the state of FIRETECH

MARCH 2022

PROGRESS | GAPS | FUTURES

Acknowledgements

The State of FireTech aims to review progress, identify gaps, and provide a visioning framework to guide philanthropic, corporate, and impact investments in the development and application of just, inclusive, and equitable technologies for wildfire risk management.

The document is the result of discussions of the Wildfire Technology Funders Group—a diverse group of philanthropists, corporates, and impact investors.

Members of the Wildfire Technology Funders Group currently support the work of community-based organizations, non-profits, researchers, and entrepreneurs in developing and scaling technologies for wildfire risk management.

The State of FireTech was conceptualized and compiled by Wonder Labs. The consultation and visioning process was co-facilitated by Wonder Labs, the Gordon and Betty Moore Foundation, and Google.org, in conjunction with members of the Wildfire Technology Funders Group.

Contact

If you have questions related to the material presented in this document, please contact:
Dr. Shefali Juneja Lakhina (Cofounder, Wonder Labs): shefali@lakhina.com

If you have questions about the Wildfire Technology Funders Group, please contact Genny Biggs (Moore Foundation): Genny.Biggs@moore.org or Alex Diaz (Google.org): ajdiaz@google.org

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Executive Summary

Infrastructure losses and ecosystem damages from wildfires are increasing each year, with significant impacts on the health, safety, and wellbeing of communities around the world. In the context of global warming trends, coupled with housing instability and hazardous fuel build up, more communities in the wildland-urban interface and intermix are likely to be exposed to wildfires and cascading impacts, including smoke, than ever before.

In recent years, local authorities, businesses, and communities have been exploring the development and application of a range of innovations to manage wildfire risk. **New and convergent technologies are being developed for wildfire risk assessment, forecasting and prediction, early fire detection, incident management, and information and communication management, including notification and evacuation systems.** In general, such technologies are contributing to saving lives and getting people out of harm's way.

After another year of devastating fires in 2021, **it is imperative to take stock of progress, gaps, and remaining challenges in the application of emerging technologies for wildfire risk management.**

There is also a need to assess how science and technology applications are contributing to the achievement of just and equitable wildfire risk reduction outcomes in the context of the Agenda 2030 commitments and the global Sustainable Development Goals.

The *Wildfire Tech Funders Group*, composed of a **diverse group of philanthropists, corporates, and impact investors, are committed to a novel and collaborative approach** to addressing the global wildfire challenge.

Members of this group recognize that no single organization can address the problem alone. Communities and local authorities on the frontlines need a coherent, strategic, and systemic approach to bring forth clarity and momentum in implementing effective solutions that can work across varied contexts.

This document aims to provide a guiding framework for technology funding and investments for just, inclusive, and equitable wildfire risk management. Through four sections, the document summarizes key areas of progress, remaining gaps, and future possibilities for wildfire technologies, hereafter referred to as 'FireTech'.

The first section introduces the objectives of the report. The second section—*What is FireTech*? —defines this emerging space as consisting of the **development and application of three kinds of technology trends—digitization, mechanization, and materials—for wildfire risk management.** The maturity of these technologies can be broadly assessed by the state of science, application, and scale.

The third section—*Key Priorities for FireTech* —**outlines the current state, remaining gaps, and recommendations along four priority areas:** risk assessment, risk reduction and mitigation, early detection and response, and recovery and adaptation.

The final section—*Guiding Framework*—outlines the normative goals, desired outcomes, priorities for action, enabling processes, and guiding principles, **for the development of just, inclusive, and equitable FireTech solutions.**

The document draws on key findings and recommendations from recent scientific and technical workshops and reports, institutional stocktaking and theory of change visioning exercises, and insights from focused group discussions with a range of philanthropies, corporates, impact investors, local agencies, and community-based organizations across geographies (see references for complete list).

Introduction

Fires are a natural occurence across biomes, affecting about four million square kilometers of Earth's surface each year. In the context of ongoing and projected trends due to climate change, wildfire risk is likely to increase in some parts of the world, with unsustainable outcomes for community wellbeing and ecosystem resilience.

Impacts are already evident in the rising cost of infrastructure losses and ecosystem damages from wildfires and related hazards in recent years. In 2020, record impacts were experienced by communities around the world, in terms of both the number of recorded events and total economic losses, as compared to the previous two decades, 2000–2019.

Coupled with housing instability, communities are increasingly more exposed to wildfires, and cascading hazards, such as extreme heat, drought, flooding, and mudslides across the wildland urban interface and intermix (WUI). In addition, wildfires can cause severe and chronic public health impacts from exposure to smoke, damage and loss of property and public infrastructure, along with long-term impacts on ecosystem resilience and carbon emissions.

To cope with the increasing risk of wildfires and cascading impacts, local authorities, businesses, and communities have been exploring a range of technologies for wildfire risk management. Technologies are being developed and adopted at a rapid pace to augment wildfire risk assessment, forecasting and prediction, early fire detection, incident management, and information and communication management, including notification and evacuation systems.

In recent years, such technologies have generally contributed to saving lives and getting people out of fire's way. However, there is also growing evidence of the ways in which the intersections of race, ethnicity, migrant status, gender, age, ability, and income, can have serious implications for whether and how people access technologies for their safety and wellbeing.

For example, people with access, functional, and linguistic needs, people living in rural and regional areas with low internet and transport connectivity, and people who are low-income and unhoused, can be left out and denied access to the benefits of 21st century technologies. There is growing evidence of how social vulnerabilities have been further exacerbated due to the COVID-19 pandemic.

Considering these compounding crises, and especially after another year of devastating fires in 2021, it is imperative to take stock of areas of progress, gaps, and remaining challenges. This document aims to review progress, identify gaps, and provide a visioning framework to guide philanthropic, corporate, and impact investments in the development and application of just and equitable technologies for wildfire risk management.

What is FireTech?

This section introduces a conceptual framework to understand key areas of innovation and identify 'white spaces' for future investments in the development and application of just, inclusive, and equitable wildfire risk management technologies—hereafter referred to as 'FireTech'.

Technology trends: Digitization, Mechanization, Materials

Acknowledging broader trends in climate tech, humanitarian tech, and disaster tech, the emerging area of 'FireTech' can be broadly defined as the development and application of three kinds of technology for wildfire risk management—digitization, mechanization, and materials. Around the world, FireTech innovations are underway in four key areas of wildfire risk management: risk assessment, mitigation and risk reduction, early detection and response, and recovery and adaptation (see Figure 1).

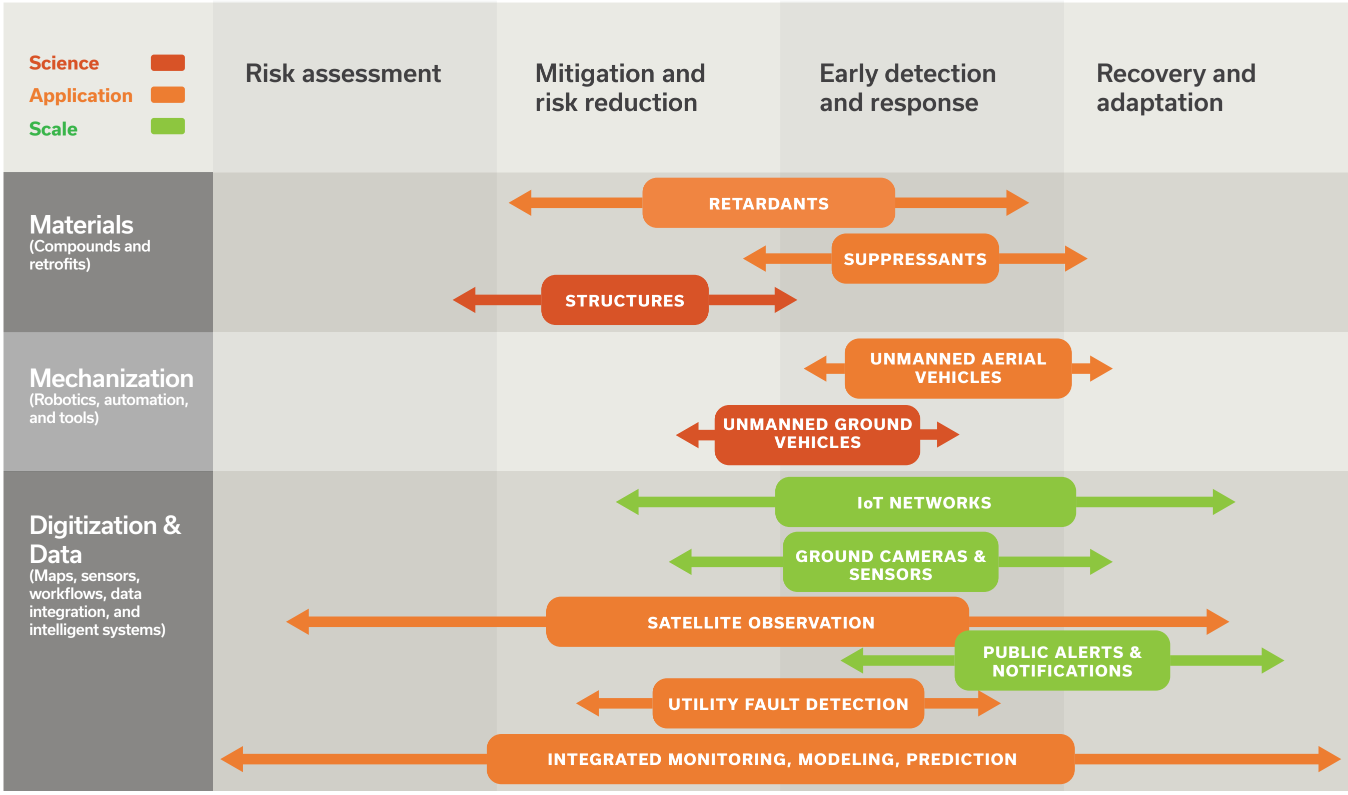


Figure 1. Defining FireTech: Technology applications for wildfire risk management (Lakhina and Lakhina 2021)

Digitization and data currently represents the most significant area of wildfire technology development and application. Digitization technologies broadly refer to the application of cloud-based Software as a Service (for mapping, workflows, information and communication systems); sensor networks (satellite, aerial, ground) and Internet of Things (IoT) for enhanced situational awareness; and data integration, analysis, and intelligent systems to augment end-to-end wildfire risk management. Digitization has been foundational for the development and application of mechanization and material technologies.

Mechanization broadly refers to robotics and automation, represented by the development and application of bionics, assistive and collaborative bots, ground-based and aerial unmanned systems, to augment emergency management response and assist fire crews with real-time risk assessment, mitigation, early detection and response, and recovery. Learning from advances in humanitarian tech and disaster tech at large, the most popular kind of robots currently being deployed in FireTech are unmanned aerial vehicles or drones.

Materials include a range of chemicals and compounds, such as suppressants and retardants, as well as engineering, structural retrofits, and tools, and equipment. Perhaps the earliest kind of FireTech materials that have been in use for at least 80 years are foam-based fire suppressants. More recently, material technology has expanded to include a range of organic compounds for use as retardants and ignition agents. These kinds of material technologies are not just being applied in fire response but also in prescribed burning and mitigation actions in wildland-urban interface (WUI) communities. Materials in FireTech also include building materials and retrofits such as vents, screens, and roofs that allow homeowners to retrofit and 'harden' structures for improved fire defense and smoke protection.

Digitization, mechanization, and material technologies in FireTech are being increasingly used in conjunction with related advances in financial technology or FinTech, such as insurance, crypto, and carbon markets, including pricing insurance offerings and guiding public-private investments.

