SCIENCE & TECHNOLOGY POLICY INSTITUTE

Gaps, Priorities, and Entities with Equities in Wildland Fire Science and Technology

Rebecca K. Miller
Hannah L. Kirk

July 2024

IDA Product 3002852

IDA SCIENCE & TECHNOLOGY
POLICY INSTITUTE
1701 Pennsylvania Ave., NW, Suite 500
Washington, DC 20006-5805

The Institute for Defense Analyses is a nonprofit corporation that operates three Federally Funded Research and Development Centers. Its mission is to answer the most challenging U.S. security and science policy questions with objective analysis, leveraging extraordinary scientific, technical, and analytic expertise.

About This Publication

This work was conducted by the IDA Science and Technology Policy Institute under contract NSFOIA-0408601, Project TP-20-1005.FP, "Research Equities and Priorities in Wildfire Science and Technology," for the Office of Science and Technology Policy. The views, opinions, and findings should not be construed as representing the official positions of the National Science Foundation or the sponsoring agency.

Acknowledgments

The authors would like to thank Marianne E. Dietz of the IDA Systems and Analyses Center and Gifford J. Wong of the IDA Science and Technology Policy Institute who served as technical reviewers for this work.

For More Information

Rebecca K. Miller, Project Leader
rkmiller@ida.org, 202-419-3726

Kristen M. Kulinowski, Director, Science and Technology Policy Institute
kkulinow@ida.org, 202-419-5491

Copyright Notice

SCIENCE & TECHNOLOGY POLICY INSTITUTE

IDA Product 3002852

Gaps, Priorities, and Entities with Equities in Wildland Fire Science and Technology

Rebecca K. Miller
Hannah L. Kirk

Executive Summary

Recommendation 110 from *ON FIRE: The Report of the Wildland Fire Mitigation and Management Commission* suggests that a wildfire research coordinating body should be established to identify research gaps and science priorities. The recommendation continues: "A first task of this group should be a review of existing reports on known research needs and a review of necessary participants." Several Federal agencies, interagency groups, and commissions have released reports in the last decade identifying wildland fire science and technology (S&T) needs, gaps, and recommendations. This report draws upon eight reports published between 2014 and 2023 to identify (1) gaps and priorities in wildland fire S&T and (2) entities with equities in wildland fire S&T. The gaps and priorities included in this analysis were selected due to their emphasis on research (both science and social science), data, or technology needs related to wildfires.

Seven cross-cutting S&T priorities emerged from reviewing the eight reports. The seven cross-cutting priority areas reflect broad needs or recommendations that are not associated with a specific disaster phase: education and training; interagency and cross-sector coordination; practitioner-informed S&T; data management; research leadership; information at appropriate scales; and diversity, equity, inclusion, and accessibility. These seven priority areas reflect the need for new, creative, and collaborative approaches to wildfire management and resilience across Federal agencies.

In addition, this report identifies S&T gaps and priorities across six focus areas defined by either the disaster cycle or the structure of *ON FIRE: The Report of the Wildland Fire Mitigation and Management Commission*. These six focus areas are detection and modeling, firefighter operations and safety, land and fuels management, construction and zoning, public health and safety, and relief and recovery. The focus areas are further divided across three or four major themes.

Finally, the report includes 1 organizational chart for Federal agencies with equities in wildland fire S&T and 14 organizational charts for interagency groups with relevant equities. These charts are intended to depict the breadth and complexity of Federal wildfire management.

Together, these gaps, priorities, and equities in wildfire S&T may inform strategic planning and improved collaboration across Federal and non-Federal partners in the wildfire research space.

Contents

1. Introduction

A. Background

The Wildland Fire Mitigation and Management Commission was established in 2021 by direction of the Infrastructure Investment and Jobs Act to develop recommendations across the wildfire system. The Commission was tasked by Congress to submit a report detailing these recommendations by September 2023. *ON FIRE: The Report of the Wildland Fire Mitigation and Management Commission* lists 148 recommendations to Congress and Federal agencies on improving fire detection and monitoring, suppression and response, land management, health and safety, and relief and recovery efforts.

Recommendation 110 from *ON FIRE: The Report of the Wildland Fire Mitigation and Management Commission* suggests that a coordinating body for wildfire research should be established to identify research gaps and science priorities. The recommendation continues: "A first task of this group should be a review of existing reports on known research needs and a review of necessary participants." Several Federal agencies, interagency groups, and commissions have released reports in the last decade identifying wildfire science and technology (S&T) needs, gaps, and recommendations.

To inform this effort, the White House Office of Science and Technology Policy (OSTP) asked the Science and Technology Policy Institute (STPI) to review eight reports published between 2014 and 2023 and to identify the gaps and priorities related to research, data, and technology described in the reports. In addition, OSTP asked STPI to develop a graphic identifying the Federal agencies, interagency coordination bodies, and non-Federal stakeholders with expertise and equity in wildland fire and wildfire S&T. Throughout this report, the term *wildland fire* refers to "any non-structure fire that occurs in vegetative or natural fuels," and the term *wildfire* refers to "all fires that burn in the natural environment, regardless of their potential interaction with the built environment."[1]

[1] Terms originally defined in USDA's report, *ON FIRE: The Report of the Wildland Fire Mitigation and Management Commission*. See pages 13 and 14: https://www.usda.gov/sites/default/files/documents/wfmmc-final-report-09-2023.pdf.

B. Approach

1. Gaps and Priorities

OSTP identified eight reports for STPI to include in its assessment of existing S&T gaps and priority areas:

A. *Modernizing Wildland Firefighting to Protect Our Firefighters* (2023),

B. *National Cohesive Wildland Fire Management Strategy Addendum Update* (2023),

C. *ON FIRE: The Report of the Wildland Fire Mitigation and Management Commission* (2023),

D. *NASA Science Mission Directorate (SMD) Wildfire Stakeholder Engagement Workshop: Summary and Key Findings* (2022),

E. *Wildland Fire Science and Technology Task Force Final Report* (2015),

F. *Wildland Urban Interface Fire Operational Requirements and Capability Analysis: Report of Findings* (2019),

G. *Fire Science Strategy* (2014), and

H. *Assessment of Indian Forests and Forest Management in the United States* (2023).

These reports represent a selection of reports written in the past decade describing wildfire S&T but are not intended to reflect a comprehensive list of possible relevant reports. The eight reports included in this analysis reflect perspectives and recommendations from various Federal departments and non-Federal stakeholders. Other reports that could be considered for future analysis include *U.S. Geological Survey Wildland Fire Science Strategic Plan, 2021–26*,[2] *Confronting the Wildfire Crisis: A Strategy for Protecting Communities and Improving Resilience in America's Forests*,[3] or *Wildland Fire Strategy Plan, 2020–2024*.[4]

First, the President's Council of Advisors on Science and Technology (PCAST) released its report, *Modernizing Wildland Firefighting to Protect Our Firefighters*, in

---

[2] U.S. Geological Survey. 2021. *U.S. Geological Survey Wildland Fire Science Strategic Plan, 2021–26*: U.S. Geological Survey Circular 1471. https://pubs.usgs.gov/circ/1471/cir1471.pdf.

[3] U.S. Department of Agriculture. 2022. *Confronting the Wildfire Crisis: A Strategy for Protecting Communities and Improving Resilience in America's Forests*. https://www.fs.usda.gov/sites/default/files/fs_media/fs_document/Confronting-the-Wildfire-Crisis.pdf.

[4] U.S. Department of the Interior. n.d. *Wildland Fire Strategic Plan*. https://www.nps.gov/subjects/fire/upload/wildland-fire-strategic-plan-20-24.pdf.

February 2023 (hereafter described as "Report A" or "A").[5] PCAST is an independent Federal Advisory Committee composed of individuals from the government, private sector, and academia to advise the President on important S&T issues. Report A emphasized technology opportunities to support wildland fire prediction, detection, response, and suppression.

Second, the Wildland Fire Leadership Council (WFLC) released its report, *National Cohesive Wildland Fire Management Strategy Addendum Update*, in January 2023 (hereafter described as "Report B" or "B").[6] WFLC is an intergovernmental committee that provides recommendations for policy, implementation, and strategy to support oversight and coordination across Federal wildfire policies. Report B expanded upon the National Cohesive Wildland Fire Management Strategy framework released in 2014 by emphasizing four new areas (climate change; workforce capacity, health, and well-being; community resilience; and diversity, equity, inclusion, and environmental justice) and five key implementation challenges (demands on the existing wildland fire management system; need for more proactive fire use; integration of science, data, and technology into decision-making; uses for biomass and other wood products; and education, communication, and marketing).

Third, the Wildland Fire Mitigation and Management Commission released its report, *ON FIRE: The Report of the Wildland Fire Mitigation and Management Commission*, in September 2023 (hereafter described as "Report C" or "C").[7] Congress established the Wildland Fire Mitigation and Management Commission in the 2021 Infrastructure Investment and Jobs Act and tasked the Commission with developing policy recommendations for wildfire mitigation, management, and recovery. Report C listed 148 recommendations from the Commission for action by both Federal agencies and Congress to address longstanding wildfire policy, programming, and workforce challenges.

Fourth, the National Aeronautics and Space Administration (NASA) Science Mission Directorate released its report, *NASA Science Mission Directorate (SMD) Wildfire Stakeholder Engagement Workshop: Summary and Key Findings*, in 2022 (hereafter

---

5 The President's Council of Advisors on Science and Technology. 2023. *Report to the President: Modernizing Wildland Firefighters to Protect our Firefighters*. https://www.whitehouse.gov/wp-content/uploads/2023/02/PCAST_Wildfires-Report_Feb2023.pdf.

6 Wildland Fire Leadership Council. 2023. *National Cohesive Wildland Fire Management Strategy Addendum Update*. https://forestsandrangelands.gov/documents/strategy/natl-cohesive-wildland-fire-mgmt-strategy-addendum-update-2023.pdf.

7 Wildland Fire Mitigation and Management Commission. 2023. *ON FIRE: The Report of the Wildland Fire Mitigation and Management Commission*. https://www.usda.gov/sites/default/files/documents/wfmmc-final-report-09-2023.pdf.

described as "Report D" or "D").[8] NASA SMD includes the Earth Science Division and sponsors basic and applied research using in-situ and space-based observations. Report D was the product of a 2-day workshop hosted in February 2022 by NASA SMD to understand and prioritize the issues and needs of the wildfire management community, focusing on pre-fire, active fire, and post-fire stages and specifically on S&T capabilities.

Fifth, the Committee on Environment, Natural Resources, and Sustainability Subcommittee on Disaster Reduction of the National Science and Technology Council (NSTC) released its report, *Wildland Fire Science and Technology Task Force Final Report*, in November 2015 (hereafter described as "Report E" or "E").[9] NSTC enables S&T policy coordination across the executive branch agencies and develops coordinated research strategies. NSTC chartered a Wildland Fire Science and Technology Task Force to review, analyze, and assess actions to promote coordination across relevant Federal agencies. Report E emphasized coordination and identified broad organizational needs for wildfire S&T, major S&T gaps, and opportunities to address existing gaps.

Sixth, the Department of Homeland Security (DHS) S&T Directorate formed an Integrated Project Team (IPT) in collaboration with the Federal Emergency Management Agency (FEMA), the U.S. Fire Administration (USFA), and other stakeholders to evaluate technology and innovation needs and opportunities. IPT published *Wildland Urban Interface Fire Operational Requirements and Capability Analysis: Report of Findings* in May 2019 (hereafter described as "Report F" or "F").[10] Report F listed both technological and non-technological gaps and solutions organized across eight mission elements: preparedness, detection, tracking, forecasting, public information and warning, evacuation, responder safety, and critical infrastructure.

