol remote areas looking for fires, a costly and inefficient use of resources (DHS 2017). Satellites coupled with drones and in-situ sensors show promise but still need to be better linked to wildfire suppression and alerting capabilities. The exposure and risks from wildfire can be lowered through more applied innovation and effective mitigation, but wildfires will still occur.

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Economic and residential development in the WUI continues to exacerbate wildfire risks, resulting in increased fatalities and damages. While building codes are fairly mature in the structural fire community, they are not so much in the wildfire community (Boomhower 2023). There have been renewed efforts to develop defensible space and landscape design guidelines for wildfires, but little attention has been paid toward pursuit of model building codes and standards such as wildfire detection and suppression systems (i.e., fire detectors and smoke alarms or fire sprinklers) and promote adoption and innovation of these technologies in WUI areas.

Defining the WUI and therefore determining those zones has been contentious (NAS 2022, Kumar et al. 2020). This has hampered improvements in wildfire risk analysis and communication and curtailed adoption of wildland fire mitigation and enhanced ecosystem services and adoption of technology to improve wildfire alerting, evacuation, and emergency sheltering. Unfortunately, the Maui fire disaster is a continuation of this story.

Additionally, solvency challenges have emerged in property and casualty insurance markets related to wildfire risk, due to the growing trends in policy claims and losses that are placing a key instrument for financial preparedness commonly available to homeowners and business in peril (Dixon et al. 2020). An interesting policy nexus exists between the role and function of federal and state regulatory authorities, federal disaster grants and mitigation programs, and insurance markets in serving as catalysts for enhancing disaster resilience such as tax credits or premiums discounts as a result of disaster risk reduction measures. Potential ideas based on systems-thinking could include improvements to community planning or architecture and landscape design; developing automated suppression systems for common outdoor ignition points such as utility lines and transformers; improving wildfire detection and alerting mechanisms; building high precision models to predict fire path and speed for frontline responders; or reducing the carbon footprint for debris removal operations during recovery operations.

A potential wildland fire roadmap should consider the following — wildfire drivers, policy issues, innovation opportunities, and reference projects.

Understanding the state of science and technology, identify key drivers and opportunities for innovation and collaboration, high potential projects and initiatives (including Cooperative Research and Development Agreements, prize challenges and leveraging and driving co-investment), interconnectedness, and cascading effects and secondary perils – improve fire response and advance fire prevention and risk reduction.

Wildland Fire Drivers and Capability Needs

- Climate change and fuel aridity
 - New solutions to lower urban/suburban heat effects (i.e., reduce heat contribution asphalt, building rooftops, and residential shingles)
 - New solutions for carbon capture and sequestration, especially in context to mitigation
- Fuel availability and increased ignition sources
 - New solutions for forest management, undergrowth thinning, and debris removal for wildfire mitigation and recovery (should be low carbon/low emissions)
 - New solutions for early detection of ignition and coupling with new solutions for fire suppression (power lines and transformers)
 - New remote detection – satellites, aerial drones



- Wildland-urban interface expansion and human development
 - New solutions for defensible space and architecture and landscape design (nature-based solutions)
 - New building codes and insurance mechanisms
 - Defining the fire risk and the WUI landscape
- Energy disruption and critical infrastructure risks – cascading effects and interdependencies
 - New solutions, strategies, and materials for hardening and protection (i.e., underground power distribution, new fire-resistant coatings)
- Public health risks, mental health, increased smoke pollution, and air quality (particulates)
 - New solutions to detect and cope with unsafe conditions and/or prophylactics (face masks)
- Public safety and population displacement risks
 - New solutions for wildfire safe rooms, refuges, or shelters
 - New modeling and simulations capabilities to speed response, evacuation, and recovery
 - New personal protective equipment
- Environmental risks, water scarcity, and impacts to water quality and natural ecosystems
 - New solutions to protect water resources and ensure availability of water to wildfire fighting crews (status on available water retention ponds, reservoirs, etc.)

Policy Issues

- States and locals are issuing preemption regulations (i.e., wildfire prevention power shutoffs) during times of high risk. This causes disruptions to critical services and facilities and required back-up power solutions.
- Use of wildfire safe rooms, refuges, or shelters may deter people from evacuating, current regulations, safety standards, and protection guidance may not exist or introduce liability to government and commercial sector.
- Federal grant guidance may not allow for new innovations and may need to be updated. There may not be a technology validation or accrediting authority to support the use of government funds to procure or implement new innovations.
- No evidence-based on the effectiveness or efficacy of potential interventions or innovations.
- Potential issues involving privacy and personal property rights.
- Ensure that outcomes are equitable and support social and environmental justice goals.

Representative Projects and Innovation Challenges - Ideas and Opportunities

- Living with fire (Resilience by Design) challenge for architecture and landscape design community
- Wildfire suppression challenge for common outdoor ignition points (utility lines, transformers, campfires, etc.) – using AI to predict ignition points and optimize suppression operations – EU-US AI4Good



- Wildfire detection and alerting challenge – persistence monitoring for wildfires, coupling of detection innovations with alerting and notifications systems at speed – S&T fire sensors
- Wildfire spread modeling challenge – providing high performance and high precision models at accuracy and speed for frontline operations – WIFIRE
- Wildfire fuel and debris removal carbon capture challenge – new ecosystem services to manage fuel loads and optimize debris removal pre/post event
- Behind-the-meter storage (back-up power) low carbon, low emissions challenge
- AI for wildfire risk analysis challenge – using AI for defining the WUI zones, developing a wildfire risk index, assessing level of wildfire resilience at national, regional, and local scales – Federal Emergency Management Agency | U.S. Fire Administration | S&T

Operations Testbeds and Field Deployments

- Establish at least three operational testbeds to assess technology readiness, fit-for-purpose reference implementations
- Leverage the Civic Innovation Challenge partnership with the National Science Foundation and Department of Energy to drive adoption and rollout of solutions at the community level
- Collaborate with the National Institute of Standards and Technology, fire communities, and insurance sectors to develop model building codes and standards for wildfire safety including partnerships in material sciences, structural design, and performance testing (i.e., Institute for Building and Home Safety, Fire Research Safety Institute)
- Develop new wildfire emergency sheltering solutions as a “shelter of last resort” to reduce fatalities and fill gaps and limits in wildfire evacuation



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