The FireTech definition and framework presented here (Figure 1) should be used as a framing device, open to iterations and adaptations. We encourage readers to expand on it, adapt it (see Convective Capital), and reflect on intersections with related verticals, such as, FinTech, BioTech, AgriTech, and CarbonTech.

Assessing progress in technology development: Science, Application, Scale

Progress in the development and application of FireTech solutions can be assessed along a three-point scale of strategies:

- prove the science and test methodology across contexts
- demonstrate applications for community wellbeing and ecosystem resilience
- achieve scale through innovative partnerships across geographies

For example, under Digitization (see Figure 1), three areas, marked in green, have proved the science, demonstrated uses in a range of applications, and are in the process of achieving scale. These areas include: 'public alerts and notifications' for evacuation and shelter management, 'IoT networks', and 'ground cameras and sensors'. Even as innovations in data science continue to develop, these technologies offer proven applications for early detection, response, recovery, and adaptation.

Successfully scaling these technology applications in recent years has generally led to the implementation of more effective evacuation, sheltering, and repopulation processes across geographies. However, scaling these technology applications can depend on a range of factors, including local implementation capacities and adequate communication infrastructure.

In contrast, 'monitoring, modeling, prediction', and 'utility fault detection' including asset management are based on proven science, are currently being applied in some industries and geographies, but have not achieved sufficient scale to be considered pervasive. For example, while the science and engineering applications of hardening power lines are now well-known, not many communities have benefited from applications at scale thus far.

Linking FireTech to international disaster risk reduction and sustainable development frameworks

It is also important to assess how science and technology applications in wildfire risk management are contributing to the achievement of just, inclusive, and equitable outcomes. In this regard, FireTech funding and investments can learn from three international frameworks and agreements that currently guide multi-stakeholder efforts in disaster risk reduction, climate change, and sustainable development—the Sendai Framework for Disaster Risk Reduction (2015-2030), the Paris Agreement (2015), and the Sustainable Development Goals as envisioned in the 2030 Agenda, respectively. Abiding by these international frameworks can help ensure that FireTech investments result in just, inclusive, and equitable outcomes.

Adapting the priorities put forth by the United Nations Sendai Framework for Disaster Risk Reduction (2015-2030) current and developing FireTech solutions can be mapped along four key priorities for wildfire risk management, which in turn, can contribute to the achievement of desired outcomes aligned with the sustainable development goals.

1 Risk assessment, modeling, and prediction

Priority	Objective	Areas	Desired Outcomes
Risk assessment, modeling, and prediction “Disaster risk management needs to be based on an understanding of disaster risk in all its dimensions of vulnerability, capacity, exposure of persons and assets, hazard characteristics and the environment” — Sendai Framework for Disaster Risk Reduction (2015-2030)	Develop a better understanding and characterization of wildfire risk to communities and ecosystems	1.1 High-resolution data for mapping 1.2 Fire behavior and human-earth system models 1.3 Data standardization and integration practices 1.4 Information, communication, and education technologies	Better understanding and characterization of historic, current, and projected risk from wildfires, and related hazards, to communities and ecosystems. Contributes to fulfilling at least three Sustainable Development Goals: Goal 11: Make cities inclusive, safe, resilient, and sustainable Goal 13: Take urgent action to combat climate change and its impacts Goal 15: Sustainably manage forests, combat desertification, halt and reverse land degradation, halt biodiversity loss

2 Mitigation and risk reduction

Priority	Objective	Areas	Desired Outcomes
Mitigation and risk reduction "Disaster risk governance at the national, regional and global levels is vital to the management of disaster risk reduction in all sectors and ensuring the coherence of national and local frameworks of laws, regulations and public policies that, by defining roles and responsibilities, guide, encourage and incentivize the public and private sectors to take action and address disaster risk" — Sendai Framework for Disaster Risk Reduction (2015-2030)	Strengthen risk governance to mitigate and reduce the risk of wildfires to communities and habitat	2.1 Utility and asset management 2.2 Land use planning and management 2.3 Managing risk in the built environment 2.4 Fuel management	Strengthened and diversified capacities for fuel treatment and landscape restoration Contributes to fulfilling at least eight Sustainable Development Goals: Goal 1: End poverty in all its forms Goal 3: Ensure healthy lives and promote wellbeing for all ages Goal 6: Ensure access to clean water and sanitation for all Goal 8: Promote inclusive and sustainable economic growth, employment, and decent work for all Goal 10: Reduce inequalities Goal 11: Make cities inclusive, safe, resilient, and sustainable Goal 13: Take urgent action to combat climate change and its impacts Goal 15: Sustainably manage forests, combat desertification, halt and reverse land degradation, halt biodiversity loss

3 Early detection and response

Priority	Objective	Areas	Desired Outcomes
Early detection and response "Public and private investment in disaster risk prevention and reduction through structural and non-structural measures are essential to enhance the economic, social, health and cultural resilience of persons, communities, countries, and their assets, as well as the environment. These can be drivers of innovation, growth, and job creation. Such measures are cost-effective and instrumental to save lives, prevent and reduce losses and ensure effective recovery and rehabilitation" — Sendai Framework for Disaster Risk Reduction (2015-2030)	Invest in effective wildfire risk management for community wellbeing and ecosystem resilience	3.1 Multi-level fire and smoke detection 3.2 Early response 3.3 Incident management 3.4 Notification and evacuation systems	Enhanced end to end systems for early detection, alerts, and response management Contributes to fulfilling at least four Sustainable Development Goals: Goal 9: Build resilient infrastructure, promote sustainable industrialization, and foster innovation Goal 13: Take urgent action to combat climate change and its impacts Goal 15: Sustainably manage forests, combat desertification, halt and reverse land degradation, halt biodiversity loss Goal 17: Strengthen resource mobilization and revitalize partnerships for sustainable development

4 Recovery and adaptation

Priority	Objective	Areas	Desired Outcomes
Recovery and adaptation "Disaster preparedness needs to be strengthened for more effective response and ensure capacities are in place for effective recovery... Women and persons with disabilities should publicly lead and promote gender-equitable and universally accessible approaches during the response and reconstruction phases" — Sendai Framework for Disaster Risk Reduction (2015-2030)	Enhance whole of community preparedness for ecosystem resilience, recovery, and adaptation	4.1 Community resilience and wellbeing 4.2 Recovery and adaptation 4.3 Wildfire loss and damage data 4.4 Public and ecosystem health	Healthy ecosystems and circular forest-based economies Contributes to fulfilling at least three Sustainable Development Goals: Goal 11: Make cities inclusive, safe, resilient, and sustainable Goal 13: Take urgent action to combat climate change and its impacts Goal 15: Sustainably manage forests, combat desertification, halt and reverse land degradation, halt biodiversity loss

Priority areas for FireTech

This section draws on recent technical workshops, reports, and journal articles to summarize the current state of FireTech, remaining needs and gaps, and key recommendations for funding short- and medium-term priorities.

The review draws on findings and recommendations of the:

1. Wildfire Technology Innovation Summit (March 2019)
2. The Moore Foundation-supported Fire Immediate Response System Workshop (April 2019)
3. The National Fire Protection Association (NFPA) and University of California Berkeley's Workshop on Advancing WUI Resilience (March 2020)
4. Keck Institute for Space Studies' Workshop on Real time Detection and Tracking of Fires that Matter (March 2021)
5. The review also draws on gaps and priorities identified in the Minderoo Foundation's Fire and Flood Resilience Blueprint (2020) for Australia

Priority 1
Risk assessment, modeling, and prediction

Objective

Develop a better understanding and characterization of wildfire risk to communities and ecosystems.

Desired outcome

Robust understanding and characterization of historic, current, and projected risk from wildfires and related hazards to communities and ecosystems.

Areas

Current progress in developing wildfire risk assessments, modeling, and prediction is reflected in four areas:
1.1) High resolution data for mapping
1.2) Fire behavior and human-earth system models
1.3) Data standardization and integration
1.4) Information, communication, and education technologies

Funding Priorities
Short term (2022-23)

- **Invest in high resolution, accurate, real-time, and multi-hazard risk assessments** including mapping terrain, fuels, homes, infrastructure, previous fire ignition points, and water points. Also contributes to Priority 2: Mitigation and risk reduction, Priority 3: Early detection and response management, and Priority 4: Recovery and adaptation outcomes.
- **Support LiDAR mapping of fuel types, including ladder fuels, with satellite observation of changing vegetation conditions,** for example, by identifying recently burned and regrowth areas. Also contributes to Priority 2: Mitigation and risk reduction and Priority 4: Recovery and adaptation.
- **Augment real-time fire behavior models** including the development of a framework and simulation model for fire spread from vegetation into and within a WUI built environment. Also contributes to Priority 2: Mitigation and risk reduction and Priority 3: Early detection and response management outcomes.
- **Support development of national standards for enabling real-time, location-based, and actionable warning information** to be made publicly available for multiple hazard types, including extreme heat, wildland fire, smoke, flooding, debris flow, and mudslides, in timely and accessible formats. Also contributes to Priority 3: Early detection and response management and Priority 4: Recovery and adaptation outcomes.
- **Invest in the integration of multi-hazard pre-event and post-event wildfire data** (including, drought, extreme heat, wind conditions, fire, smoke, flooding, debris flow, landslide, erosion) **in a single data clearing house to enable universal access on a range of operating platforms.** Also contributes to Priority 2: Mitigation and risk reduction and Priority 4: Recovery and adaptation outcomes.
- **Support the training and certification of certified forestry and fire professionals** trained in the deployment of appropriate FireTech—digital, mechanized, and materials. Also contributes to Priority 2: Mitigation and risk reduction, Priority 3: Early detection and response management, and Priority 4: Recovery and adaptation outcomes.

Funding Priorities
Medium term (2023-25)

- **Develop end-to-end human-earth system models** to determine landscape and individual parcel level fire risk based on fire hazard potential, exposure, and social vulnerability data. Also contributes to Priority 2: Mitigation and risk reduction and Priority 4: Recovery and adaptation outcomes.
- **Invest in interconnected systems to link ground, aerial, and space-based data**, including in low connectivity environments. Also contributes to Priority 2: Mitigation and risk reduction, Priority 3: Early response and management, and Priority 4: Recovery and adaptation outcomes.
- **Establish high density, automated, networked weather stations** with micro-wind sensors, in high-risk and low connectivity environments. Also contributes to Priority 2: Mitigation and risk reduction, Priority 3: Early response and management, and Priority 4: Recovery and adaptation outcomes.
- **Develop public-private partnerships to create and manage core WUI research and testing facilities/ hubs** that are geared towards better understanding WUI fires including, fire and wind tunnels, ember facilities, and associated fire testing laboratories. Also contributes to Priority 2: Mitigation and risk reduction and Priority 3: Early response and management outcomes.
- **Expand topics discussed in wildfire education for a range of industry stakeholders, and improve public information, communication, and education technologies,** including for notification and evacuation. Also contributes to Priority 2: Mitigation and risk reduction, Priority 3: Early response and management, and Priority 4: Recovery and adaptation outcomes.