Seventh, the Strategic Environmental Research and Development Program (SERDP) and its associated demonstration program, the Environmental Security Technology Certification Program (ESTCP), produced the *Fire Science Strategy* report in September

---

[8] National Aeronautics and Space Administration. 2022. *NASA Science Mission Directorate (SMD) Wildfire Stakeholder Engagement Workshop: Summary and Key Findings*. https://aam-cms.marqui.tech/aam-portal-cms/assets/ki2yd52vavkccskc.

[9] National Science and Technology Council Committee on Environment, Natural Resources, and Sustainability Subcommittee on Disaster Reduction. 2015. *Wildland Fire Science and Technology Task Force Final Report*. https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/NSTC/sdr_wildfire_st_task_force_final_report.pdf.

[10] U.S. Department of Homeland Security. 2019. *Wildland Urban Interface Fire Operational Requirements and Capability Analysis: Report of Findings*. https://www.dhs.gov/sites/default/files/publications/wui_fire_report_of_findings_july_24_2019v2_508.pdf

2014 (hereafter described as "Report G" or "G").[11] SEDRP and ESTCP demonstrate and develop innovative technological solutions to environmental challenges for the Department of Defense (DoD). Report G focused primarily on DoD priorities and management issues both as distinct from and in conjunction with those of other land management agencies.

Eighth, the Fourth Indian Management Assessment Team for the Intertribal Timber Council wrote the *Assessment of Indian Forests and Forest Management in the United States* report in 2023 (hereafter described as "Report H" or "H").[12] The Intertribal Timber Council is a nonprofit consortium of Indian Tribes, Alaska Native Corporations, and individuals seeking to improve natural resources management and promote social, economic, and ecological values for Tribal nations. Report H described challenges and recommendations specific to Tribal forest management. Report H did not focus explicitly on wildfire-related issues and instead primarily covered workforce, funding, and administrative requirements.

The STPI team reviewed the eight reports and identified the S&T gaps and priorities listed in each report. STPI selected the gaps and priorities included in this analysis due to their emphasis on research (both science and social science), data, or technology needs related to wildfires. We then organized the gaps and priorities across six focus areas, informed by the disaster cycle and the organizational structure of Report C. These six focus areas are detection and modeling, firefighter operations and safety, land and fuels management, construction and zoning, public health and safety, and relief and recovery. We further divided the gaps and priorities within the six focus areas across three or four major themes. The gaps and priorities are presented as bullet points to avoid indicating a degree of criticality and may range significantly in their anticipated implementation timeline. In focusing on research, data, and technology needs, we did not capture all challenges related to funding, personnel, and agency authority, though these themes appeared across all reports. In addition, we also described additional gaps to consider across each of the six focus areas. These "gaps within the gaps" cover important S&T topic areas but were not explicitly listed within the eight reports included in the analysis. We have included them here to reflect that the eight reports and their contents do not reference all possible gaps or priority topics in wildfire S&T.

In addition, the STPI team identified seven cross-cutting priority areas that were not associated with a specific focus or disaster phase: education and training; interagency and cross-sector coordination; practitioner-informed S&T; data management; research

---

[11] Strategic Environmental and Research Development Program; Environmental Security Technology Certification Program. 2014. *Fire Science Strategy: Resource Conservation and Climate Change*. https://climateandsecurity.org/wp-content/uploads/2020/01/serdp_fire-science-strategy.pdf.

[12] The Fourth Indian Forest Management Assessment Team for the Intertribal Timber Council. 2023. *Assessment of Indian Forests and Forest Management in the United States*. https://www.bia.gov/sites/default/files/media_document/ifmat_iv_report.pdf.

leadership; information at appropriate scales; and diversity, equity, inclusion, and accessibility (DEIA). These seven priority areas reflect the need for new, creative, and collaborative approaches to wildfire management and resilience across Federal agencies.

Each gap and cross-cutting priority recommendation includes an in-line reference to the report of origin. For example, recommendations from *Modernizing Wildland Firefighting to Protect Our Firefighters*, or Report A, depict "(A)" to enable tracking of which gaps and priorities stem from which reports. The recommendations are accompanied by a letter (signifying the report) and a number (signifying the order of the gap or priority recommendation from that report within this analysis). In addition, the original text in each of these reports associated with an individual gap or recommendation included in the six focus areas is provided in Appendix A.

2. Entities with Equities in Wildfire S&T

STPI compiled and organized a list of entities that participate in wildland fire research, prediction, mitigation, or policymaking. To generate an initial list of participating entities, we reviewed Reports C and E. We reviewed Report C in full, capturing each mention of a relevant participant. We also reviewed Appendix C in Report E, which listed Federal programs involved in fire science. We captured all Federal fire science programs in the Report E appendix that were not already included in the Commission report.

During our initial review, we compiled a data sheet with over 300 wildland fire-related entities. Next, we removed duplicates and programs that no longer existed. We also added wildland fire-related efforts not mentioned in either Report C or E (e.g., Science for Disaster Reduction, USFS Fire and Aviation Management). Next, we removed non-Federal entities, unless they belonged to an interagency partnership (e.g., State government representatives in the Wildland Fire Mitigation and Management Commission). As non-Federal participants could include multiple agencies within individual State, local, and Tribal governments, we limited our focus in the organizational charts to Federal entities to highlight the principal participants.

We created an organizational chart for these Federal entities (Appendix B), as well as separate charts for interagency efforts (Appendix C). We added each entity in order of hierarchical status, placing broad organizations on the left and sub-entities on the right. While the organizational charts may not list every entity involved in wildfire S&T research, they include the primary Federal participants with relevant equities.

2. Cross-Cutting S&T Priorities

A. Education and Training

Current education and communication efforts alone are inadequate to ensure public familiarity with wildfire risks and policy options. Communities affected directly or indirectly by wildfires need information about their wildfire risks, mitigation options, and the complexities of wildfire management (C). For example, frequent education on the differences between wildfires and prescribed fires can inform risk assessments and tradeoffs between more and less extreme smoke (B, D, E). Public education should also cover the benefits of fire as a natural ecological process (E). Similarly, education on fire prevention (specifically for human-caused ignitions) reduces the likelihood of future wildfires and associated damages and costs (E). Targeted educational interventions that are tailored to the community and local ecosystems could minimize human-caused ignitions (E, F).

National wildfire policies and strategies should be circulated and discussed widely across different levels of government to promote community buy-in, engage local experts and resources, and promote greater wildfire resilience (B). Community engagement that actively includes more vulnerable and historically excluded populations is critical for effective partnerships and broad community protection (B).

Public communication should be informed by social science research to promote learning, reduce uncertainty and fear, and promote equity and justice (D). Communities in particularly risky areas or the *wildland-urban interface* (WUI)[13] need additional information—provided across many formats—describing localized risks associated with fire and post-fire impacts (D, F). Best practices on public communication and understanding of natural hazard risks should be adopted across information providers to ensure the greatest uptake and comprehension (D).

Easy-to-understand trainings should be developed to make data and information more accessible to laypeople or practitioners (A, D, F). For example, training programs for firefighters on new products and technologies, including guidance on when and how to use such tools (as well as details on their limitations), can improve the use and effectiveness of these new tools (A, D, F). New firefighting technologies may need on-the-ground rapid

[13] The *wildland-urban interface* is "The line, area, or zone where structures and other human development meet or intermingle with undeveloped wildland or vegetation fuels" (Department of the Interior [DOI] n.d.).

education and training services (A). Wildfire management professionals may interpret publicly available products like burn severity maps or notifications like Red Flag Warnings differently than the public, potentially creating confusion during emergencies. Research on how to provide relevant and useful information on wildfire risks for the public should be conducted and incorporated into existing data products prior to a disaster (E).

In addition, training and professional development for fire management and firefighting professionals could improve response efforts and fill existing workforce gaps through a combination of upskilling and new career pathways (C). Training courses and fire assignments should be opened to non-Federal practitioners to demonstrate competence and gain certification (C, H). Training opportunities for mid-career professionals and agency administrators could improve fire management and keep people in the fire workforce (C). New training programs for structural firefighters on how to respond to wildland fires and WUI fires could expand existing firefighting capacity (C). Trainings for wildfire professionals should also shift toward a greater recognition of the interconnectedness of preparedness, mitigation, response, and resilience (C).

Training should be available for Federal and non-Federal practitioners on wildfire mitigation and recovery, such as through prescribed fire training exchanges that increase prescribed fire capacity (C). Expanded training programs could improve interagency and cross-disciplinary coordination (F). In addition, fire management teams need training on cultural burning practices; such training should recognize Tribal sovereignty and reflect respect and support for Indigenous knowledge (C, H).

B. Interagency and Cross-Sector Coordination

Enhanced coordination across a variety of mechanisms could be critical to successfully address S&T needs and wildfire response across Federal agencies and non-Federal entities, including the private sector (A, C, E). Currently, the siloed approach by individual agencies results in poor interoperability and inefficiency; for example, more than 30 Federal entities have responsibility across the disaster recovery phase (C, D). Standardized guidelines on resources, responsibilities, and processes could improve interoperability and consistency beyond those from existing interagency bodies (C, G).

Agencies should recognize the value of coordination to leverage funding efforts and consider how their relevant niche areas could interact to guide future S&T research and avoid redundancy (G). For example, DoD installations could be used as outdoor laboratories for modeling and testing of fire behavior for other agencies (G). DoD could work with other members of the intelligence community, the National Oceanic and Atmospheric Administration (NOAA), and NASA to review archived, classified data on wildfire perimeters and terrain characteristics for possible artificial intelligence (AI) modeling purposes (A). Coordination across Federal public health, land management, and emergency response agencies could support the incorporation of health and well-being into

ongoing wildfire management activities (C). Land management agencies with bordering jurisdictions could collaborate for wildfire mitigation and management (C). Agencies with equities in wood products and biomass could coordinate to develop commercially viable products (C), while those involved in wildfire smoke monitoring and impacts could engage in coordinated communication and air quality protection (B, C).

In addition, partnerships across the range of entities with equities in wildfire S&T—Tribal, State, and local government; the private sector; non-governmental organizations; residents; and the research community—could provide financial and technical benefits to participants (B, C). For example, engaging the private sector could prompt new technological innovation (A). These partnerships should recognize the authority and perspectives of the non-Federal entities (C). However, such partnerships often require authorization, funding, and flexibility to be most effective (C).

Finally, Federal agencies should recognize Tribal stewardship, management, cultures, and sovereignty (B, C, D, H). Tribal goals should be incorporated into existing Federal land management plans (C, H), and Tribes should be engaged in management of treaty lands or those adjacent to their reservations (H). Tribes should be involved in pre-fire, response, and post-fire activities to ensure respect for culturally important areas and practices (C, H).

C. Practitioner-Informed Science and Technology

Wildfire practitioners, including those working in mitigation and recovery efforts across communities, should have a voice in informing wildfire research to ensure its accessibility and utility for practitioners on the ground. Producers and users of wildfire data and products should coordinate to share best practices and needs across their parallel groups (C). Communication, with direct feedback and input from practitioners, can result in the creation of more effective tools that respond to the specific needs and limitations of the users. The wildfire science community should establish both research-to-operations and operations-to-research pathways to ensure the highest utility yield for stakeholders (C).