Priority 1
Risk assessment, modeling, and prediction

1.1. High-resolution data for mapping

A. Current state

In recent years, there has been a concerted effort to develop higher resolution data outputs, leveraging artificial intelligence, satellite imagery, and LiDAR to produce detailed and dynamic wildfire risk maps. Some examples of digital technologies in this area include:

- North American Wildfire HD Model, created by RMS in 2019, quantifies the location and severity of wildfire risk at 50-meter resolution. The model characterizes fire spread, ember accumulation, and smoke dispersion.
- California Forest Observatory, formed in 2020, seeks to offer a publicly available, data-driven forest monitoring system that integrates forest structure, weather, topography, and infrastructure from satellite information at 10-meter resolution. Future iterations will use PlanetScope multispectral sensors at 3-meter resolution.
- The Amazon Real Time Fire Monitoring app uses aerosol detection data which is verified with hotspot data and satellite imagery.
- Brazil's national space research institute, Programa Queimadas, uses hotspot data from a range of different satellites to inform its fire dashboard and fire monitoring program.
- InfoAmazonia's Fire Map uses hotspot data from VIIRS—the Visible Infrared Imaging Radiometer Suite instrument.
- DIEGO is a proposed multispectral sensor system with 11 spectral bands and a ground sampling distance of less than 60-meters to reduce the thermal infrared observation gap. Such technology can help understand global fluxes of energy and matter, for example, by assessing sea and land surface temperatures (Schultz et al. 2020).
- Efforts to create higher density weather measurements are also contributing to improved ground-based automated monitoring and coverage. For example, in Australia, the BurnMonitor and Automated Bush Detection use ground sensing cameras for automated monitoring to inform risk assessment and predictions. Attentis Inc. deploys self-powered intelligent sensors to provide dynamic information on a range of environmental factors, including wind, fire, smoke, and heat detection.

B. Needs and gaps

- **High-resolution data inputs are required to increase the accuracy** of wildfire risk assessment and prediction (see Moore Foundation 2019 and Wildfire Technology Innovation Summit 2019).
- **Existing and new satellite data is not consistently factored** into risk assessments, prediction, modeling, and mapping.
- Recent advances in temporal and spatial resolution of satellite data can **provide open-access information** about historical fire footprints, fire detection and progression, and landscape change due to fires, for example, NASA FIRMS (Gollner et al. 2021).

- **High-density weather networks are often isolated, creating fragmented temporal and spatial data availability** (Moore Foundation 2019, Wildfire Technology Innovation Summit 2019).
  - There is a **need for higher density wind and micro-wind measurements**. Wind conditions can vary greatly and change quickly based on terrain, which necessitates real-time wind monitoring for effective wildfire risk management.
  - **Enabling more extensive and real-time reporting of humidity and fuel moisture data** can also contribute to more accurate and dynamic risk assessments.
  - Coverage can be enhanced by **adopting thermal imaging to capture nighttime observations** since many ground-based sensors can be limited to daytime observations (Moore Foundation 2019).
- Many countries, including the United States, currently **lack consistent application of LiDAR mapping to assess vegetation structures and characterize fuel types** (Moore Foundation 2019).

C. Funding priorities

Short term (2022-23)

- **Invest in spatially detailed, accurate, real-time, and multi-hazard risk assessments** created through high-resolution mapping of terrain and fuels, homes, infrastructure, previous fire ignition points, and water points (Moore Foundation 2019). Risk maps should ideally result from personalized and accessible risk evaluations and incorporate ignition risks at landscape and individual parcel scale (Gollner et al. 2021).
- **Augment LiDAR mapping of fuel types, including ladder fuels, with satellite observation of changing vegetation conditions,** for example, by identifying recently burned and regrowth areas (Moore Foundation 2019).

Medium term (2023-2025)

- **Invest in interconnected systems** to link ground (including camera-based sensor networks, LiDAR, and crowd sourced data from social media), with aerial (drone, airborne), and space-based data, including in low connectivity environments (Keck 2021).
- **Invest in higher density automated, networked weather stations with micro-wind sensors** in high-risk and low connectivity wind corridors (Moore Foundation 2019, Wildfire Technology Innovation Summit 2019).

1.2. Fire behavior and human-earth system models

A. Current state

Past and ongoing efforts in wildfire technology development have focused on advances in modeling to better understand the historic, real-time, and projected behavior of wildfires by integrating human-earth system models. Real-time fire behavior modeling has seen advances and can be useful in integrating multiple types of data (for example, fuel, topography, and weather) from multiple sources (ground, air, satellite) to predict fire spread for effective wildfire risk management decisions. Some examples of digitization trends in this area include:

- National Bushfire Simulation Capability, a partnership with the Australasian Fire and Emergency Service Authorities Council (AFAC) supported by the Minderoo Foundation, conducts predictive simulation modeling of fire behavior using real-time fire, fuel, topography, and weather inputs. Through Spark Operational, the capability offers a nationally consistent bushfire modeling and prediction capability for Australia.
- University of California Berkeley's FUEGO utilizes machine learning to detect wildland fires early, measure fire spread with high precision, and feed into fire simulation programs.
- Technosylva's Wildfire Analyst models varying scenarios and output information such as time of fire arrival and perimeter, critical fire paths, HD wind field generation, fuels mapping, and fire behavior calculation.
- WRF-SFIRE is a coupled fire-atmosphere model that models fire predictions under various topographical, meteorological, and vegetation conditions.
- Microsoft's Terrafuse is a hyperlocal model that combines historical fire data, existing physical simulations, real-time satellite observations, and machine learning to determine climate-related risk.
- Willow Labs combines remote sensing data that builds on AI from the ground up to offer structure-specific wildfire analytics and forecasts for insurance underwriting, policy pricing, and personalized homeowner risk scores.

B. Needs and gaps

- A **comparative study of fire models is needed** to determine strengths and weaknesses for real-time applications, such as wildfire risk assessment and response management strategies (Moore Foundation 2019). Also, modeling requires diverse data inputs from different sources with due consideration to data fidelity, latency, resolution, and access. Yet, **metadata is not always well documented, leading to data gaps and lack of interoperability** (Gollner et al. 2021).
- Current models largely **do not account for micro-climates or fire-created weather** which is essential for improving real-time monitoring of fire spread (Moore Foundation 2019).
- There is a need for an **end-to-end human-earth system model** to understand the true dynamics of real-time fire behavior and management. Ideally, such a model will be informed by a user needs assessment including intelligence needs and acceptance thresholds (Keck 2021).

C. Funding priorities

Short term (2022-23)

- **Augment real-time fire behavior models,** including:
  - Conduct a **comparative analysis of current fire models** in use to determine strengths and weaknesses of models for real-time application (Moore Foundation 2019).
  - To predict the **track of maturing wildfire with different probabilities** (Moore Foundation 2019).
  - Create a **wildfire model user data repository and guidelines to streamline modeling processes,** providing the user community with greater access to all available resources and plugging data gaps (Gollner et al. 2021).
  - Develop a **framework and simulation model for fire spread for the built environment** that can simulate and predict spread from vegetation into and within a WUI built environment (Gollner et al. 2021).

Medium term (2023-2025)

- **Augment fire behavior models, to refine and improve scientific understanding of megafires** including what makes a fire large and severe, and mine new data to fill gaps in scientific understanding of ecosystem health, change, and regrowth (Moore Foundation grants, 2021).
- **Develop end-to-end human-earth system models,** including:
  - **Dynamic pre-fire assessments and end-to-end modeling framework for human-earth systems** that identify fire hazard potential as well as **exposure and social vulnerability** (Keck 2021).
  - **Create an integrated infrastructure to catalog, curate, exchange, analyze, and communicate human-earth system data** (Wildfire Technology Innovation Summit 2019).
  - **Synchronize signal data** (live information, infrastructure and/or demographics, and natural environment) **for a range of wildfire risk management applications** including, to gather data around fire footprints, faster and more accurate predictions, and to understand human evacuation behavior during various fire scenarios (Wildfire Technology Innovation Summit 2019, Gollner et al. 2021).

1.3. Data standardization and integration practices

A. Current state

Standardization and integration of high-resolution data can bolster the effectiveness of wildfire risk assessment and prediction capabilities. Some data standardization projects have been developed to map and address WUI risk, including:

- The National Wildfire Coordinating Group's data standards which are commonly used across wildfire information systems and approved by the NWCG Data Standards and Terminology Subcommittee.
- CALFIRE in partnership with USFS and the USDA California Climate Hub and other agencies propose to establish a Forest Data Hub to serve as a multi-institutional information clearinghouse.
- The Fire Hazard Severity Map created by CALFIRE in 2007, designates responsibilities for areas (federal, state, local) and denotes a value of fire hazard severity to each area (CAL Fire 2007).
- Wildfire Risk to Communities offers nationwide interactive maps using data from LANDFIRE, National Weather Service, and the United States Census Bureau. However, data are not locally calibrated and do not provide local, neighborhood, or parcel-scale risk assessments (USDA 2021b).

B. Needs and gaps

- **Free, open access, sustained, accurate, and standardized data continue to be a limitation** in delivering real-time fire risk assessment, modeling, and prediction (Keck 2021). As standardization efforts continue, it is expected that systems for data integration will become more efficient.

- There is a need **for an integrated system of systems linking ground, air, and satellite data** that is accessible in a single data clearinghouse for access across agency interfaces (Keck 2021). Data integration efforts will require **integration across domains** (e.g., meteorology, topography, demography) **and sources** (e.g., ground-based, air-based, satellite-based) (see Wildfire Technology Innovation Summit 2019, Moore Foundation 2019, Keck 2021). It will be important to **include agencies and other end users in the design, assessment, and iteration of such tools to ensure data relevance, use, and interoperability.**
- In addition, a concerted effort is required to **standardize risk mapping methodologies** (Gollner et al. 2021). There is **currently a lack of local, neighborhood, and parcel-level risk mapping for WUI communities.**

C. Funding priorities

Short term (2022-23)

- **Integrate multi-hazard pre-event and post-event wildfire data** (including, drought, extreme heat, wind conditions, fire, smoke, flooding, debris flow, landslide, erosion) **in a single data clearing house to enable universal access on a range of operating platforms** (Wildfire Technology Innovation Summit 2019, Gollner et al. 2021, Keck 2021).

Medium term (2023-2025)

- **Standardize wildfire risk quantification and develop a framework for mapping risk to WUI communities** at landscape and parcel level (Gollner et al. 2021).
- **Standardize data and protocols** including, format, quality, and metadata, such as provided by the national protocols for data collection and archives (Keck 2021, Gollner et al. 2021).

1.4. Information, communication, and education technologies

A. Current state

Creating opportunities to educate the end users of wildfire technologies is important to translate technology pilots and best practices into scalable solutions. Examples of education for such emergency and fire personnel, utilities, including water, power, and transport, and relevant local, state, and federal representatives, include:

- The Western Energy Institute webinar series addressing wildfire risk for utility planners and operations.
- National Security Innovation Network's Beat the Blaze Hackathon, completed in April 2021, focused on information and data sharing solutions to help the National Guard and first-responder end-users solve mission-critical problems.
- The incorporation of immersive technologies such as UC San Diego's "SunCAVE" has been used to train first responders.
- IBM Z Advanced Technology Group's Mainframe System Education – Wildfire Workshops demonstrates how IBM's leading technology works on Mainframe Systems.
- Google.org supports the Forestry & Fire Recruitment Program which supports, trains, and employs formerly incarcerated firefighters.

Design and innovation challenges have also been an effective tool for engaging scientists, researchers, and industry professionals in understanding the development and applications of wildfire technologies. Examples include:

- IBM's Call for Code: Spot Challenge for Wildfires was launched in 2021, in Australia, to better understand the application of machine learning technologies to forecast fire behavior.
- Minderoo Foundation's DataQuest 2020 brought together the best scientific minds in bushfire research, machine-learning, and earth observation in an intensive research sprint to more accurately predict fuel loads across Australia, detect fires earlier, and better predict fire behavior.
- Wonder Labs' Reimagining 2025: Living with Fire Design Challenge, launched in 2021, provides funding for interdisciplinary scientific research by university-led teams collaborating with community partners to facilitate the development of novel projects for reimagining just, equitable, and sustainable pathways to living with fire.