The Federal Government could support this effort by (1) soliciting well-articulated needs from practitioners, (2) establishing clear lines of communication between researchers and practitioners, and (3) supporting the sharing of research findings and distribution of new technologies to practitioners (B, E). "Practitioners" should be considered a broad term that extends beyond Federal users, including local, State, and Tribal governments and non-governmental entities given the diverse array of stakeholders with wildfire equities (B). Solicitations should cover immediate and near-term needs in addition to long-term (10–20 years) requirements (B). A fire S&T advisory board could coordinate research-to-operations with an emphasis on both practitioner needs as well as testing and evaluation (C). Other pathways for solicitation and communication should be created so producers and users of S&T can share their perspectives and needs directly to policymakers (C). Such

engagement—likely with congressional committees—would improve policymakers' understanding of how and why land managers, emergency responders, and scientists use and develop data products (C).

Improvements in observations and data may result in better models, but those models may not directly translate into better information for fire managers and communities on the ground (D). For example, offering more fire model options to incident commanders may result in greater frustration and confusion over what model is the "best" for a particular situation, particularly in time-sensitive situations. Instead, advances and investments in federally funded wildfire S&T efforts should be guided by practitioner needs and targeted to end users, with training for new products to ensure their ultimate utility and applicability (C, G).

D. Data Management

Data should be findable, accessible, interoperable, and reproducible (FAIR), and should exist in a common operating environment so the data can be incorporated into decision support tools and other products (A, D). Wildfire management often requires real-time data (e.g., weather conditions) or near-real-time data products (e.g., satellite-derived fire perimeter maps) to inform operational decision-making. Data must therefore be assessed for quality control, catalogued with metadata information, and incorporated into products, which then must be communicated to, accessed by, and interpreted by the user as quickly as possible to match the need for rapid and relevant information (D).

A technological common operating environment for wildfire data across the disaster cycle (mitigation, preparedness, response, and recovery) could improve the organization, cohesiveness, and operationalization of wildfire data by identifying applicable data standards for wildfires and ensuring interoperability (such as XML, JSON, or NIEM formatting) (A, C). Researchers and practitioners need access to a range of data such as public health information, built and natural environment geospatial layers, fire perimeters, and resource deployment data to capture the broad scope and complexity of wildfire management (C). While agencies could maintain stewardship of their data, data should be catalogued based on the FAIR principles (C). An interagency joint office focused on operational decision-making and planning could lead and shape this effort, incorporating Federal and non-Federal data (C). Ideally, non-Federal data would be compatible with Federal data and usable at local scales (C). These data may stem from Tribal, State, and local governments and community organizations involved in wildfire management and decision-making.

A centralized data library of wildfire-related data could improve data discoverability (D). Data standard formats (e.g., those that meet Committee on Earth Observation Satellites [CEOS] or Open Geospatial Consortium [OGC] guidelines) and coordination across data services could facilitate analysis and modeling (D). Comprehensive geospatial layers that

should be made available for post-fire analysis include vegetation data, geologic and topographic data, burn severity maps, high resolution imagery, soil type and moisture data, structure and built environment information, and spectral and photogrammetry data, in addition to cultural or community details (D). Similarly, combining data from very high-resolution remote sensing, hyperspectral, fine-resolution LiDAR, and uncrewed aerial systems through explicable data fusion algorithms could support decision-making for fire and land managers (D). In addition, jurisdictions and agencies should build data interoperability protocols and plans prior to fires, including data for and from emergency responders (F). Data, including non-Federal data, should not be withheld due to concerns about completeness, accuracy, or velocity, though they could be marked for incompleteness or other accuracy-related concerns (D, F).

E. Research Leadership

The Joint Fire Science Program (JFSP) currently provides funding and science delivery for wildfire studies as a partnership across the Department of the Interior (DOI) and the U.S. Department of Agriculture (USDA). However, many other relevant agencies could engage formally in the wildfire science space, such as through a new coordinating and leadership body focused on wildfire science—distinct from the existing JFSP (E). A new coordinated structure could be established to serve as an authoritative leader that brings together relevant Federal agencies, coordinates technology development, assesses practitioner priorities, and identifies fire management needs (A, B, C, E). This new institution could formally lead and coordinate multidisciplinary S&T programming and planning (A, B, C, E, G). The institution could systematically organize future research opportunities and forecast user requirements, measure and assess programmatic progress, and develop a road map of technology development (A, B, C, D).

A new wildfire research body should have a senior leader with familiarity in wildfire S&T and an adequate mandate, personnel, multi-year funding budget, and authority to meet research and operational needs for S&T; the new institution could also enable greater interagency coordination (A, C). Wildfire leadership at agencies need greater awareness of wildfire S&T topics from both research and operational angles (D). More Federal funding for wildfire S&T could support resilience (B), including via competitive grants issued through a new program or institution (C). Significant fire science breakthroughs could occur with more comprehensive funding and an organized approach to fire science (G).

In addition, a comprehensive system that is consistent both within and external to the Federal Government should be established to ensure uniformity in workforce (including recruitment and retention efforts), training, technology, and equipment (B, C). Similarly, a governance structure should be established to coordinate Federal agency efforts in post-fire recovery and to engage local jurisdictions and community organizations in improving access to relevant S&T products (C). A coordinated effort with clear leadership could

address the cross-cutting priorities and other challenges identified here such as practitioner-informed S&T, data management and interoperability, and technology adoption (C).

F. Information at Appropriate Spatial Scales

Practitioners frequently report an inability to use existing datasets or products because they are not available at the appropriate spatial scale. For example, hazard and risk maps may be too coarse for wildfire planning purposes or may have poor interoperability with other products due to scaling differences (C). Similarly, such products may not exist across all jurisdictions, creating gaps across Federal, State, and private lands (C). Existing State hazard maps may be outdated, inconsistently developed or used across jurisdictions, or too coarse for parcel-level assessments (C). Cross-jurisdictional hazard mapping assessments that are consistently applied and collaboratively developed—and include local community characteristics—could support firefighter response efforts (C).

Information regarding wildfire risk is often most valuable at smaller scales, and is ideally available across a very large region or even nationally. Wildfire suppression and response become more challenging if models, forecasts, and other predictive services are not available at the appropriate spatial scale (D). For example, fire-related data (including weather, fuels, and soil moisture) would ideally be captured at the scale of fires themselves (e.g., less than 0.25 or 0.5 degree), and then incorporated into regularly updated models that are shared with firefighting leadership (D).

Fire scientists should create products that provide information across multiple spatial scales to best inform risk-based decision-making (E). Hazard information across multiple scales supports multi-level decision-making. For example, national hazard mapping can indicate general risk and areas of concern. By contrast, more localized maps can inform decisions around building and municipal codes, incorporating information about local weather conditions, topography, and vegetation (C). For example, land management protocols and dispersion modeling are most effective at local scales (G). Wildfire researchers often already consider site- or region-specific characteristics such as climate change impacts, invasive species, or fuel treatments when conducting research on best management practices; subsequent hyper-local assessments and models offer significant value to managers because they reflect the particular features of a location (B). However, modeling at such local scales can be prohibitively expensive and challenging to validate (G).

Federal agencies could assess existing Federal and non-Federal data and tools and identify opportunities for improved compatibility and coordination across State, local, and Federal governments; a Federal coordinating body could supervise this effort. Products should be developed at the right spatial scale for practitioners, which may require new sensors and data collection instruments and better interoperability across systems (C). In addition, determining the "right scale" for such information will inherently entail having a

clear understanding of practitioner needs, further underscoring the importance of practitioner-informed S&T.

G. Diversity, Equity, Inclusion, and Accessibility (DEIA)

Wildfires often exacerbate systematic inequities, resulting in disproportionately negative impacts on more vulnerable populations (B, C). In particular, disparities in post-wildfire recovery can compound preexisting equity concerns, highlighting the need to support socially vulnerable populations in the immediate aftermath of a disaster (C). Equity and environmental justice should be actively incorporated into Federal, State, and community-level wildfire resilience activities, with recognition of capacity limitations when engaging with community members (B). Collaboration should be inclusive, representative, and informed by active and meaningful partnerships between government agencies and non-Federal entities (B).

Promoting environmental justice among vulnerable communities likely entails grants and programmatic support for mitigation and recovery activities (B, C). For example, block grants or subsidies for low-income residents in high-risk areas could enable structural improvements like building retrofits (C). Federal agencies should be cautious of funding mechanisms like matching grants that favor wealthier communities and should instead consider support for wildfire resilience based on financial need (C). Simplifying the Federal grant application process could ensure greater accessibility and equity of grant funding for communities and individuals with limited grant application resources or experience (C). Additional research on how agencies can best support affected populations and incorporation of social vulnerability data could help identify best practices in community wildfire resilience (C).

In recognition of Indigenous knowledge and land management practices (B), the Federal Government should collaborate and consult with Tribal nations (C). However, many of the recommendations note the limitations of Federal agencies to act without additional authority granted by Congress to pursue co-stewardship or co-management agreements (C, H). Additional resources, funding, and workforce programs could support Tribal forestry efforts to promote forest health (H).

Finally, DEIA principles should be incorporated into efforts to strengthen and expand the fire management workforce, specifically to recruit, retain, and train people from different backgrounds (B, C).

3. S&T Gaps and Priorities by Focus Area

A. Detection and Modeling

1. Fire Potential and Prediction

S&T gaps identified in the Fire Potential and Prediction space stemmed from Reports B, C, D, and E. Gaps and recommended priorities primarily covered improving fuels data and developing predictive services to improve understanding of possible ignitions. Gaps and recommendations included:

- Improve understanding of human-caused ignitions to identify and implement alternative options to reduce the likelihood of ignitions (B1, C1, E1);
- Use ground and remote sensing observations to develop and update weather, fuel, and other databases to support fire prediction (E2);
- Ensure continuity of missions for moderate-resolution (15–30m) satellites with relevant data for fuel characterization and burn severity (E3);
- Establish national databases of burn severity and fire perimeters for wildland and WUI fires (E4);
- Integrate forecast and climatology data at fine resolutions (fire scale; less than 0.25 or 0.5 degrees) for microclimates for weather, fuel, soil moisture, and fire danger (D1);
- Gather and share global fuels data through global partnerships (D2);
- Decrease data latency on understory and canopy cover, snow cover, land cover, and soil moisture data (D3);
- Gather data on pre- and post-fire vegetation composition, as well as regrowth trajectories, to assess future fire risk and management decisions (D4);
- Develop methods to integrate experimental data into national weather forecasting tools and other existing government products (D5);
- Provide funding and resources to improve agency coordination around predictive services (C2); and
- Support agencies that currently provide tools and products to support pre-fire assessments and predictions (C3).