In the United States, several state and federal public awareness campaigns provide guidance and recommendations for making homes and communities fire safe. For example:

- California Wildfire Retrofit Guide
- Ready, Set, Go
- California's Listos Campaign
- USDA's Wildfire Risk to Communities portal
- Emergency Assessment of Post-Fire Debris-Flow Hazards web map that allows the public to understand risk of post-fire debris flows (USGS 2021).
- Also, utility companies regularly release public information regarding mitigation actions and community preparedness (PG&E 2018).

In addition to web-based tools, wildfire education for the public has also been conducted through neighborhood groups such as the Firewise USA program which was launched in 2002 for neighborhood-scale wildfire preparedness. Community organizations such as Firewise fill an important niche for disseminating information and providing resources for communities to adapt to increasing fire risk.

B. Needs and gaps

- There is a general need for **more robust communication networks using predictive, real-time, location-based, and integrated risk communication technology via multiple channels to ensure personalized messaging,** especially in low connectivity areas (Gollner et al. 2021, Keck 2021, Lakhina et al. 2021). Integrated tsunami warnings and location-based earthquake notifications are good examples to learn from.
- Fire management agencies can have limited resources and capacity to uptake new technology and often **need assistance with evaluating new technology and ensuring its interoperability with existing public and agency platforms** in use (Moore Foundation 2019).
- There is a **need for capacity development initiatives that can expand the pool of skilled fire and forestry professionals** capable of assessing and deploying appropriate digital, mechanized, and material technologies for effective wildfire preparedness, response, and recovery.

- There is an opportunity to **integrate more immersive fire training that offers virtual and augmented reality collaborative learning** for fire professionals and community volunteers (Wildfire Technology Innovation Summit 2019).
- Effective fire prevention, mitigation, and recovery measures, especially around the built environment, are still understudied and need **more fire research and testing facilities** (Gollner et al. 2021).
- The research and development of new technology should be directed by a **human-centered design which requires a greater reliance on social science research insights** (Gollner et al. 2021). An interdisciplinary, convergence research approach that is human-centered and community-led can help deliver effective, just, and sustainable solutions (Lakhina et al. 2021).

C. Funding priorities

Short term (2022-23)

- **Develop national standards for enabling real-time, location-based, and actionable warning** information to be made publicly available for multiple hazard types, including extreme heat, wildland fire, smoke, flooding, debris flow, and mudslides, in timely and accessible formats.
- **Capacity development for forestry and fire professionals:**
    - **Support the training and certification of certified forestry and fire professionals** trained in the deployment of appropriate digital, mechanized, and material technologies.
    - **Develop a one-stop operational assistance platform** for fire and forestry professionals to receive advice on evaluating new technologies and ensuring interoperability with existing public and agency platforms in use.
    - **Develop simulations-based curricula on dynamic forest and weather conditions** to facilitate better decision making on what fires to respond to (Gollner et al. 2021).
    - Develop **wearable technologies to enhance first respondent safety,** including first responder location information (Wildfire Technology Innovation Summit 2019).

Medium term (2023-2025)

- **Expand topics discussed in wildfire education for a range of industry stakeholders:**
    - **Create Massive Open Online Courses (MOOCs) with interdisciplinary curricula** to train architects, landscape designers, and planners on WUI design principles (Gollner et al. 2021).
    - **Integrate WUI concepts into fire service curricula based on social science research** insights (Gollner et al. 2021).
    - **Develop public-private partnerships to create and manage core WUI research and testing facilities/ hubs** that are geared towards better understanding WUI fires including, fire and wind tunnels, ember facilities, and associated fire testing laboratories (Gollner et al. 2021).
- **Improve public information, communication, and education technology:**
    - **Implement personalized and accessible risk evaluations in multiple languages** including for medically vulnerable populations and outdoor workers, especially for wildfire and prescribed fire smoke. Engage with users early in the development of technology solutions (Gollner et al. 2021).

- **Make wearables with augmented reality capabilities more widely available** to help the public better understand personalized and landscape risks from wildfires and related hazards (Wildfire Technology Innovation Summit 2019).
- **Create interactive data visualizations and gamify public awareness campaigns** to appropriately translate current fire resilience research in ways that inform the public on how to live with fire, and related hazards such as smoke and post-fire debris flows, in sustainable ways (Gollner et al. 2021). Such awareness campaigns must also work to expand the public's acceptance of prescribed fire as a fire management and prevention method.
- **Increase public awareness of current fire technology efforts and funding allocations** such as, through the release of the State of FireTech, and other reports, media engagement, public webinars, and podcasts.
- **Sponsor capacity development of experts/ leaders to conduct community outreach and build public awareness** on topics such as personalized wildfire risk assessments, mitigation including insurance, home hardening and retrofits for fire and smoke, defensible space, and the use of prescribed fire, and evacuation planning.

Priority 2
Mitigation and risk reduction

Objective

Strengthen risk governance to mitigate and reduce the risk of wildfires to communities and habitat

Desired outcome

Strengthened and diversified capacities for fuel treatment and landscape restoration.

Areas

Recent progress in applying technology innovations for wildfire mitigation and risk reduction outcomes has centered around four areas:
2.1) Utility and asset management
2.2) Land use planning and management
2.3) Managing risk in the built environment
2.4) Fuel management

Funding Priorities
Short term (2022-23)

- **Upgrade utility and asset management systems** including system hardening, weather monitoring, deploying thermal cameras, drones, conducting vegetation management and fuel reduction, among other measures. Also contributes to Priority 3: Early detection and response management and Priority 4: Recovery and adaptation outcomes.
- **Improve data integration and flows to enable real-time and precise decisions** on grid safety and help communities to adequately prepare for necessary public safety power shut offs. Also contributes to Priority 3: Early detection and response management and Priority 4: Recovery and adaptation outcomes.
- **Standardize wildfire risk quantification and mapping methodology** for WUI communities at landscape and parcel level. Also contributes to Priority 1: Risk assessment, modeling, and prediction, and Priority 4: Recovery and adaptation outcomes.
- **Develop wildfire and smoke resilience rating/ score for commercial, public, and residential structures** in collaboration with Insurance Institute for Business and Home Safety (IBHS), LEED, and others, as appropriate. Also contributes to Priority 4: Recovery and adaptation outcomes.
- **Improve WUI retrofit and rebuilding processes, including** quantifying the effectiveness of different kinds of retrofits, including weighing the benefits of installing exterior/interior sprinklers, and home spacing. Also contributes to Priority 4: Recovery and adaptation outcomes.
- Develop and **maintain an integrated database/ app to longitudinally track fuel treatments and monitor outcomes** including from mechanical thinning and prescribed burning for different vegetation types, terrains, and landscapes. Also contributes to Priority 1: Risk assessment, modeling, and prediction and Priority 4: Recovery and adaptation outcomes.

Funding Priorities
Medium term (2023-25)

- **Reduce vulnerabilities in the grid system** and put measures in place for protection of critical infrastructure including system hardening and undergrounding, where appropriate. Also contributes to Priority 3: Early detection and response management and Priority 4: Recovery and adaptation outcomes.
- **Create air regulations and protocols for monitoring and assessing wildfire risk, loss, damage,** including evacuation, mobility, and displacement data collected/ monitored by air. Also contributes to Priority 1: Risk assessment, modeling, and prediction and Priority 4: Recovery and adaptation outcomes.
- Improve understanding, applications, and certifications **for novel and safe retardant/ suppressant technologies for pre-treating vegetation, defending critical infrastructure, and securing evacuation routes.** Also contributes to Priority 3: Early detection and response management and Priority 4: Recovery and adaptation outcomes.
- **Support research-informed WUI guidelines on building construction** and holistic performance-based design for WUI communities. Also contributes to Priority 4: Recovery and adaptation outcomes.
- Accelerate the translation of research **findings** related to wildland fire and smoke **impacts** into **common structural standards and mitigation strategies** that reduce harm to **homes**, buildings, and **critical community infrastructure, including libraries, schools, hospitals, assisted living facilities, and clean air centers.** Also contributes to Priority 3: Early detection and response management and Priority 4: Recovery and adaptation outcomes.
- Enable the **integration of Indigenous, cultural, and contemporary fire management practices** into wildfire risk reduction policy and program implementation. Also contributes to Priority 1: Risk assessment, modeling, and prediction and Priority 4: Recovery and adaptation outcomes.
- Support the development of **novel fuel reduction technology innovations that can address both landscape and individual parcel risks,** including transportation corridors, and utility and asset management objectives. Also contributes to Priority 3: Early detection and response management and Priority 4: Recovery and adaptation outcomes.

Priority 2
Mitigation and risk reduction

2.1. Utility and asset management

A. Current state

Utility and asset management is an important component of wildfire mitigation and risk reduction because of the potential for utility systems to initiate a fire and the high likelihood of utility services to be disrupted during a wildfire event. In addition to decision support tools, utility companies are creating strategic management plans to lower vulnerabilities in their grid systems. For example:

- California's San Diego Gas & Electric (SDGE) uses an advanced camera network, drone technology, underground power lines, steel poles, vegetation management, and advanced wireless communications to lower their disruption risk (San Diego Gas & Electric 2020) SDGE also created the Fire Science and Climate Adaptation Department.
- California's Pacific Gas & Electric (PG&E) in the 2021 Wildfire Mitigation Plan outlined initiatives to build a safer and more resilient grid by deploying ignition probability mapping, weather-driven risk map and modeling, fuel moisture sampling and modeling, continuous monitoring sensors and weather stations, cameras, covered conductor installation and maintenance, system automation, undergrounding, and early fire response drone technology. PG&E also initiated the Community Wildfire Safety Program to support customers, especially those with medical needs, during scheduled Public Safety Power Shut-off (PSPS) events.

Also, digital and material technologies are currently being deployed in this area; some examples include:

- Digital Immune System, created by Dispatchr and Hitachi Consulting, to protect utilities during wildfires and power outages by integrating data for display on one platform to inform real-time management decisions.
- MITIGATE is a platform for automated dispatch of mitigation strategies, control zone grouping of distribution assets, and compliance, reporting, and auditing.
- Overstory uses machine learning to deliver real-time vegetation intelligence, based on high spatial and temporal resolution satellite data, including multi- and hyper spectral imagery, SAR, and video.
- Gridware uses telemetry data to analyze vegetation around utilities.
- Neara conducts grid analysis to understand dynamic risk to assets and prioritize workflows.
- Perimeter Solutions offer a range of fire-retardant materials to protect utilities and infrastructure assets before and during fires, including prescribed burns.

B. Needs and gaps

- Current wildfire mitigation technology applications for utility and asset management provide a suite of helpful decision support tools that providers can use to bolster systems. However, these tools are not yet widely used and **barriers to adoption need to be addressed to increase uptake.**

- In addition, plans such as the ones made by SDG&E and PG&E help organize efforts and meet goals, as well as communicate efforts to the public. These types of strategic plans need to be adopted more widely for utility and asset management, including along transportation corridors and for other critical infrastructure.
- Overall, utility and asset management entities need to **increase system protection capabilities** (Gollner et al. 2021).
- In addition, utility management entities need to **utilize available data flows to enable real-time and accurate decisions** (Wildfire Technology Innovation Summit 2019).

C. Funding priorities

Short term (2022-23)

- **Utility and asset management system advancements:** Upgrade systems by adopting weather monitoring, thermal cameras, drone technology, conducting vegetation management and fuel reduction (Wildfire Technology Innovation Summit 2019).
- **Better utilize available data flows to enable real-time and precise decisions** on grid safety and help communities to adequately prepare for necessary public safety power shut offs (Wildfire Technology Innovation Summit 2019).

Medium term (2023-2025)

- **Increase system protection:** Reduce vulnerabilities in the grid system and put measures in place for protection of critical infrastructure and system hardening including undergrounding lines, wool to steel poles, among other measures (Gollner et al. 2021).

2.2. Land use planning and management

A. Current state

Land use planning is critical for ensuring the adaptive management of high-risk environments including forests and grasslands in the WUI interface and intermix. Developing a robust understanding of how the WUI is growing and why can be essential to implement effective policy and management responses. Some examples of current digital technology applications in this area include:

- "Zombie forests" research in California is helping to advance to identify, map, and co-design adaptive management of landscape-level change to help advance scientific understanding and inform better land-use planning practices and standards.
- Berkeley Lab Foundation is researching ways to improve the simulation and prediction of fire and vegetation change in California over the next decades with implications for where future development occurs (Moore Foundation 2020).
- Land Tender, Vibrant Planet's first product is an interactive cloud-based visualization, planning, and monitoring tool that aims to simplify and streamline land use planning and management by supporting shared stewardship for public and private lands at any scale.
- SILVIS Lab at the University of Wisconsin Madison, has mapped WUI changes within both intermix and interface communities, for 1990, 2000, and 2010, at 30-meter resolution.

B. Needs and gaps

- The **incorporation of fire resilient practices in land-use planning tools need better implementation.** Available guidance is not consistently implemented.
- Critical to the implementation of standards is the **ability to incorporate them into existing agency regulations and planning processes,** such as, Federal Aviation Administration (FAA), National Environmental Policy Act (NEPA), and Community Wildfire Protection Plans (Wildfire Technology Innovation Summit 2019; Gollner et al. 2021).
- There is also a need to **build the advocacy capacities of nonprofits and community-based organizations to hold local land use and planning agencies accountable** in upholding WUI development restrictions.

C. Funding priorities

Short term (2022-23)

- **Standardize wildfire risk quantification and mapping methodology:** Standardize quantification of wildfire risk and develop a framework for mapping risk to WUI communities at landscape and parcel level (Gollner et al. 2021).

Medium term (2023-2025)

- **Develop protocols for data collected by air:** Work with FAA to create specific regulations and protocols for wildfire risk, loss, and damages data collected by air (Wildfire Technology Innovation Summit 2019).

2.3. Managing risk in the built environment

A. Current state

Development in the WUI requires data-driven guidelines and standards to create resilient communities. There are several projects currently underway that offer metrics and standards for assessing structures, landscape, and fire-resilient designs. Examples of such standards and guidance include:

- Safer from Wildfires, a California interagency initiative recommends a three-pronged approach to wildfire resilience in the WUI: reducing structural vulnerability, creating defensible space in the immediate surroundings, and preventing fire spread in neighborhoods.
- Wildfire Prepared Home provides structural mitigation measures for wildfire resilience in the WUI.
- Building a Wildfire-Resistant Home: Codes and Costs outlines cost differences between a typical home and a fire-resistant one.
- Pathways for Building Fire Spread at the WUI provide some understanding of how to prevent and protect fire spread.
- WUI Building and Fire Codes and Standards Project to assess and integrate risk reduction tools and practices in WUI building codes and standards.
- Guidance Document for Incorporating Resiliency Concepts into NFPA Codes and Standards, covers the background, risk-informed approaches, existing and future NFPA codes and standards, and emergency preparedness planning information.

- Increasingly, FireTech startups are focused on quantifying and rating parcel-level structural vulnerability. For example:
  - Firemaps is currently using drone-based surveys to simplify the home hardening and defensible space process, in turn creating a new marketplace for homeowners and renters.
  - Z-Fire, Zesty's AI driven predictive scoring model is being piloted with insurers such as Farmers Insurance and Aon to assess property level wildfire risk to homeowners in California and recommend mitigation actions.
  - BlackSwan Analytics constructs an individualized wildfire risk pricing model that offers property owners a comprehensive wildfire risk assessment based on fuel source, ignition source, susceptibility, and hazard exposure.
  - FlameMapper uses machine learning to predict the relative loss and survivability of individual structures during a wildfire.

B. Needs and gaps

- There is a **need to test methods and codes for WUI development, understand the co-benefits of retrofits and vegetation management, and quantify retrofit effectiveness** (Gollner et al. 2021).
- **Currently, there is insufficient guidance on environmental efficiency, structural mitigation, and cost-effective retrofits to protect structures and inhabitants** from the long-term health impacts of wildfire smoke (Lakhina et al. 2021).
- There needs to be a greater focus on **encouraging insurance companies to offer discounts and incentives for retrofitting older homes.**
- Also, there is a general need **for more precise community and parcel-level vulnerability analysis** (Gollner et al. 2021).

C. Funding priorities

Short term (2022-23)

- **Improve WUI retrofit and rebuilding processes:**
  - Investigate the co-benefits of retrofits and actions alongside vegetation management (Gollner et al. 2021).
  - Quantify the effectiveness of different kinds of retrofits, including weighing the benefits of installing exterior/interior sprinklers, and home spacing (Gollner et al. 2021).
  - Develop guidance for resilient rebuilding that exceeds current code requirements (Gollner et al. 2021).
- **Develop wildfire and smoke resilience rating/ score for commercial, public, and residential structures** in collaboration with Insurance Institute for Business and Home Safety (IBHS) and LEED in the United States, or similar standards elsewhere.

Medium term (2023-2025)

- **Research-informed WUI guidelines on construction:**
  - Develop a voluntary homeowner wildfire rating (i.e., LEED) (Gollner et al. 2021).
  - Develop a methodology for holistic performance-based design for WUI communities (Gollner et al. 2021).

- Compare international WUI building codes and outcomes (studies to quantify the effectiveness of outreach and mitigation measures) (Gollner et al. 2021).
- Develop test methods and codes for construction materials and assemblies (Gollner et al. 2021).
- Improve understanding of firebrands (Gollner et al. 2021).
- Improve and standardize community-wide design principles rather than parcel-level only (Gollner et al. 2021).

- **Invest in environmentally safe novel retardant/ suppressant technologies** for pre-treating vegetation, defending critical infrastructure, and securing evacuation routes.
- Accelerate the translation of research **findings** related to wildland fire and smoke **impacts** into **common structural standards and mitigation strategies** that reduce harm to **homes,** buildings, and **critical community infrastructure, including libraries, schools, hospitals, assisted living facilities, and clean air centers.**

2.4. Fuel management

A. Current state

There are some emerging digital, mechanized, and material technologies being applied for more effective fuel management. Some recent examples of digital technologies include:

- Overstory uses machine learning to interpret satellite imagery and climate data to deliver real-time vegetation intelligence.
- Pyrezo offers a wildfire risk assessment tool to identify, measure, and prioritize fuel mitigation at community and individual parcel levels.
- Madronus Wildfire Defense offers end-to-end wildfire assessments, inspections, fuels reduction, vegetation management, and forest and wildland restoration services.

In addition to digital technologies, novel mechanized and material technologies are also being developed for fuel management. These technologies are contributing to the development of an expanded and reskilled forest restoration and prescribed burn workforce to act as force multipliers to reach more untreated lands, especially in the WUI interface and intermix. Examples include:

- BurnBot, a mechanized ground-based fuel treatment solution for conducting safe, all-weather, smoke-free controlled burns adjacent to homes, power line easements, and transportation corridors.
- IGNIS from Drone Amplified delivers an aerial approach to assisting safer controlled burn and fuel treatments.

B. Needs and gaps

There is a need to **longitudinally track treatment outcomes from mechanical thinning and prescribed burning for different vegetation types, terrains, and landscapes.**

There is also a need to **facilitate a transition from reliance on historical models to explore parametric insurance** models to effectively assess and score emerging individual parcel and landscape scale wildfire risk.

Finally, there is a **critical need to rapidly scale fuel treatments.** However, scaling remains a challenge due to the lack of workforce capacities and the adoption of emerging technologies.

C. Funding priorities

Short term (2022-23)

- Develop and maintain an **integrated database to longitudinally track fuel treatments and monitor outcomes including from mechanical thinning and prescribed burning** for different vegetation types, terrains, and landscapes.

Medium term (2023-2025)

- Enable the i**ntegration of Indigenous, cultural, and contemporary fire management practices** into wildfire risk reduction policy and program implementation.
- Support the **development of novel fuel reduction technology innovations that can address both landscape and individual parcel risks,** including transportation corridors, and utility and asset management objectives.

Priority 3
Early detection and response management

Objective

Invest in effective wildfire risk management for community wellbeing and ecosystem resilience.

Desired outcome

Enhanced end to end systems for early detection, alerts, and response management.

Areas

Recent progress in early detection and response management has centered around four areas:
3.1) Multi-level fire and smoke detection
3.2) Early response
3.3) Incident management
3.4) Notification and evacuation systems

Funding Priorities
Short term (2022-23)

- **Build wireless integrated sensor networks** including **ground cameras with thermal imaging capability** to augment early fire and smoke detection capabilities across high-fire risk areas with complex microclimates and wind corridors. Also contributes to Priority 1: Risk assessment, modeling, and prediction outcomes.
- Sponsor regular **opportunities for demo days to showcase emerging early fire detection and suppression technologies and build trust with the user community.** Also contributes to Priority 1: Risk assessment, modeling, and prediction outcomes.
- **Develop standard methodology and operating procedure to prioritize resources and capacities for fires that matter** and are most likely to get out of control. Also contributes to Priority 1: Risk assessment, modeling, and prediction outcomes.
- **Develop standards for enabling real-time, location-based, and actionable warning information** to be made publicly available for multiple hazard types, including extreme heat, wildland fire, smoke, flooding, debris flow, and mudslides, in timely and accessible formats. Also contributes to Priority 1: Risk assessment, modeling, and prediction and Priority 4: Recovery and adaptation outcomes.
- **Leverage available community demographics data and research on social behavioral factors for evacuation modeling,** including development of trigger points, highway and shelter capacity mapping, and improvement of predictive evacuation modeling. Also contributes to Priority 1: Risk assessment, modeling, and prediction and Priority 4: Recovery and adaptation outcomes.

Funding Priorities
Medium term (2023-25)

- **Develop autonomous vehicles with smoke detection systems** patrolling high-risk WUI areas. Also contributes to Priority 1: Risk assessment, modeling, and prediction and Priority 4: Recovery and adaptation outcomes.
- **Increase the number of manned aircraft and crews with fire detection sensors.** Also contributes to Priority 1: Risk assessment, modeling, and prediction and Priority 4: Recovery and adaptation outcomes.
- **Improve satellite-based, automatic smoke plume recognition that uses AI machine learning** to understand the size of the plume and smoke dispersion, fire size, and fuel consumed. Also contributes to Priority 1: Risk assessment, modeling, and prediction and Priority 4: Recovery and adaptation outcomes.
- Develop **capability for nighttime airborne tanker delivery especially in smoke-obscured** environments with strong winds. Also contributes to Priority 1: Risk assessment, modeling, and prediction and Priority 4: Recovery and adaptation outcomes.
- **Create a unified platform to collect and analyze multiple sources of distributed and dynamic data** and develop integrative models for synergistic decision support that can be seamlessly used throughout the fire mitigation-preparedness-response-recovery continuum. Also contributes to Priority 1: Risk assessment, modeling, and prediction, Priority 2: Mitigation and risk reduction, and Priority 4: Recovery and adaptation outcomes.
- **Bolster notification and evacuation communication technology,** increasing reliance on real-time data sensor networks for evacuation planning, response, mapping, and modeling. Also contributes to Priority 1: Risk assessment, modeling, and prediction, Priority 2: Mitigation and risk reduction, and Priority 4: Recovery and adaptation outcomes.