2. Fire Detection

S&T gaps identified in the Fire Detection space stemmed from Reports A, C, D, and F. Gaps and recommended priorities primarily covered use and improvement of wildfire detection technologies. Gaps and recommendations included:

- Acquire real-time accurate geolocation of fire detections in the WUI (D6);
- Use wildfire detection systems to provide automated early warnings (C4);
- Expand satellite monitoring capabilities to enable wildfire detection from an array of orbits, altitudes, and resolutions (D7);
- Improve fire detection technologies, such as prototype autonomous detection systems or analytics for ground-based camera networks, including along electric utility corridors (A1, D8, C5);
- Improve fire detection with real-time and continuous identification of heat sources and smoke, incorporate risk factor data (e.g., weather, fuels, topography, fire history) for baseline risk assessments, and incorporate social media data in ignition detection (F1);
- Share ignition detection data from utility companies with emergency responders (F2);
- Improve coordination with Tribes using fire for cultural or ceremonial purposes to ensure privacy and confidentiality of fire ignitions and to avoid deploying unnecessary resources following early detection of smoke used for Tribal purposes (C6);
- Establish an automatic information sharing program that disseminates ignition detection data with relevant agencies and jurisdictions in a standardized format that provides actionable information (F3);
- Integrate ground-based and remote sensing data with AI algorithms and models to support fire detection and associated decision-making (D9);
- Assess existing technology for use in detection and alerts, and develop a plan for testing and transition to operations (A2); and
- Integrate social media posts, pictures, and videos into existing wildland and WUI fire tracking and emergency response (F4).

3. Fire Behavior Modeling

S&T gaps identified in the Fire Behavior Modeling space stemmed from Reports A, C, D, E, F, and G. Gaps and recommended priorities primarily covered improvements to models due to additional data inputs, better understanding of physics and fire behavior, and assessments of existing models. Gaps and recommendations included:

- Explore opportunities to use machine learning and AI to forecast fire spread in complex terrain based on available climate data and incorporate historic fire events across diverse landscapes and conditions (A3, D10);
- Automate wildfire models using real-time data of fire characteristics to avoid requiring an operator to manually input data (F5);
- Improve models and develop dynamic risk maps to support more accurate fire behavior predictions, incorporating extreme wind, weather conditions, structure fuels, and recent changes in vegetation, fire activity, fuels consumed in a fire, fine fuel burning, consumption across fuel bed categories, impacts on fire spread, and post-fire impacts (B2, C7, F6, G1);
- Use ground and remote sensing observations to develop and update weather, fuel, and other databases to support fire monitoring (E5);
- Update LANDFIRE (Landscape Fire and Resource Management Planning Tools) fuel models at least every 6 months (D11);
- Review classification of archived satellite data from defense and intelligence sources, and expand access of declassified data to the research community to support predictive wildfire modeling, including through AI training (A4);
- Incorporate fuels from the built environment into wildfire modeling in the WUI (D12);
- Improve understanding of core issues of physics-based fire behavior (G2);
- Improve understanding of processes of fine fuel heat exchange, ignition, and fire spread, and their incorporation into fire behavior models (G3);
- Expand research on basic heat transfer processes to support understanding of wildland fire spread based on fuel particle exchange, role of convection, ignition, and burning of live fuels (G4);
- Improve understanding of the processes of wildland fire events and incorporate this understanding into 3-D fire behavior and prediction models drawing from data on natural and built environment fuels, terrain, and fire probability, behavior, severity, and impacts (E6);
- Assess fire behavior models, including WUI fire behavior models, by developing a standard usage or methodology (F7);
- Improve real-world validation of behavior modeling by developing and compiling comprehensive datasets (G5);

- Compare models for their limitations, costs, usability, and performance across scales, scenarios, and fuel types based on ecosystem conditions and vegetation (G6);
- Coordinate predictive modeling at the interorganizational level and across pre-fire mitigation, fire response, and post-fire recovery (C8);
- Reduce data latency, especially for satellite data products, to support planning for smoke events and better fire weather forecasting (D13);
- Improve understanding of microscale and synoptic-scale meteorology and their influence on wildfire behavior across individual and regional landscapes, respectively (D14);
- Improve available information on boundary layer height, vertical information, and its diurnal evolution to support forecasts and air quality management of *pyrocumulonimbus events*[14] and smoke plumes, particularly at night (D15);
- Improve truthing of short- and long-term fire-related forecasts (D16);
- Identify land cover and terrain characteristics associated with faster or slower wildfire spread (A5);
- Use ground and remote sensing observations to develop and update weather, fuel, and other databases to support fire monitoring (E7);
- Improve real-time wildfire monitoring capabilities to penetrate wildfire smoke cover and other WUI fire conditions (F8);
- Ensure mission continuity for moderate-resolution satellite data (15–30m) for active fire monitoring (E8); and
- Incorporate smoke and wind data into fire monitoring, such as stereo-derived estimates of smoke plume height to capture potential pyrocumulonimbus events (D17).

4. Additional Gaps to Consider

Additional gaps beyond those identified in reports related to the "Detection and Modeling" focus area include new resources to support early fire detection, incorporation of firefighter experiences into predictive modeling, and improvements in computing and modeling for complex wind-driven fires. First, more funding and resources for early fire detection could support faster response times by identifying smoke plumes more rapidly.

[14] *Pyrocumulonimbus event* refers to "an extreme manifestation of a pyrocumulus…cloud, generated by the heat of a wildfire, that often rises to the upper troposphere or lower stratosphere" (American Meteorological Society 2024).

AI and other fire detection technologies can improve existing fire detection efforts, but developing a broader network of fire detection posts in high-risk areas could offer more widespread protection.

Second, firefighter experiences could be incorporated into wildfire modeling. As wildfires often follow similar patterns, incorporating perspectives and tactics in fighting previous fires may improve model outcomes and guide future firefighter deployment decision-making. Inclusion of such perspectives could directly support site-specific fire behavior modeling.

Third, complex wind-driven fires, especially those that occur during significant wind events like the Santa Ana or El Diablo winds, can be particularly difficult to model due to ember-related spread. Additional computing power and research dedicated to analyzing and improving prediction of significant destructive events like the 2017 Tubbs Fire could support suppression efforts. Improved early behavior modeling could be shared with incident commanders responding to complicated WUI fires.

B. Firefighter Operations and Safety

1. Deployment and Decision Support

S&T gaps identified in the Deployment and Decision Support space stemmed from Reports A, B, C, D, E, F, G, and H. Gaps and recommended priorities primarily covered developing decision support tools based on real-time information and improving response and resource tracking. Gaps and recommendations included:

- Improve understanding among decision makers of the limitations of existing data products (D18);
- Coordinate and support jurisdictions in making safe, effective, efficient, and risk-based wildfire management decisions (B3);
- Develop and use decision support tools that use real-time information to help firefighting personnel identify high-risk communities, structures, and wildlands and the most appropriate tactical responses (E9);
- Gather and communicate real-time, accurate data on fire behavior, perimeter, and characteristics to support decision-making to protect communities (F9);

- Incorporate real-time data into the Wildland Fire Decision Support System (WFDSS) for rapid turnaround information,[15] including for WUI fire models (E10, F10);
- Address spatial and temporal gaps in satellite coverage, and incorporate more comprehensive data coverage into existing wildfire management (D19);
- Improve access to real-time, accurate information on demographics, infrastructure, and the pre-fire environment to inform decision-making in response to WUI and wildland fires (D20);
- Integrate high-resolution, detailed, and near-real-time ground-based and remote sensing data with AI algorithms and models into Decision Support Systems (DSS) based on ground conditions during ignition that are freely available and accessible for land managers and the public (D21);
- Use the Potential Operational Delineations (PODs) framework[16] in conjunction with spatial analytical tools and consultation with local fire management to identify and develop potential control lines for future wildfires (C9);
- Develop a performance metric to track the use of PODs or other fire planning frameworks to prepare for fire management (C10);
- Improve equipment access, training, funding, and supplies for Rangeland Fire Protection Associations (RFPAs)[17] (C11);
- Improve aviation coordination within and around the Fire Traffic Area[18] (A6);
- Improve deployment and resource tracking on wildfire response efforts with an inventory or database of available local, State, and Federal firefighting resources (C12, F11);

---

[15] The *Wildland Fire Decision Support System* is a system that "assists fire managers and analysts in making strategic and tactical decisions for fire incidents" and "integrates the various applications used to manage incidents into a single system, which streamlines the analysis and reporting processes" (U.S. Geological Survey [USGS] 2024).

[16] Potential Operational Delineations are "spatial units or containers defined by potential control features, such as roads and ridge tops, within which relevant information on forest conditions, ecology, and fire potential can be summarized. PODs combine local fire knowledge with advanced spatial analytics to help managers develop a common understanding of risks, management opportunities, and desired outcomes to determine fire management objectives" (USDA 2024).

[17] Rangeland Fire Protection Associations "organize and authorize rancher participation in fire suppression alongside federal agency firefighters" composed of "all-volunteer crews of ranchers [who] have training and legal authority to respond to fires on private and state lands in landscapes where there had been no existing fire protection, and can become authorized to respond on federal lands as well" (Northwest Fire Science Consortium 2023).

[18] The Fire Traffic Area is "a section of airspace with a five nautical mile (NM) radius from the center point of an incident during fire suppression operations" (Mills and Clark 2022).

- Create "standards of cover" to guarantee a response to a wildfire incident within a certain region and within a fixed period of time (C13);
- Enable access for non-Federal entities and individuals to assignments and dispatching information in the Interagency Resource Ordering Capability (IROC)[19] and Incident Qualifications and Certification System (ICQS)[20] (C14);
- Evaluate the strengths and limitations of IROC and make any identified improvements (C15);
- Develop methods to assess whether community resources are adequate for a possible wildfire threat (E11);
- Conduct research on the effectiveness of current wildfire firefighting and management responses and identify opportunities for improvement (E12); and
- Improve understanding and recognition of locations and species that are culturally significant to Tribal nations or are sites with historical, environmental, or national security/military sensitivity that may be affected by fire management decisions (C16, F12, G7, H1).

2. Communication

S&T gaps identified in the Communication space stemmed from Reports A, C, D, E, and F. Gaps and recommended priorities primarily covered extending communication infrastructure to reach firefighters on the ground, ensuring firefighters have accurate and pertinent information, and improving interoperability among cross-jurisdictional firefighters. Gaps and recommendations included:

- Expand adoption of interoperable communication systems and extended field connectivity for active firefighting (C17);
- Enable last mile connectivity by expanding communication infrastructure and services (e.g., cellular, radio, WiFi) to support strategic coordination and near-real-time response and decision support with information such as fire location, behavior, and forecasts (A7, D22);
- Implement new technologies for situational awareness and communication (E13);

---

[19] IROC "provides the Dispatch Community with a fast and stable system that works well even during peak activity" (USDA and DOI n.d.).

[20] ICQS "is a management tool to record, track and report on responder qualifications for 'NWCG Standards for Wildland Fire Position Qualifications,' PMS 310-1, and agency-specific standards" (National Wildfire Coordinating Group [NWCG] n.d.).

- Establish mobile area networks or mobile ad-hoc networks for communication in remote areas, and provide training for use of the networks (A8);
- Maintain telephone and internet connections during WUI incidents by improving resilience of communications infrastructure (F13);
- Extend cloud computing environments to remote locations such as spike camps[21] (A9);
- Continue use of satellites for communication services across orbits and altitudes (A10);
- Improve situational awareness and tracking system interoperability for emergency responders to create a common operating picture and share information on emergency response arrival, resources, and hazard assessments across jurisdictions (F14);
- Establish cross-jurisdictional agreement on the process for (1) verifying and validating of fire and land products and (2) transferring products for use by firefighting operations and suppression personnel with clearly defined time scales (i.e., hours, days, weeks) (D23);
- Increase frequency of briefings for emergency responders in WUI fires to improve awareness among firefighters, emergency managers, and the public (F15);
- Establish a process to rapidly deliver wildfire information through user-friendly tools and data products for firefighters and incident commanders (A11, D24);
- Ensure information provided to fire management teams is useful, available, actionable, and properly scaled to avoid overabundance of irrelevant or confusing data (D25); and
- Coordinate information and data sharing from both ground assets and crewed and uncrewed aviation to firefighters (A12).