Priority 3
Early detection and response management

3.1. Multi-level fire and smoke detection

A. Current state

There are generally four components to early fire detection: a) detecting the location of the fire start, b) using multivariate sensors (satellite, air, ground-based) to determine c) the rate and area of spread, and d) assessing and communicating the risk to all relevant institutions and communities in a timely and appropriate manner (Moore Foundation 2019). Several digital technologies have been developed to assist with multi-level fire and smoke detection in recent years:

- Satellite-based data provides near real-time active fire data for a range of applications. For example:
  - NASA's Fire Information for Resource Management System (FIRMS) distributes near-real time thermal data within 3 hours of observation.
  - Planet, Salo Sciences, and Vibrant Planet's partnership resulted in the California Forest Observatory which contributes to early detection capabilities, also see Priority 1.1.
  - Fion uses satellite imagery, wind vectors, vegetation indices, and topography data with machine learning to provide fire departments, forestry services, financial institutions, and insurance companies with fire detection, spread prediction, and destruction estimations.
- Unmanned Aerial Vehicle technology is increasingly being developed and applied for early detection and suppression of wildfires. For example:
  - Robotto incorporates AI, machine learning, and edge computing to deploy autonomous drones into remote areas, providing first responders with important real-time information and situational awareness.
  - KrattWorks deploys autonomous surveillance system drones with novel machine vision technology to detect fires.
  - The Rain System is an unmanned aerial suppression system that detects and suppresses wildfires within 10 minutes of ignition.
- Ground-based sensors can also be used to increase the density of weather measurement networks, as mentioned in Priority Area 1, and provide real-time operational intelligence. For example:
  - One of the earliest and currently most widely used ground-based sensors include the AlertWildfire Network of 160 cameras across the state of California.
  - WeatherNode is currently integrating with AlertWildfire to provide visual and wind situational awareness in Northern California.
  - Descartes Lab's Wildfire Detector leverages satellite data and AI to detect and send accurate fire alerts within nine minutes.
  - Delphire uses onboard AI to continuously monitor powerlines for a set of variables in addition to data provided by visual environmental sensors.

  - Dryad's large-scale IoT network sensors can detect wildfires while providing continuous insights into the microclimate and forest health.
  - UC Berkeley's FUEGO delivers a machine learning smoke detection system with 200 fire tower cameras with ~95% detection accuracy.
  - Pano provides actionable intelligence to utilities, enterprises, homeowners, and fire professionals by deploying AI for fire and smoke detection and prediction.
  - Robotics Cats deploys an AI powered Wildfire Detection System that combines AI, computer vision, and IoT, to deliver early detection robots and a citizen facing ReportFire app.

B. Needs and gaps

- Satellite-based data **needs increased spatial and temporal resolution to increase the accuracy and timing of fire and smoke detection** (Moore Foundation 2019; Gollner et al. 2021).
  - A geostationary sensor with fire and smoke detection capability at 500m resolution would significantly enhance current efforts (Moore Foundation 2019).
  - Satellite data with **calibrated shortwave, mid, and longwave infrared fire** detection can enable more precise fire detection (Moore Foundation 2019).
  - **Automated plume recognition and artificial intelligence (AI)** can enable fire detection even in the presence of thick clouds and smoke (Moore Foundation 2019).
- Ground-based sensors (e.g., cameras, weather stations) provide critical data for fire detection; however, these systems **remain fragmented and limited** (Gollner et al. 2021). Specifically, there is a need for a **higher density network of automated, networked wind measurements or weather stations** to support operational decisions (Moore Foundation 2019).
- **Air-based systems development is currently limited to only a few applications in early detection and response,** with a general need to explore more sophisticated fire and smoke detection capabilities, in particular triangulating real-time data from satellite and ground-based sensors.
- **Autonomous vehicles have not been fully explored as an air-based solution,** considering manned aircrafts require skilled staff, can be expensive, and are limited in operating times and abilities (Moore Foundation 2019; Gollner et al. 2021).

C. Funding priorities

Short term (2022-23)

- Deploy **field sensor networks and ground cameras with thermal imaging capability** across high-fire risk areas with complex microclimates and wind corridors (Moore Foundation 2019, Gollner et al. 2021).
- **Establish continuous monitoring through medium or high altitude long-endurance drones** to provide information about fire and act as a communication link through radio and relay voice and data between front line firefighters and those at the incident command center (Moore Foundation 2019).
- **Improve spatial and temporal resolution of satellite-based fire detections** (Gollner et al. 2021).

Medium term (2023-2025)

- **Develop autonomous vehicles with smoke detection systems** patrolling high-risk areas at the WUI (Moore Foundation 2019).

- **Increase the number of manned aircraft and crews with fire detection sensors** (Moore Foundation 2019).
- **Design a geostationary sensor with fire detection capability at 500m spatial resolution** (Moore Foundation 2019).
- **Design a satellite-based, automatic smoke plume recognition that uses AI machine learning to understand the size of the plume and smoke dispersion, fire size, and fuel consumed** (Moore Foundation 2019).

3.2. Early Response

To improve the scope of early fire response technology applications, it is critical to decrease the time between ignition and fire suppression. Some examples of technology applications in this sector include:

- The U.S. Department of Interior's concept of optionally piloted helicopters offers the first direct action unmanned aircraft system solution for initial/extended attack and logistics support, covering night and during smoke conditions.
- Strong Water Technology, which enhances firefighting effectiveness by increasing water capacity.
- Erickson Helicopters' S-64 Air Crane® combines the capacity of a fixed wing tanker with the accuracy, speed, and refill capacity of a helicopter.
- Also see The Rain System, as described in Priority 3.1.
- FireTech Connect provides novel funding and programmatic support to emerging fire technology entrepreneurs and startups in Australia, such as Fireball International, Helitak Fire Fighting Equipment, and BIA5 Pty Ltd.

B. Needs and gaps

- As mentioned in Priority Area 1, there is a **need to improve spatially explicit modeling of pre-fire risk** to help fire responders before a fire event that considers the fire, local terrain, fuels, infrastructure, and current conditions in a dynamic manner (Moore Foundation 2019).
- More research is needed to **understand which fire detections matter through incorporating contextual information and pre-fire assessments in the fire detection process** (Moore Foundation 2019; Keck 2021). This would call for a shift in the traditional thinking that every fire demands a response to a more selective response strategy informed by forest management principles and risk models (Moore Foundation 2019).
- There is a significant shortage of available resources for suppression, especially when there are concurrent fires (Wildfire Technology Innovation Summit 2019). There is a **need for more early detection and suppression technology to meet this limitation** (Wildfire Technology Innovation Summit 2019). This shortage can result in conservative estimates of resources for initial attack and there is also **potential distrust of new technologies** (Moore Foundation 2019).
- In addition, there is a **need to improve manned aircraft's ability to handle harsh conditions such as night-time tanker delivery or smoke-obscured environments** (Moore Foundation 2019).

C. Funding priorities

Short term (2022-23)

- Sponsor **opportunities for demo days to showcase emerging early fire detection and suppression technologies.**
- Continue to develop a robust methodology and simulations to **prioritize suppression resources and capacities for fires that matter** and are most likely to get out of control.

Medium term (2023-2025)

- Focus funding on **initial-attack oriented augmented infrared to identify ignition quickly** (Wildfire Technology Innovation Summit 2019).
- Develop **capability for nighttime airborne tanker delivery especially in smoke-obscured** environments with strong winds (Moore Foundation 2019).

3.3. Incident management

A. Current state

Data integration and standardization for display on a singular platform bolsters effective communication of important information and coordinated fire management efforts. Examples of digital technologies that currently facilitate incident management decision-making processes include:

- SCOUT (State Situational Awareness Platform) is a California-based mobile app for operational and tactical collaboration for emergency responders during emergencies.
- Jupiter FireScore combines fire behavior, weather, and climate modeling for a real-time decision support system.
- Technosylva's fiResponse is a platform to support decision-making through the entire lifecycle of an incident and allows for incident management, resource management, resource tracking, and situational awareness. Technosylva's Wildfire Analyst Enterprise software offers Firecast and Firesim which enable early wildfire detection and projections of wildfire paths.
- Intterra offers an all-hazards common operating picture with real-time situational awareness and aggregate data on a single platform accessible across emergency response agencies.
- University of California San Diego's WIFIRE Firemap offers a real-time operational tool that enables environmental data visualization, fire behavior modeling, and forecasting by integrating and interpreting data from weather stations, forecasts, cameras, and air quality.
- Cornea, a spin-up by public sector focused venture studio Hangar, merges geographical, weather, and historical fire data into a machine learning model that can augment situational awareness for frontline firefighters while presenting a common operating picture to local, state, and federal agencies.
- The Geographic Area Coordination Center provides a centralized database for incident information, predictive services, logistics/dispatch, and administrative resources (Geographic Area Coordination Center 2021).

B. Needs and gaps

- There is a remaining need to **address interoperability and technological fragmentation**

issues so that local emergency and fire response organizations can be offered a common operational intelligence platform that integrates various sources of data for real-time decision-making (Moore Foundation 2019).

- While several initiatives currently exist to enable better decision-making, **an assessment of the current data and technology needs of incident commanders does not exist** (Moore Foundation 2019). Based on these findings and working with existing programs, a co-developed and shared platform can be made available for synergistic decision support (Moore Foundation 2019; Wildfire Technology Innovation Summit 2019).

C. Funding priorities

Short term (2022-23)

- **Needs assessment of relevant data and technology:** Conduct a current needs assessment and landscape analysis of relevant data and technology that already exist for incident commanders (Moore Foundation 2019).
- **Improve next-day and highly localized fire risk calculations** enabling targeted alerts for communities and individual parcels (Gollner et al. 2021)

Medium term (2023-2025)

- **Unified platform for interagency coordination:** Create a unified platform to collect and analyze multiple sources of distributed and dynamic data and/or develop integrative models for synergistic decision support that can be seamlessly used throughout the fire mitigation-preparedness-response-recovery continuum (Moore Foundation 2019; Wildfire Technology Innovation Summit 2019).

3.4. Notification and evacuation systems

A. Current state

There have been some advances to notification and evacuation systems because of integration with real-time models. For example, cloud-based platforms are helping first responders plan, train, and implement evacuations based on pre planning, training and drills, and targeted, reliable communication with affected populations. Examples of digital technologies in this space include:

- Everbridge offers a unified notification and emergency management platform for multiple threat types, including notifications via text, voice, and email, in multiple languages.
- Zonehaven, a Genasys company, is a cloud-based evacuation notification platform that helps first responders plan, train, and execute live all-hazard evacuations, while bridging safety communications with the public.
- Watch Duty, a volunteer citizen information service, provides crowdsourced and real-time information about fire movement and firefighting efforts enabled by live photos and push notifications of on the ground conditions.
- Of increasing significance are also county-led innovations, such as the Ready Nevada County Dashboard, which provide residents with real-time location-based emergency information, alerts, and notifications through multiple channels and languages.

B. Needs and gaps

- **Notification and evacuation systems need to be better informed by social science insights** on evacuation scenarios and models to inform decisions (Gollner et al. 2021).
- There also needs to continue efforts in the **personalization of notification and evacuation systems to make them more inclusive and targeted for specific access, functional, and linguistic needs** (Wildfire Technology Innovation Summit 2019, Gollner et al. 2021, Lakhina et al. 2021).
- In addition, **warning systems, including alert level messaging, need to be standardized** across state and county boundaries (Gollner et al. 2021).