3. Firefighting Technology

S&T gaps identified in the Firefighting Technology space stemmed from Reports A, C, and E. Gaps and recommended priorities primarily covered assessing and leveraging existing technology, and developing and improving technologies to support wildland firefighting. Gaps and recommendations included:

---

[21] A "spike camp" is "a smaller camp separate from the main fire camp ... [that] generally draw[s] their supplies and food from the main camp and are used to support operation areas that require personnel to travel extended distances to return to the main camp" (U.S. Fish and Wildlife Service n.d.).

- Assess existing technology across government and private sector for operational wildland firefighting, including uncrewed aerial and ground vehicles, commercial satellite data feeds, field sensors, WUI firefighting simulation training, wildfire-specific personal protective equipment (PPE), and information technologies (referring to aviation coordination, satellite monitoring, integrated data services, data standards and processing, situational awareness tools, and last mile connectivity) (A13);
- Develop a technology roadmap for research and testing to support firefighting operations (A14);
- Leverage autonomous drones and robotics to reduce physical burdens on and needs for human firefighters (A15);
- Leverage technology to facilitate rapid access to wildfires in forested and steep terrain (A16);
- Improve development, field demonstration, and deployment of uncrewed aerial vehicles and other autonomous systems to increase early response capacity and protect firefighters (A17);
- Incorporate warfighting technology into wildland firefighting, as applicable (A18);
- Identify innovative approaches to contain large wildfires more efficiently (E14);
- Establish standards for supporting, training, and equipping the firefighter workforce (C18);
- Improve safety with implementation of new technologies for situational awareness, communications, and PPE (E15); and
- Adjust contracting models to incentivize contractors and private industry to invest in and adopt new firefighting technology (C19).

4. Additional Gaps to Consider

Three S&T gaps outside of those identified in the reports in the "Firefighter Operations and Safety" focus area include education for practitioners using new data or technology, research on differences in fighting wildfires across different land cover types, and the creation of a pathway to allow lower-level firefighters on the ground to share their technology concerns. First, the research gaps and priorities within this focus area likely require teaching firefighting practitioners and fire managers how to use the new data and tools. New tools intended for immediate use require clear and informative training for users so they can be deployed imminently by first responders.

Second, research could be conducted to identify best practices in suppressing wildfires across different ecosystem or land cover types. Understanding the differences in how wildfires spread across rangelands, forests, suburban, rural, or chaparral, among others, could improve training and equipment for firefighters. Experienced firefighters in such landscapes could inform best practices in response.

Third, and related to the "Practitioner-Informed Science and Technology" cross-cutting priority, a pathway could be developed to enable firefighters who are not in leadership positions to provide feedback on their experiences with S&T. Those who are actively fighting fires on the ground should be able to inform the design and use of their equipment based on their needs and experiences.

C. Land and Fuels Management

1. Land Management

S&T gaps identified in the Land Management space stemmed from Reports C, G, and H. Gaps and recommended priorities primarily covered forest management plans, carbon accounting, and the impacts of fire on landscapes. Gaps and recommendations included:

- Improve understanding of impacts from choosing not to use fire as a management tool (G8);
- Improve understanding of fire behavior for wildland fire use for management, including for ecosystems managed by DoD (G9);
- Improve understanding of how fire (including stand-replacement fire regimes[22]) affects ecological disturbance and succession (B4, G10, H2);
- Develop forest management plans that incorporate fuel treatments, carbon sequestration, and sustainable yield (H3);
- Characterize vegetation and fuel bed information across landscapes, including DoD lands such as the Southeast and arid and semi-arid Southwest (G11);
- Improve fuel monitoring, mapping, and characterization across DoD facilities for smoke management and fire planning purposes (G12);
- Anticipate and prepare for future regulation of greenhouse gas emissions for Federal land management agencies (G13);

[22] *Stand-replacing fire* refers to "fire which kills all or most of the living overstory trees in a forest and initiates forest succession or regrowth" (NWCG 2024). *Fire regime* refers to "the historical ecological role of fire in creating and maintaining vegetation communities for a period before Euro-American settlement activities and active fire suppression began" (U.S. Forest Service [USFS] n.d.).

- Incorporate the carbon cycle and its impacts on fire into ecosystem research and assess carbon sequestration goals, anticipating the uncertainty of climate change (G14);
- Improve carbon accounting across ecosystem types (G15);
- Estimate long-term carbon changes in ecosystems due to different management options (B5);
- Incorporate carbon sequestration goals into land management (G16, H4);
- Create a flexible carbon footprint tool to estimate stocks and fluxes across management options (G17);
- Improve forest management facilities across Tribal lands (H5);
- Assess the condition of Indian forest lands and management, including forest health, productivity, timber sales, and institutional capacity (H6);
- Incorporate Tribal values, goals, and standards around non-timber forest products[23] into management plans (H7);
- Monitor, review, and update non-expiring forest management plans and acknowledge Tribal priorities (H8);
- Synthesize existing studies on longleaf pine restoration and management (G18);
- Characterize all fuels (canopy to surface), evaluate fuel measuring protocols and tools against field sampling verification, and create a central data repository for fuel datasets (G19);
- Maintain an active forest monitoring program to identify forest density and fuel conditions (H9);
- Identify desired outcomes of Federal land management to develop appropriate performance metrics and funding levels, with an emphasis on ecosystem resilience and societal benefit (C20);
- Improve understanding of nutrient cycling under non-stationary conditions and community assembly in a fire-managed future (G20); and
- Reduce wild horse and burro populations to sustainable levels (H10).

[23] Non-timber forest products refer to "plants and mushrooms used for food, medicine, and other purposes" and "traditional practices of fishing, gathering, and hunting, as well as uses of firewood" (The Fourth Indian Forest Management Assessment Team for the Intertribal Timber Council 2023).

2. Fuel Treatments

S&T gaps identified in the Fuel Treatments space stemmed from Reports B, C, D, E, G, and H. Gaps and recommended priorities primarily covered prescribed burns, woody biomass, and assessments of the costs and benefits of fuel treatments. Gaps and recommendations included:

- Develop prescribed fire targets based on local fire regimes and fire return intervals, recognizing how climate change, invasive species, and other ecosystem stressors have affected historic fire regimes (C21, H11);
- Improve identification of burn windows for prescribed burning through more personnel, enhanced computing resources, integrated fuels-meteorology-smoke transport models at microscales, and improved seasonal and monthly forecasts that integrate climate, weather, fuels, and projected air quality impacts (D26);
- Expand training to increase personnel capacity for prescribed and cultural fire (C22, H12);
- Establish cooperative burn plans to enable more prescribed and managed fire (H13);
- Improve understanding of public perceptions and attitudes around wildland fire, and educate communities on the differences between wildland fire and prescribed burning (D27, E16);
- Improve forest road maintenance to support hazardous fuel reduction, including access, signage, repair, and resurfacing (H14);
- Identify opportunities to use woody biomass and other wood products for renewable energy development, reduced climate change impacts, and reduced mitigation costs (B6, C23, H15);
- Research, conduct pilot projects, and develop commercial wood processing industries and technologies that combine woody biomass fuel reduction, ecological restoration, and commercial viability (C24, H16);
- Support bioenergy opportunities through carbon capture and storage, biochar production, and cogeneration using waste biomass from fuel treatments (C25);
- Conduct risk-based research to identify appropriate fuel treatment approaches that will maximize the effectiveness of fuel treatments across different landscapes with minimal consequences to ecosystem services and communities, incorporating remote sensing and burn severity mapping (C26, E17);
- Evaluate fuel treatment options based on future emissions characterizations or reductions (B7, G21);

- Assess the costs and benefits of fuel treatments in mitigating wildfire impacts through fuel treatments (E18);
- Understand what factors motivate wildfire mitigation actions (E19);
- Improve Federal agency capabilities to pursue fuel treatments (E20, H17);
- Develop models that combine community information and geospatial data to predict how fuel treatments and community design may mitigate wildfire impacts (E21);
- Conduct risk assessments and probabilistic forecasts to characterize and assess local fire risk with and without fuel reduction activities (D28);
- Create operational wildfire containment lines through hazardous fuel reduction (H18); and
- Improve targeted grazing through remote sensing and virtual fencing (C27).

3. Impacts of Climate Change and Other Stressors

S&T gaps identified in the Impacts of Climate Change and Other Stressors space stemmed from Reports B, C, E, G, and H. Gaps and recommended priorities primarily covered research and modeling on how climate change and other stressors affect ecosystems and fire regimes. Gaps and recommendations included:

- Improve understanding of how climate change impacts, insects, disease, invasive species, and other stressors affect ecosystems (including vegetation type conversion,[24] habitats, ecosystem services, and post-fire regeneration), their fire regimes, and their need for fuel treatments (B8, E22, G22, H19);
- Develop and evaluate modeling tools to anticipate ecosystem sensitivity to climate variability swings that may affect fire regimes or impacts (G23);
- Identify and test approaches to reduce the impact of climate change and other stressors on ecosystems, their fire regimes, and their need for fuel treatments (B9);
- Incorporate climate change impacts, insects, disease, invasive species, and other stressors in scientific research and modeling tools to estimate potential future reference conditions under various scenarios (B10);

[24] *Vegetation type conversion* refers to cases in which "change in community type and dominant plant functional types are extensive, and the alternative state is persistent and reinforced by novel interactions among climate, vegetation, and disturbances." Examples include conversion of a forest to a shrubland or a shrubland into a grassland following a wildfire (USGS 2022).

- Incorporate current and projected impacts of climate change and other stressors on landscapes in qualitative and quantitative assessments of fire mitigation decisions (C28); and
- Improve understanding of how fire (including stand-replacement fire regimes[25]) and changing fire regimes (i.e., too much or too little fire) affect ecological disturbance and succession (B11, G24, H20).

4. Traditional Ecological Knowledge

S&T gaps identified in the Traditional Ecological Knowledge (TEK) space stemmed from Reports B, C, D, and H. Gaps and recommended priorities primarily covered increased recognition of and respect for Indigenous knowledge and Tribal sovereignty related to fire management and mitigation. Gaps and recommendations included:

- Research pre-European settlement Indigenous cultural burning regimes to improve understanding of historic fire regimes (B12);
- Include and respect Indigenous knowledge in fire management (C29, D29, H21);
- Maintain confidentiality of Tribal data and Indigenous knowledge (C30);
- Restore Tribal cultural burning practices through partnerships, changes in regulation, and Tribal leadership (H22);
- Incorporate multiple stakeholders, worldviews, and priorities—including Indigenous values and knowledge—in the science, culture, and values around wildfire resilience (D30, H23); and
- Incorporate TEK into mitigation training programs, without appropriation and with recognition of Tribal sovereignty and culturally important areas and resources (such as significant sites or plants) that may be affected by fire management or mitigation (C31, H24).