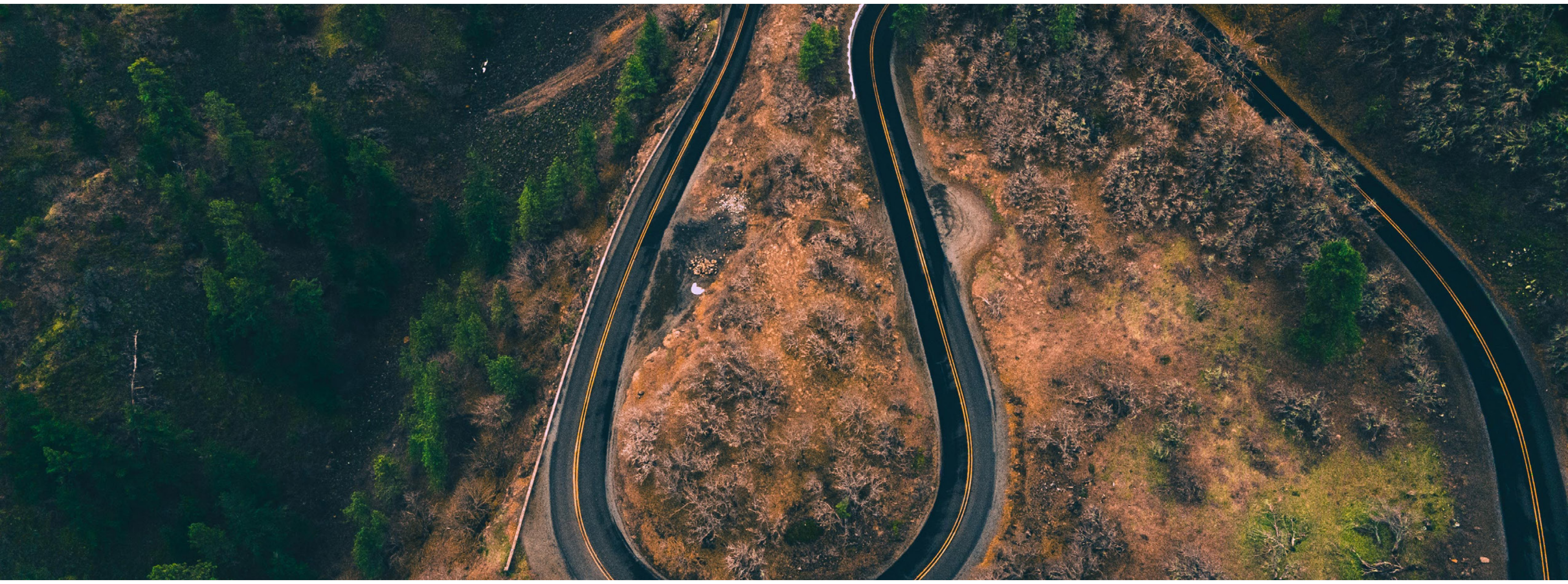
C. Funding priorities

Short term (2022-23)

- **Invest in alternative means of communicating real-time alerts, such as WEA, TV, and local and radio channels in multiple languages,** and identify those communication modes that could still be used in longer-term power outages, e.g., community warning sirens or Ham radios.

Medium term (2023-2025)

- Continue to **develop real-time fire modeling tools** which can be tied to evacuation and notification systems to inform agency and public decisions about when and where to evacuate (Gollner et al. 2021).
- **Leverage available community demographics data and research on social behavioral factors for evacuation modeling,** including development of trigger points, highway and shelter capacity mapping, and improvement of predictive evacuation modeling.
- **Bolster notification and evacuation communication technology,** increasing reliance on real-time data sensor networks for evacuation response, mapping, and modeling. Personalized evacuation routing can be integrated with pre-existing navigation apps such as Google Maps and Waze (Gollner et al. 2021).



Priority 4
Recovery and adaptation

Objective

Enhance whole of community preparedness for ecosystem resilience, recovery, and adaptation

Desired outcome

Healthy ecosystems and circular forest-based economies

Areas

Recent progress in community resilience has centered around four areas:
4.1) Community resilience and wellbeing
4.2) Recovery and adaptation
4.3) Loss and damage data
4.4) Ecosystem health

Funding Priorities
Short term (2022-23)

- **Create a single data clearing house to integrate multi-hazard pre-event and post-event data** (including, drought, extreme heat, wind conditions, fire, smoke, flooding, debris flow, landslide, erosion) to enable universal data access on a range of agency operating platforms. Also contributes to Priority 1: Risk assessment, modeling, and prediction, Priority 2: Mitigation and risk reduction, and Priority 3: Early detection and response management outcomes.
- **Improve post-fire data collection methods and tools by** including data on smoke dispersion, flooding, landslides, mudslides, erosion, rehabilitation, and restoration of burnt areas, as well as **monitoring long-term community recovery and wellbeing data,** including public health, poverty, displacement, and housing instability trends. Also contributes to Priority 1: Risk assessment, modeling, and prediction, Priority 2: Mitigation and risk reduction, and Priority 3: Early detection and response management outcomes.
- **Improve post-disaster information sharing and coordination** between responding public, nonprofit, and funding agencies (e.g., for case management). Also contributes to Priority 1: Risk assessment, modeling, and prediction, Priority 2: Mitigation and risk reduction, and Priority 3: Early detection and response management outcomes.
- **Assess economic incentives and disincentives for wildfire recovery and adaptation programs,** including managed retreats, government buyouts, and insurance reforms, among other measures. Also contributes to Priority 2: Mitigation and risk reduction outcomes.
- Support the **development of adaptive land management tools to identify and monitor areas that would benefit from regular fuels reduction, controlled burning, and ecological thinning,** as appropriate. Also contributes to Priority 1: Risk assessment, modeling, and prediction and Priority 2: Mitigation and risk reduction outcomes.

Funding Priorities
Medium term (2023-25)

- **Improve digital and wireless connectivity** for displaced and low-income residents to ensure more effective wildfire response and recovery. Also contributes to Priority 1: Risk assessment, modeling, and prediction, Priority 2: Mitigation and risk reduction, and Priority 3: Early detection and response management outcomes.
- Support the **integration of Indigenous, cultural, and contemporary fire management practices into wildfire recovery and adaptation programs.** Also contributes to Priority 1: Risk assessment, modeling, and prediction, and Priority 2: Mitigation and risk reduction outcomes.
- **Identify and invest in large scale forest and watershed restoration projects** that contribute to sustainable local forest economies, including through emerging carbon markets and forest products, such as biochar. Also contributes to Priority 1: Risk assessment, modeling, and prediction, and Priority 2: Mitigation and risk reduction outcomes.
- Wildfire recovery and adaptation measures can be **expanded to incorporate nature-based solutions for ecosystem-based adaptation,** which can include measures for drought mitigation and creating a greenbelt to serve as a fuel break while restoring habitat and improving air quality. Also contributes to Priority 2: Mitigation and risk reduction outcomes.
- **Pilot innovative insurance offerings** that can substantially reduce individual parcel level and landscape scale risk for WUI communities. Also contributes to Priority 1: Risk assessment, modeling, and prediction, and Priority 2: Mitigation and risk reduction outcomes.

Priority 4
Recovery and adaptation

4.1. Community resilience and wellbeing

A. Current state

Wildfire recovery is a complex process and can vary depending on the needs of affected communities, especially vulnerable populations. Increasingly, digital technologies can be usefully applied for community resilience and recovery after wildfires:

- CrisisReady predicts and responds to wildfire crises by mapping fires, power outages, and medical vulnerability in California. Initially developed to manage COVID-19, this program was also deployed during the 2020 California wildfires to facilitate collaboration amongst agencies and predict and respond to care needs.
- Tetra Tech provides digital tools to track debris removal, hazardous waste, and asbestos, enabling communities to rebuild.

The effect of wildfires on public health and wellbeing is a relatively new area of research. Some examples of scientific research and technology innovations in this area include:

- EPA funded public health research examines how wildfire smoke affects humans, animals, and plants, in a range of fire conditions, including fine particle pollution from wildfire and prescribed fire, and the impact of historical and future fires under various climate scenarios on air quality, public health, and environmental management.
- The Wildfire Smoke: A Guide for Public Health Officials (2021) developed by the California Air Resources Board (CARB) and the California Department of Public Health (CDPH) enables public health officials to prepare for smoke events by implementing mitigation measures and communicating smoke risk to protect the public.
- AirNow and the US Forest Service's Fire and Smoke Map give real time updates on fire events and smoke dispersion across the United States.
- Minderoo Foundation's Fire & Flood Resilience Blueprint enables intenerated community-led resilience programs which include initiatives such as temporary accommodation pods, infrastructure for agriculture, social programs, including mental health for youth, and mobilizing disaster resilience volunteers.

B. Needs and gaps

- There is a **general lack of support for localized solutions to build wildfire resilient communities.** Community resiliency programs are still in their infancy and would benefit from focused efforts in reach and impact (Keck 2021).
- Firewise programs across the United States have helped increase neighborhood-level preparedness, however, **expanding to the community level could increase preparedness** (Gollner et al. 2021).
- In addition, it would be helpful to review all previous efforts for community resiliency to understand what works and what areas need improvement.

- There is also a **need to learn from traditional ecological practices** because they consider a more holistic view of fire feedback loops between the natural system and the human system (Keck 2021).
- **Wildfire smoke is a new area of concern** and, in general, needs much more research to understand the structural and non-structural impacts of smoke on public health (Gollner et al. 2021).

C. Funding priorities

Short term (2022-23)

- Enable **better data and tracking of physical, social, and psychological health outcomes** of impacted residents.
- Develop **methods to collect and apply real-time structure loss data and increase use of satellite and other real-time data for decision-making** and post-event data collection (Gollner et al. 2021).
- **Improve post-disaster information sharing and coordination** between responding public, nonprofit, and funding agencies (e.g., for case management).
- Support research and technology development to holistically address the impacts of wildfires, and smoke, on public health (Gollner et al. 2021).

Medium term (2023-2025)

- **Expand the footprint of neighborhood preparedness programs, such as the Firewise program, across WUI communities** (Gollner et al. 2021).
- **Improved internet connectivity post disaster response,** as displaced low-income residents often find themselves without the needed connectivity to recover (e.g., applying for FEMA individual assistance).
- **Enable the integration of Indigenous, cultural, and contemporary fire management practices into wildfire risk reduction policy and program implementation.**

4.2. Recovery and adaptation

A. Current state

A significant component of recovery and adaptation is how communities are rebuilt after a fire. Post-wildfire events, houses are often rebuilt in impacted neighborhoods due to the tensions around managed retreats/resilience and rebuilding, with the latter often driven by insurance incentives and emotional attachment to a sense of community and place. In most communities affected by wildfires and related hazards, homes are rebuilt with some home hardening improvements, but they are still rebuilt in high fire risk areas. Some FinTech offerings could help address wildfire recovery and adaptation in innovative ways, examples include:

- Delos Insurance merges ecological, topological, climatic, and ignition data sets with spatial AI to deliver predictive wildfire analytics to homeowners, including home hardening and defensible space suggestions to protect against total loss.
- RedZone provides assessments of loss potential based on historical loss data to better inform insurer's underwriting decisions.
- Kettle uses machine learning to offer a reinsurance model for predicting the catastrophic impacts of climate change, including wildfires.

B. Needs and gaps

- There needs to be a **continued interdisciplinary effort towards understanding recovery and adaptation processes** from fire and cascading hazards (Gollner et al. 2021).
- There is general agreement that **incorporating longitudinal studies on recovery and adaptation processes will help examine place-based and underlying drivers.**
- There is a general need to **explore insurance-led innovations** in helping homeowners and communities' recovery from wildfires and adapt to changes in their environment.

C. Funding priorities

Short term (2022-23)

- **Assess economic incentives and disincentives for wildfire recovery and adaptation programs,** including government buyouts and insurance reforms, among other measures.
- **Address the ground-aerial-space data integration gap to contribute to critical pre-event applications,** such as more targeted defensible space inspections **and post-event investigations,** including case management (see Keck 2021 and Gollner et al. 2021).