5. Additional Gaps to Consideration

In addition to the gaps identified in the reports in the "Land and Fuels Management" focus area, Federal S&T priorities could include localized return intervals for fuel treatments, social science research on implementing fuel treatments across jurisdictions or property ownership, and the formal elevation of Tribal knowledge at a Federal fire

---

[25] *Stand-replacing fire* refers to "fire which kills all or most of the living overstory trees in a forest and initiates forest succession or regrowth (NWCG 2024)". "Fire regime" refers to "the historical ecological role of fire in creating and maintaining vegetation communities for a period before Euro-American settlement activities and active fire suppression began" (USFS n.d.).

leadership level. First, knowing the ideal return interval for fuel treatments could reduce the risk of a significant wildfire. Developing a tool or method that would provide that information on a site-specific basis and incorporate different types of fuel treatments could optimize treatment activities and inform budget and resource decisions.

Second, planned large-scale fuel treatments may require crossing jurisdictions or multiple owners' property. Social science research could explore challenges and best practices in conducting large-scale fuel treatments that cross different properties. Identifying opportunities for widespread fuel treatments such as prescribed burns could dramatically increase the pace and scale of much-needed mitigation activities.

Third, agencies involved in Federal fire leadership could formally recognize Tribal knowledge and its relevance to fire management. In 2021, the California State Legislature required the California Department of Forestry and Fire Protection (Cal Fire) to appoint a cultural burning liaison who would advise Cal Fire on increasing cultural burning in the State.[26] A similar effort at the Federal level or within a Federal agency could support the formal recognition of Indigenous knowledge and TEK on an equal par with Western wildfire science.

D. Construction and Zoning

1. Ignition-Resistant Construction

S&T gaps identified in the Ignition-Resistant Construction space stemmed from Reports A, C, E, F, and G. Gaps and recommended priorities primarily covered improved wildfire-resistant building materials through research and private sector partnerships. Gaps and recommendations included:

- Research the relationship between wildland fires and adjacent structures (E23);
- Document the effectiveness of risk-mitigation technologies and techniques in protecting communities and structures (C32, G25);
- Research improvements to and best practices for developing more wildfire-resistant building materials, infrastructure, and communities, including for retrofitting existing buildings and remediating buildings following fire and smoke events (C33, E24);
- Identify critical infrastructure at risk of WUI fire and prioritize relocation or hardening (F16);

[26] AB-642 Wildfires. (2021–2022). https://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=202120220AB642.

- Use existing research to provide the baseline for architects, designers, and planners to create certifications, contests, or other incentives to spur innovation in ignition-resistant design and wildfire resilience (C34);
- Partner with private industry to research and adopt new technology for wildfire mitigation (C35); and
- Emphasize and prioritize protecting and reducing risks to life and property across Federal fire science producers and users (E25).

2. Codes and Standards

S&T gaps identified in the Codes and Standards space stemmed from Reports B, C, D, E, and F. Gaps and recommended priorities primarily covered instituting science-based building codes in high-risk areas, reducing electric utility ignitions, and developing hazard maps. Gaps and recommendations included:

- Implement ignition-resistant codes and standards for new construction and rebuilding in wildfire-prone areas (B13, C36, F17);
- Research science-informed improvements to current building codes and standards for new construction and retrofits, with improvements informed by data analysis and geospatial modeling (C37, E26);
- Conduct socioeconomic surveys to understand the psychology and economics of home hardening and defensible space choices (D31);
- Conduct social science research to understand political will and action around local building codes (D32);
- Establish a national requirement for risk disclosures in real estate transactions to provide common familiarity with risk among buyers (C38);
- Construct more resilient critical infrastructure to avoid cascading impacts from wildfire damage, and improve awareness of the status of critical infrastructure during emergency response (F18);
- Establish wildfire shelters based on NIST shelter design research (C39);
- Identify best practices for permitting risk reduction work in the rights-of-way for utility lines that cross Federal, public, and private lands (C40); and
- Develop, update, and maintain neighborhood-level hazard maps based on changes in climate, development, mitigation action, and prior exposure to disasters (C41, D33).

3. Education and Decision-Making

S&T gaps identified in the Education and Decision-Making space stemmed from Reports C, D, E, and F. Gaps and recommended priorities primarily covered development and evaluation of decision support tools, education on wildfire-resistant construction, and creation of community hazard maps. Gaps and recommendations included:

- Develop decision support tools to inform mitigation and risk reduction efforts using information, data, assessments, and models that incorporate climate conditions, fuels, home ignition, structure-to-structure spread, and values at risk (C42);
- Use data-based models, AI models, remote sensing, and field-based warning systems to anticipate (and mitigate) wildfire impacts on infrastructure (B14, C43);
- Assess characteristics of community design (e.g., layout, landscaping, structural design and materials) to identify recommendations for improving wildfire safety (E27);
- Prepare critical infrastructure in anticipation of high-risk fire warnings (F19);
- Provide information and tools for homeowners and planners on how to improve fire safety through construction, landscaping, and community planning (E28);
- Provide public education on building codes and standards, ignition-resistant building materials, and defensible space (C44);
- Develop spatially explicit, long-term datasets with very high-resolution remote sensing imagery that include building footprints, defensible space, and demographics to inform WUI design, fire management, and recovery (C45, D34);
- Develop and implement modeling and analysis systems to inform risk-based strategies for community design, risk mitigation, and ecosystem protection (C46, E29);
- Incorporate community information into geospatial data to evaluate and anticipate impacts across local to national scales on fire safe community design (E30);
- Improve accuracy in WUI fire models to identify the highest-risk WUI areas based on fire behavior and history, weather history, fuel type, and current conditions, and quantify potential impacts of fire based on economic and social impacts (F20); and
- Evaluate data, tools, and resources for reducing community risk that are currently available for local, State, and Federal governments, and implement

improvements, including technical assistance, technological innovations, and data acquisition and access (C47).

4. Additional Gaps to Consider

Beyond the gaps associated with the "Construction and Zoning" focus area identified in the reports, potential priorities for Federal S&T efforts include new guidance on construction standards in communities with limited space between structures, grants and other resources to support mitigation activities for homeowners, and research on local community mitigation programs. First, current defensible space guidance lists three zones (Zone 0: 0–5 feet extending the structure; Zone 1: 5–30 feet; and Zone 2: 30–100 feet) with distinct recommendations for vegetation in each zone. However, most homes in suburban wildland-urban interface or in more urban areas do not have 60 feet between them, meaning neither house has the full extent of Zone 1 available, let alone the 200 feet between homes that would comprise a complete Zone 2 for each home. Given these realities, new research could be conducted on how to best protect homes clustered very close together that would not have adequate defensible space. Such research could then be incorporated into local or State codes and standards.

Second, additional grants and resources could improve the implementation of defensible space and home hardening among homeowners. For example, the California Department of Forestry and Fire Protection (Cal Fire) aims to inspect each of the 768,000 parcels within its fire protection jurisdiction every 3 years but has not met its annual goals (Kerstein 2021). Support for similar programs across the country could reduce losses from wildfires due to proactive inspections that prompt defensible space or home hardening.

Third, local wildfire mitigation programs engage millions of homeowners in teaching them about mitigation activities such as home hardening. As one example, Firewise USA is run by the National Fire Protection Association (NFPA) and co-sponsored by USFS, DOI, and the National Association of State Foresters. Firewise USA helps community members develop and implement neighborhood action plans to protect communities against wildfires.[27] The program operates around the country, with more than 1.5 million residents participating in Firewise sites.[28] Similarly, FireSafe Councils in California connect residents with fire officials to implement mitigation projects.[29] However, minimal research has been conducted on programs like these regarding who participates, why they

---

[27] See NFPA's Firewise USA for more info: https://www.nfpa.org/education-and-research/wildfire/firewise-usa.

[28] See NFPA's Firewise USA Sites for more info: https://www.nfpa.org/education-and-research/wildfire/firewise-usa/firewise-usa-sites.

[29] See California FireSafe Council's Fire Safe Councils for more info: https://cafiresafecouncil.org/resources/fire-safe-councils/.

participate, how to reach non-participants, and if they are effectively reducing wildfire risks.

E. Public Health and Safety

1. Alerts and Warnings

S&T gaps identified in the Alerts and Warnings space stemmed from Reports A, C, D, E, and F. Gaps and recommended priorities primarily covered improvements to existing warning systems and greater adoption of alternative emergency alert systems. Gaps and recommendations included:

- Improve adoption of alternative emergency alert systems and communication to ensure complete and redundant coverage, including through interoperable communication systems, siren alarm systems, NOAA Weather Radio, and social media (C48, E31, F21);
- Improve emergency communication to enable multi-platform messaging from a single source with national reach (F22);
- Coordinate with telecommunication carriers to improve service delivery of emergency messages, including in remote areas (C49, F23);
- Conduct and implement findings of social science research on risk communication and uniform warnings for fire, recognizing geographic differences, complex regulatory environments, varying levels of fire knowledge, equity and social justice concerns, and the need to avoid public panic or desensitization due to over-warning or under-warning (D35, F24);
- Integrate public safety answering points into Incident Command (F25);
- Tailor warnings and notifications for hard-to-reach and vulnerable populations, considering options beyond traditional text, visual, and audible notifications such as different languages or alert styles (F26);
- Use multiple messaging providers to reach affected populations, including geographically targeted notifications and warnings (F27);
- Ensure early warning systems (EWS) provide relevant, clear, and timely information by evaluating the effectiveness of existing and alternative systems for best practices, developing a standardized approach for communicating wildfire-related evacuations, integrating terminology for wildfires into an all-hazard standard (and possibly a new lexicon), transitioning opt-in alert systems to opt-out systems, developing EWS capacities for Tribal lands, and enabling emergency operations centers (EOCs) and the National Weather Service to serve as dissemination points for Weather Emergency Alerts (WEAs) through the

Integrated Public Alert & Warning System (IPAWS) when issuing non-weather emergencies (C50, D36, E32, F28);

- Build DSSs by integrating information, data (including ground-based and remote sensing data), and models (including AI algorithms and wildfire models) to inform automated early warning detection, logistical needs, advance planning, and evacuation decisions across different wildfire scenarios (A19, C51, D37, E33);
- Identify a consistent approach across jurisdictions on thresholds for when to issue warnings and who has the authority to issue warnings (F29);
- Incorporate local fire departments and emergency managers into declarations and decisions around degree of risks, particularly for potential Red Flag Warnings with possible WUI fire implications (F30); and
- Communicate realistic expectations among the public for firefighting protection in high-risk areas (F31).

2. Evacuations

S&T gaps identified in the Evacuations space stemmed from Reports C, E, and F. Gaps and recommended priorities primarily covered planning, monitoring, and establishing guidelines for evacuations. Gaps and recommendations included:

- Develop best practices on evacuation patterns and schema, such as whether to begin evacuations farthest from the hazard or closest to the hazard (F32);
- Incorporate pre-fire spatial planning and evacuation drills into evacuation planning (C52);
- Establish public-private partnerships to communicate escape route information to emergency management, label evacuees as "safe" on social media, and provide evacuation guidance to transient populations (F33);
- Integrate evacuation planning across jurisdictions and agencies by developing pre-established relationships with neighboring jurisdictions and partners (F34);
- Identify multiple evacuation routes, safe zones, and shelter-in-place facilities across jurisdictions (F35);
- Develop an inventory of evacuation capabilities and available resources by jurisdiction (F36);
- Implement a national education campaign to promote "Ready, Set, Go!" terminology across jurisdictions while incorporating flexibility in local decision-making on evacuation routes and other preparedness efforts (C53);

- Conduct social science research on why individuals choose to evacuate or stay (E34);
- Provide public education on evacuation preparedness, planning, and warning language (C54, F37);
- Improve local evacuation communication systems to meet national standards (C55);
- Improve existing evacuation models to account for realistic traffic conditions, evacuation routes, population behavior, and safety areas (F38);
- Establish evacuation thresholds for decision-making that can be adapted for different incidents (F39);
- Establish standards and guidelines for evacuation procedures for vulnerable populations, such as individuals with medical needs (F40);
- Develop a system to track communities and vulnerable populations in high-risk areas to plan and prepare for complex mobility requirements, communication, and evacuation procedures (F41);
- Create a common platform to monitor evacuation routes, safety zones, and population evacuation in real-time to assess individual- and community-level evacuation responses (F42); and
- Establish procedures and directions for animal evacuations (including farm, exotic, and pet animals) (F43).

3. Wildfire Smoke

S&T gaps identified in the Wildfire Smoke space stemmed from Reports A, B, C, F, and G. Gaps and recommended priorities primarily covered the need for improved plume modeling, smoke emissions characterization, more smoke monitoring, and smoke mitigation for vulnerable communities. Gaps and recommendations included:

- Improve wildfire plume dispersion modeling through model validation and improved understanding of plume structures, dispersal simulations, emissions release rates, relationship to prescribed fire ignition patterns, dispersion predictions for low intensity fires, terrain effects on smoke transport, and WUI conditions (F44, G26);
- Develop night-time smoke dispersion modeling tools that address existing visibility limitations (G27);
- Validate smoke models against field experiments, focusing on heavy fuels and high-intensity fire events (G28);

- Characterize fire emissions, their dispersion, and associated uncertainties into the atmosphere, and establish exposure thresholds for hazardous air pollutants (G29);
- Characterize emissions based on vegetation types under both flaming and smoldering combustion, current weather conditions, and fire severity (G30);
- Improve emissions estimates including reconciling results from different data sources and assessing existing approaches and limitations (G31);
- Characterize greenhouse gas emissions profiles of wildfires (G32);
- Develop wildfire smoke models based on emissions from archival satellite data (A20);
- Improve quality of field data on prescribed burns and wildfire emissions to include measurement methodology and conditions during fires (G33);
- Determine source contribution of prescribed fires and wildfires to regional air quality through a characterization protocol that is standardized across the regulatory community and incorporates (1) the role of emissions in climate forcing and (2) differences in emissions across ecosystems with different fire histories and regimes (G34);
- Establish a near real-time database for prescribed burns across all levels of government to improve ignition coordination and reduce smoke impacts (C56);
- Educate communities on the differences associated with smoke across cultural fire, prescribed burns, and wildfires (B15);
- Invest in data collection, analysis, and research on how prescribed and managed fires affect human health, ecosystems, air quality emissions, and mission support (C57, G35);
- Expand current air quality forecasts, notifications, and alerts to include wildfire and prescribed fire smoke, such as incorporating smoke into the National Weather Service's weather alert system or creating a public county-level smoke alert notification system (B16, C58);
- Establish a nationally consistent smoke monitoring and alert system to provide real-time information and forecasts on smoke events (C59);
- Increase research on, the number of, and use of smoke sensors, speciation monitors, and other smoke forecasting and monitoring capabilities for research and operational purposes (C60, G36);
- Incorporate information, data, and models in public health decision-support efforts, such as improvements to Fire and Smoke Map from AirNow, AirNow

Forecast Submittal System, AirNow mobile app, AirNow.gov, and AirNow-Tech (C61);

- Identify populations and communities at heightened risk or vulnerability to wildfire smoke, and implement mitigation and communication strategies to improve preparedness and protect populations with worst exposures (C62, F45);
- Develop evidence-based guidance and educate communities on smoke mitigation strategies, including on remediating buildings affected by a fire or smoke event (C63); and
- Develop data tracking capabilities to recognize smoke from wildfire and beneficial fire for regulatory distinctions (Exceptional Events Rule) (C64).

4. Physical and Mental Health

S&T gaps identified in the Physical and Mental Health space stemmed from Reports A, C, and E. Gaps and recommended priorities primarily covered comparing the health concerns of wildland firefighters and structural firefighters, understanding the composition of wildfire smoke emissions, developing better PPE, and designing a human health risk assessment. Gaps and recommendations included:

- Research the chemical composition of smoke, ash, and synthetic materials (i.e., from fires in the WUI) and associated short-term and cumulative, long-term occupational exposures (e.g., inhalation, dermal) on health (C65, E35);
- Research the mental and physical health impacts from exposure to smoke among structural firefighters, wildland firefighters, and firefighters in both the natural and built environment (C66);
- Research the health impacts from immediate and long-term exposure to structural fire smoke compared to wildfire smoke (C67);
- Research the health impacts of wildfire smoke on agricultural and other outdoor workers (C68);
- Research the compounding health effects of smoke inhalation, heat, and minimal available healthcare (C69);
- Conduct research and explore interventions for firefighter mental health during fire and off seasons (C70);
- Develop PPE for wildland firefighters, including conducting research on the physiological effects of PPE and best practices for PPE decontamination (C71);
- Identify effective mitigation and adaptation techniques to reduce acute and cumulative exposures to smoke and heat (C72);

- Train healthcare providers and public health agencies on treating and educating on the immediate health impacts of wildfires and wildfire smoke, particularly for patients with pre-existing conditions (C73);
- Train and provide resources to community healthcare providers to support patients experiencing long-term physical and mental health impacts of wildfire exposure (C74);
- Create national, science-based guidance for occupational smoke standards with particulate matter (PM) indicators (C75); and
- Develop (1) a nationally consistent smoke monitoring system and (2) a human health risk assessment for occupational exposure informed by the smoke monitoring system that can identify likely health impacts and associated mitigation strategies (C76).

5. Additional Gaps to Consider

Additional S&T issues exist in the "Health and Safety" focus area beyond those listed throughout the reports. First, protocols should be established across jurisdictions and clearly communicated to the public that support continued medical access during evacuations. For example, evacuees may not be able to access dialysis centers or pharmacies, and may not have evacuated with their medications or prescriptions. Training medical staff on how to provide such services in the event of an emergency can enable continuity of critical care.

Second, public health and epidemiological research could explore the impacts of wildfire smoke on indoor air quality. Sheltering inside may not fully protect residents from hazardous particulate matter exposure. Improved understanding of home air filtration systems could alter public health guidance on remaining indoors. In addition, resources for indoor filtration devices, including homemade air filters, could be more widely distributed in wildfire-prone areas.

Third, exposure to wildfires and to wildfire smoke may affect subpopulations differently, requiring distinct guidance or equipment. Air quality alerts could recommend actions for specific at-risk groups, such as pregnant individuals. Researchers could collect disaggregated health impact data to evaluate differences among male and female firefighters, or across other demographic factors. Designing and distributing sex-specific firefighting PPE could protect female firefighters, as existing uniform sizes may be too large for comfort and safety (McQuerry et al. 2023).

F. Relief and Recovery

1. Post-Fire Data and Risk Assessments

S&T gaps identified in the Post-Fire Data and Risk Assessments space stemmed from Reports C, D, G, and H. Gaps and recommended priorities primarily covered additional resources for post-fire assessments, improved access to datasets, and centralized wildfire data management infrastructure. Gaps and recommendations included:

- Provide additional funding and resources to support agencies in rapidly collecting highly perishable post-fire data, conducting assessments of burned landscapes, and pursuing reforestation and revegetation (C77, G37);
- Enable Burned Area Emergency Response (BAER) assessments to be conducted on non-Federal land (C78);
- Expand and improve data latency for programs like BAER and Monitoring Trends in Burn Severity (MTBS) (D38, H25);
- Integrate ground-based and remote sensing data with AI algorithms and models to support post-fire impact assessments (D39);
- Improve accessibility, training, and usability of datasets, tools, and post-fire maps and analyses for communities to use for post-fire assessments (C79);
- Assess impacts of fire on built infrastructure and DoD operational missions (G38);
- Consider wildfires and anticipated post-wildfire impacts in preliminary environmental planning and regulatory analyses to support faster recovery following a fire event (C80);
- Create a centralized, cross-departmental clearinghouse for wildfire-related data that is easily discoverable and includes information on post-fire impacts, funding opportunities, ecosystem restoration, assessment science, and wildfire mitigation (C81, D40);
- Create a centralized data mapping platform that incorporates vegetation, geology, burn severity, soil type, fuel moisture, topography, structures, and other data layers to improve understanding of post-fire impacts (D41);
- Hire trained data management personnel to process, classify, and share data within wildfire data repositories with stakeholders involved in post-wildfire activity, including groundcrews, researchers, and communities (D42); and
- Develop common standards and protocols to define the "post-wildfire period," with implications for Federal resource deployment (C82).

2. Societal Impacts

S&T gaps identified in the Societal Impacts space stemmed from Reports C, D, and E. Gaps and recommended priorities primarily covered financial support, post-fire community planning, and community damage estimates. Gaps and recommendations included:

- Research financial protection solutions available from government and the private sector to ensure complementarity (C83);
- Identify incentives to encourage individuals to have sufficient financial protection for post-wildfire recovery (C84);
- Identify gaps in access to Federal recovery resources and technical assistance, and adjust programs and policies to promote access for underserved groups (C85);
- Improve accessibility of Federal grant applications by auto-populating fields or automatically notifying eligible applicants of grant opportunities (C86);
- Offer competitive grants to develop strategies for post-disaster recovery prior to the disaster (C87);
- Coordinate with universities, consulting firms, and agencies to improve community planning for post-fire impacts (C88);
- Create a wildfire module in FEMA's Hazus Program to standardize estimates of potential post-wildfire building losses (C89);
- Research and develop alternative shelter solutions during and after wildfire events (C90);
- Research policy and technological solutions to improve community recovery, incorporating social science and Indigenous knowledge where applicable (C91, D43, E36); and
- Assess how community and landscape designs affect infrastructure damage through validated models (E37).

3. Ecosystem Impacts

S&T gaps identified in the Ecosystem Impacts space stemmed from Reports D, E, G, and H. Gaps and recommended priorities primarily covered restoring fire-impacted ecosystems and improving seed collection and storage. Gaps and recommendations included:

- Develop methods to model the impacts on and recovery of fire-impacted ecosystems under various fire management scenarios, climate change scenarios, and community and landscape designs (E38, G39);

- Improve and apply methods to assess the risk of post-fire erosion, flooding, and other types of ecosystem damage (E39);
- Develop best practices and strategies to support post-fire landscape and watershed recovery (including monitoring for ecosystem type conversion) that are tailored to diverse ecological conditions (C92);
- Conduct research on how fire severity, disturbance history, topography, site characteristics, local weather, and other variables affect post-fire restoration (D44, G40);
- Gather data on pre- and post-fire vegetation composition, regrowth trajectories, and ecological conditions to inform rapid post-fire management decisions (D45);
- Improve information, data, and models that support post-fire decision-making related to vegetation recovery, debris flows and flooding, watershed protection, and ecosystem health (C93, E40);
- Increase funding and expand networks for rain and stream gauge placement and monitoring to provide warnings to downstream or downslope communities (C94);
- Improve seed collection, processing, storage, and cultivation systems to support post-fire demand surges (C95, H26);
- Develop climate-informed strategies and support research and development to improve short- and long-term survival rates for planted seedlings, including addressing challenges in exchanging appropriate seed stock across jurisdictions (C96);
- Establish consistent and comprehensive standards regarding seed collection, processing, storage, and testing guidelines to align with industry standards and improve post-fire recovery (C97);
- Modernize seed data management systems for public nurseries and seedbanks to incorporate data from Federal and State sources (C98); and
- Improve integration of ecological and watershed recovery science into wildfire management strategies (C99).