Medium term (2023-2025)

- **Pilot innovative insurance offerings** that can substantially reduce individual parcel level and landscape scale risk for WUI communities.
- Support **convergence research,** education, and training to expand the number of students and researchers **contributing interdisciplinary insights on wildland fires and related hazards, including drought, extreme heat, smoke, flooding, debris flow, and mud/landslides.**

4.3. Wildfire loss and damage data

A. Current state

To improve recovery and adaptation processes, post-fire data collection is necessary, some examples of initiatives in this area include:

- Pre-fire and Post-fire Data Studies in the WUI discuss the extent of data collected by previous studies.
- CCST's Cost of Wildfire report (2021) indicates a lack of damage loss data in terms of public health and community wellbeing outcomes.
- Drones are becoming especially useful for gathering data during and post-wildfires. For example, UC Berkeley is currently developing data-gathering drones for predicting a fire's path, as well as exploring giant air scrubbers to suck smoke-filled air from the sky.

B. Needs and gaps

- **Post-fire data collection, both short-term and long-term, needs to be improved** through increased quality and standardization of measurements (Gollner et al. 2021).
- There is a need for **more granular social vulnerability data and analysis,** especially for marginalized populations such as undocumented workers and people living in subsidized housing in fire hazard zones.

C. Funding priorities

Short term (2022-23)

- **Work with community-based organizations and local authorities to improve post-fire damage, loss, and mobility data collection efforts** including from smoke, landslides, mudslides, erosion (Gollner et al. 2021).
- **Develop systems to collect and monitor robust exposure and social vulnerability data** to longitudinally track the physical, social, economic, and psychological outcomes of wildfire and related hazards on impacted populations.

Medium term (2023-2025)

- **Integrate multi-hazard pre-event and post-event wildfire data** (including, drought, extreme heat, wind conditions, fire, smoke, flooding, debris flow, landslide, erosion) **in a single data clearing house to enable universal access on a range of operating platforms** (Wildfire Technology Innovation Summit 2019, Gollner et al. 2021, Keck 2021).
- **Improve post-fire data collection methods and tools** by including data on smoke dispersion, flooding, landslides, mudslides, erosion, rehabilitation, and restoration of burnt areas, as well as **monitoring long-term community recovery and wellbeing data**, including public health, poverty, displacement, and housing instability trends (Gollner et al. 2021, Lakhina et al. 2021).

4.4. Ecosystem health

A. Current state

Supporting ecosystem health is an important strategy to prevent and recover from wildfires and related hazards. Increasingly, digital, robotic, and material technologies are being deployed in conjunction with innovations in FinTech resulting in the deployment of green, blue, and grey infrastructure:

- DroneSeed enables rapid wildfire recovery by enabling drone-based reforestation at scale.
- Caribou Mobile Biorefinery which assists in converting biomass into useful forest products at the point of forest clearing and wildfire recovery operations.
- The Tahoe Fund's Smartest Forest on the Planet initiative seeks to deploy a range of sensing technologies using innovative financing models, including public-private partnerships, to restore the Tahoe forest and substantially reduce wildfire risk.
- The Nature Conservancy and Willis Towers Watson recently piloted a novel wildfire resilience insurance project through the French Meadows Restoration project in the Sierra Nevada with the aim of determining how the risk reduction benefits of ecological forestry practices can be incorporated in insurance modeling, structuring, and pricing resulting in insurance premium savings for communities and businesses in or near forests.
- CrowdDoing, a global volunteer driven collaborative, brings together social enterprises, technology startups, universities, and small businesses, to co-develop novel financing and nature-based solutions for drought mitigation and wildfire risk reduction.

B. Needs and gaps

- Several uncertainties remain in **understanding how forest-related carbon emissions** will affect ecosystem health over the medium to long term, especially regarding animal habitats, vegetation health, and fire regimes.

- Private and public land managers currently do not have access to **adaptive land management tools** to longitudinally evaluate pre- and post-fire forest treatments.
- Wildfire risk reduction measures currently do not include **nature-based solutions that can address multiple hazards and enable ecosystem-based adaptation.**

C. Funding priorities

Short term (2022-23)

- Support the development of technology applications to **identify and monitor areas for regular fuels reduction, controlled burning, and ecological thinning,** as appropriate.
- Private and public land managers will benefit from access to more **adaptive land management tools** that enable them to longitudinally evaluate pre- and post-fire forest treatments.

Medium term (2023-2025)

- Support the **development of adaptive land management frameworks** that enable a longitudinal analysis of pre- and post-fire forest treatment outcomes.
- Wildfire risk reduction measures can be **expanded to incorporate** nature-based solutions for ecosystem-based adaptation**,** which can include measures for drought mitigation and creating a greenbelt to serve as a fuel break while restoring habitat and improving air quality.
- **Identify and invest in large scale forest and watershed restoration projects** that contribute to the development of **sustainable forest economies,** including through emerging carbon markets and forest products, such as biochar.

Guiding framework for just, inclusive, and equitable FireTech

In the context of ongoing conversations around social and environmental justice, diversity and inclusion, and equity and access, it is important for wildfire technology entrepreneurs, funders, non-profits, and community-based organizations, to commit to an ethical framework that guides how technology is developed, applied, and scaled, for the achievement of just, inclusive, and equitable wildfire risk reduction outcomes.

This guiding framework seeks to provide a pathway to addressing compound hazards, such as extreme heat, drought, fire, flood, and mudslides (for example, see Palmer 2022) within the larger context of cascading disaster impacts, such as from housing instability, displacement, and racial injustice. Currently, one of the most significant gaps in the development and application of FireTech is a general lack of understanding of design justice issues (Costanza-Chock 2020) with implications for the development of inclusive, accessible, and diverse user interfaces that are co-developed with diverse community needs and capabilities in mind. For example, FireTech capabilities for alerts and notifications currently do not sufficiently address the functional, access, and linguistic needs of diverse communities.

To address this gap, in 2021, with support from Wonder Labs' Living with Fire Design Challenge, a student-led team partnered with Marin County, California, and industry partner, Zonehaven, to co-develop a methodology for inclusive evacuation mapping to provide timely and relevant information to county residents from culturally and linguistically diverse backgrounds (Wonder Labs 2021). This project is one example of how agile partnerships between universities, industry partners, community partners, and donors, can enable just, inclusive, and equitable FireTech outcomes.

Normative goals	**Vulnerability reduction**	**Systems change**	**Community wellbeing**	**Ecosystem resilience**
Priorities for action	**Risk assessment**	**Mitigation and risk reduction**	**Early detection and response**	**Recovery and adaptation**
Desired outcomes	**Better understanding and characterization of wildfire risk for communities and ecosystems**	**Strengthened and diversified capacities for fuel treatment and landscape restoration**	**Enhanced end to end systems for early detection, alert, and response**	**Healthy ecosystems and circular forest-based economies**
Enabling processes/ approaches	**Convergence research**	**Community-based disaster risk reduction**	**Adaptive governance**	**Ecosystem-based adaptation**
Guiding principles	**Collaboration**	**Accountability**	**Responsiveness**	**Empowerment**

Figure 2: Visioning just, inclusive, and equitable technologies for wildfire risk management (Lakhina and Lakhina 2021)

Figure 2 presents a guiding framework for visioning just, inclusive, and equitable approaches for technology development and applications in wildfire risk management. The framework is composed of five interrelated entry points for engaging with institutional visioning, reimagining, and theory of change processes:

Normative goals
signal a shared commitment to high-level goals such as 'vulnerability reduction', 'systems change', 'community wellbeing', and 'ecosystem resilience'. These normative goals can enable greater commitment towards actualizing international agreements outlined in the Sendai Framework for Disaster Risk Reduction (2015-2030), the Sustainable Development Goals 2030, and the Paris Climate Agreement.

Priorities for action
adapted from the Sendai Framework for Disaster Risk Reduction (2015-2030), and contributing to the achievement of the priorities defined in the four main areas of work where technology can contribute to achieving wildfire risk reduction goals. Technology here includes Digitization, including IoTs, SaaS technologies that streamline workflows and offer information and communication management, Mechanization, including trends in robotics and automation of aerial and ground-based vehicles, and Materials including compounds, engineering, and tools, in the context of related FinTech verticals such as insurance, crypto, and carbon markets.

Expected or desired outcomes
outline how FireTech's four priorities for action will achieve: 1) a better understanding and characterization of wildfire risk for communities and ecosystems; 2) strengthened and diversified capacities for fuel treatment and landscape restoration; 3) enhanced end to end systems for early detection, alerts, and response; and 4) healthy ecosystems and circular forest-based economies.

Enabling processes
suggest pathways to achieving wildfire risk management goals, such as through convergence research, community-based disaster risk reduction, with due consideration to equity, justice, and care principles, engaging with and supporting forms of adaptive governance, and committing to learning from nature-based solutions that contribute to ecosystem-based adaptation.

Guiding principles
outline how FireTech can commit to engaging communities with CARE—collaboration, accountability, responsiveness, and empowerment (see Lakhina 2019). For example, FireTech startups can engage in community-centered innovations that co-develop solutions based on context, needs, and capacities of communities living with wildfire risk. FireTech startups can create Impact Funds that grant money directly to communities to co-develop and pilot technologies with, thereby contributing to community infrastructure and workforce capacities. These are low-tech but foundational processes that can enable community resilience and wellbeing outcomes. Finally, FireTech startups can commit to a data ethics framework whereby data collected from community users and residents is secure, protected, and does no harm to marginalized people and communities.

This guiding framework for just, inclusive, and equitable FireTech also seeks to enable a greater focus on cross-industry collaboration so that technology entrepreneurs can build off existing data, mechanized, and material platforms to showcase coupled benefits to end users.

This will entail collaboratively working with champions and early adopters in local departments and communities to understand needs, capacities, and operating environments. Too often, local departments are unlikely to engage with technologies that seem redundant or overlapping with existing pilots. Showcasing how new technologies fit into existing platforms can enable institutional uptake and the delivery of coupled approaches.

The guiding framework also encourages funders and technology entrepreneurs to explore the co-benefits to communities on the frontlines, for example, by contributing to capacity development and circular economies that enable reinvestment in community's infrastructure, wellbeing, and ecosystem health (Lakhina and Lakhina 2022, In press).

Committing to co-develop new technology with a pilot community can be instrumental in ensuring the usefulness and sustained adoption of the technology. While FireTech startups have traditionally positioned their technology as assisting law enforcement and firefighters on the frontlines, current trends show that wildfire technology entrepreneurs are increasingly engaging with communities, neighborhoods, and homeowners for landscape and parcel-level wildfire risk management.

Products and services are increasingly being designed to meet homeowner needs and address community risk, in terms of data, mechanization, and materials. This trend is also leading to progressive changes in how insurance companies engage with communities, offering the possibility of sustaining justice and wellbeing outcomes through new kinds of insurance approaches and products (see The Nature Conservancy 2021).

However, this guiding framework underlines the importance of looking beyond the development of products and services, to also being cognizant of enabling processes and approaches that can deliver just and equitable wildfire risk reduction outcomes (see Izumi et al. 2019).

Finally, FireTech funders—philanthropy, corporates, and impact investors, can require grantees to show how community-centered collaboration, accountability, responsiveness, and empowerment principles have been integrated into the technology design and development process. Science and technology innovations can be assessed based on how they address inequities (see Parthasarathy 2022 for a discussion on health innovations).

Looking into the future, FireTech funding and investments can strive to move from 'do no harm' to 'do the greatest good for the most vulnerable'. It is hoped this guiding framework will enable FireTech funders to choose suitable entry points and reflect on how technologies for wildfire risk management can be developed in ways that are accountable and responsive to social justice, equity, and sustainable development goals.

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