4. Post-Wildfire Environmental Health and Safety

S&T gaps identified in the Post-Wildfire Environmental Health and Safety space stemmed from Reports C and D. Gaps and recommended priorities primarily covered post-fire water quality and impacts on wastewater, with additional recognition of the need to assess other post-fire impacts. Gaps and recommendations included:

- Establish guidance and provide resources for contamination removal, including for volatile organic compound (VOC) identification, prevention, and control (C100);
- Provide training, equipment, and clear guidance for testing water quality for contaminants and toxins for public water sources and private wells (C101);
- Gather information on the timing and scale of new post-fire vegetation impacts on water infiltration capacities to understand their effects on downstream water supplies (D46);
- Conduct research on how changes in ground and surface source waters may impact the ability to treat and produce safe drinking water (C102);
- Conduct risk assessments and modeling to identify the greatest negative impacts to water and wastewater utilities from wildfires to prioritize utility replacements, upgrades, or improvements (C103); and
- Provide guidance on disposal of disaster debris (C104).

5. Additional Gaps to Consider

Priority areas associated with "Relief and Recovery" that are not included in the wildfire reports include cascading events, research on the societal impacts of wildfires and post-wildfire recovery, and education on post-fire vegetation. First, cascading events such as floods and landslides are common after a severe wildfire. Conducting research on, preparing for, and managing these cascading events is a critical aspect of wildfire relief and recovery. For example, the 2018 Montecito mudslide was a direct result of the 2017 Thomas Fire in Southern California, and resulted in 23 deaths (California Governor's Office of Emergency Services 2024), damage to more than 400 homes and businesses, and over $421 million in insurance claims (California Department of Insurance 2018). Cascading events tied to wildfires could be incorporated into Federal S&T priorities.

Second, additional research could be conducted on the impacts of wildfires and subsequent recovery on communities. Collecting perishable data on non-ecosystem impacts such as indoor air quality or medical needs within evacuation shelters following a wildfire could improve future relief efforts. In addition, social science research could inform how populations (particularly those in the WUI) respond to government actors, how many social workers are needed following a wildfire, how community populations change following significant property destruction, and how best to provide trauma-informed counseling and resources to affected individuals. Such research could support the development of best practices and new Federal programs to support short-term relief and long-term recovery.

Third, and related to the cross-cutting priority of "Education," resources, training, and education related to post-fire revegetation could be expanded to include non-Federal stakeholders. For example, homeowners, businesses, non-governmental organizations, and preservation or conservation groups may pursue inappropriate revegetation, whether by attempting to replant too quickly or selecting plants that are not well suited to the ecosystem. Implementing effective ecosystem recovery following a wildfire will require not only research on its impacts and subsequent best practices but also support and training to implement those best practices.

Appendix A.
References to Original Reports

The following quotes provide the original text from the eight reports considered in this analysis. Each quote is accompanied by a letter (signifying the report) and a number (signifying the order of the gap or priority recommendation from that report within this analysis). Therefore, quote A1 indicates that the quote is from Report A (*Modernizing Wildland Firefighting to Protect Our Firefighters*) and is the first gap or priority recommendation identified in this analysis. The quotes below may not provide the entire context behind the recommendation but offer additional insight into the gaps and priority recommendations listed here.

A. *Modernizing Wildland Firefighting to Protect Our Firefighters* (2023)

- A1: "Expand our nation's wildfire response capacity by encouraging development and field demonstration of prototype autonomous detection, assessment, and containment systems for wildland fire."
- A2: "Strengthen the full operational sequence of wildland firefighting—detection, alert, response, and suppression—by assessing existing technologies available within the federal arena, the private sector, and allied nations that could be integrated at each stage. The assessment should establish clear priorities and develop a roadmap for testing and transition into operations."
- A3: "Effective AI modeling of wildfire spread based on terrain, vegetation cover, soil moisture, wind, and other factors is within our grasp, but only with much broader access to abundant historical data—some of which exists in defense archives but is currently classified."
- A4: "Accelerate improvement of predictive wildfire modeling tools by expanding research community access to archived satellite data from defense and other government sources…. We recommend that the Department of Defense (DoD), with the support of partners in the intelligence community, NOAA, and NASA, lead a review of the classification level of the archived data."
- A5: "Models developed with the recommended new data streams could inform wildfire prediction and wildfire resilience work underway in several federal departments and agencies (e.g., DOI, USDA/USFS, DOE, NOAA, NASA,

NIST, NSF) by identifying terrain and land cover characteristics that promote or retard wildfires."

- A6: "Aviation coordination inside and outside the Fire Traffic Area can enhance safety for aviation and ground fire operations."
- A7: "'Our biggest hurdle with all these different technologies is what we call our "last mile connection." How do we get this data to boots on the ground? ... The communication infrastructure is just not there.' … Foundational communication infrastructure and services are a critical capability for strategic coordination and near-real-time awareness, resource tracking, and decision support."
- A8: "Technologies such as mobile area networks are now commonly used in the commercial and defense sectors, and they can enhance communications in terrain that is especially challenging and dangerous for wildfire response. USDA and DOI should also develop a program to begin training all federal wildland firefighters on the use of the new technologies immediately."
- A9: "The cloud computing environment is extended to remote locations, such as firefighting spike camps distant from the command post."
- A10: "Satellites provide both detection and communication services from an array of orbits and altitudes."
- A11: "In the aforementioned context of situational awareness, pilot projects funded by the federal government have demonstrated technologies to give wildfire incident commanders constant, real-time, situational awareness of all firefighters on the scene of an active fire.[24] But in many cases, the fire services are left to implement this technology translation by themselves on an ad hoc basis in the snippets of time not consumed by fighting fires, refurbishing equipment, training, or clearing fuels to reduce fire hazard."
- A12: "Incident awareness and assessment: Manned and unmanned aviation along with ground assets collect information to share with fire personnel."
- A13: "Strengthen the full operational sequence of wildland firefighting—detection, alert, response, and suppression—by assessing existing technologies available within the federal arena, the private sector, and allied nations that could be integrated at each stage. This assessment should establish clear priorities and develop an all-agency roadmap for testing and transition into operations. In addition to the information technologies identified in Recommendation 1, this broader assessment should identify existing technologies, such as uncrewed aerial and ground vehicles, commercial satellite data feeds, field sensors, wildland-urban interface firefighting simulation

training, and personal protective equipment that can enhance the safety and effectiveness of wildland firefighting. We recommend that the U.S. Fire Administrator lead this effort until the above-mentioned Joint Office is established. The U.S. Fire Administrator could be supported by other government agencies, including, but not limited to NASA, in assessing current technologies that would help validate the technology roadmap."

- A14: "Strengthen the full operational sequence of wildland firefighting—detection, alert, response, and suppression—by assessing existing technologies available within the federal arena, the private sector, and allied nations that could be integrated at each stage. This assessment should establish clear priorities and develop an all-agency roadmap for testing and transition into operations."
- A15: "Recent advances in autonomous drones and robotics can be leveraged to decrease the physical burdens of wildland firefighting, increase situational awareness, and perhaps even reduce the need for human firefighters to be present on the front lines of active wildfires.[57,58]"
- A16: "Recent advances in autonomous drones and robotics can be leveraged to decrease the physical burdens of wildland firefighting, increase situational awareness, and perhaps even reduce the need for human firefighters to be present on the front lines of active wildfires.[57,58] These tools can be particularly helpful in addressing major wildfires that can grow rapidly in forested, steep terrain areas, which are challenging to reach in a timely fashion using traditional firefighting equipment."
- A17: "Expand our nation's wildfire response capacity by encouraging development and field demonstration of prototype autonomous detection, assessment, and containment systems for wildland fire. Uncrewed aerial vehicles and other autonomous systems are poised to be able to dramatically increase our nation's wildfire response capacity, especially at a fire's incipient stages, while also providing new means to protect firefighters on the scene of active wildfires."
- A18: "The strategic framework for science and technology (S&T) that supports America's warfighters could be adapted to protect and empower wildland firefighters. Indeed, the needs of our wildland firefighters overlap substantially with those of America's warfighters. The Department of Defense (DoD) has dedicated research programs and S&T offices whose primary duty is to ensure that our warfighters are not sent into harm's way without the best of American science and technology at their disposal. A similar strategy for technology development and deployment is urgently needed to support our wildland

firefighters. In fact, we see considerable possibility for benefit to firefighters from the warfighter investments already made."

- A19: "In addition, better modeling of wildfires near the built environment can inform advance planning for evacuations, particularly of vulnerable populations within such communities."
- A20: "Modeling of wildfire emissions, which can also be validated by archival satellite data, can be used to assess the impact of wildfire smoke—from both unplanned fire incidents and from prescribed burns—on the immediate and long-term health of the firefighting force and downwind communities."

B. *National Cohesive Wildland Fire Management Strategy Addendum Update* (2023)

- B1: "Additional research may be needed to understand sources of human-caused ignitions and alternatives that can reduce wildfire starts."
- B2: "There are a number of explicit issues facing land and fire managers as well as communities including: never-before-seen fire behavior and fire effects, cross-cutting climate change issues, a lack of a comprehensive national assessment of the ongoing wildland fire situation and its impacts, fire behavior prediction and other tools are not effectively utilized and communicated to decision-makers and practitioners, a need for an assessment or inventory of ecosystem data, and a need for increasing investments in the building science related to wildland fire and community resilience."
- B3: "Safe, Effective, Risk-based Wildfire Response—All jurisdictions participate in making and implementing safe, effective, efficient risk-based wildfire management decisions."
- B4: "Prescribed and managed wildfire for resource objectives may not be options in all places. Fire regimes and ecosystems (e.g., chaparral and lodgepole pine) that require stand replacement fire may create complicated situations because of subsequent vulnerability to invasive species (e.g., chaparral) or hazardous burning conditions (e.g., lodgepole pine)."
- B5: "Furthermore, scientific research can provide estimates of long-term ecosystem carbon changes of different management options, to reduce the emissions that cause climate change."
- B6: "It was noted in the original Cohesive Strategy framework that developing markets and infrastructure for utilizing woody biomass (small diameter material) was a key management option. Today, there remains a lack of markets, infrastructure, and skilled human resource capacity to utilize this biomass….

New and expanding markets for biomass will create new ways to reduce fuel loads and accelerate forest restoration. Hazardous fuels, forests that are too dense, and event driven fuels such as those created by severe storms can be treated at scale and at an accelerated pace because the demand for biomass will be considerably greater."

- B7: "Furthermore, scientific research can provide estimates of long-term ecosystem carbon changes of different management options, to reduce the emissions that cause climate change."
- B8: "Nearly all ecosystems—shrublands, deserts, grasslands, forestlands, woodlands, tundra, and wetlands—are undergoing several cascading effects from climate change. The heat and aridity of climate change can impede post-fire natural regeneration, increasing the risks of vegetation type conversion (e.g., trees to shrubs, or shrubs to grass). These impacts threaten the function of these systems and the ecosystem services they provide including water, carbon sequestration, biodiversity, and more. Work to bring fire back into balance must account for climate change. New management options for climate change address how these altered conditions change the reference conditions - fire frequency by vegetation type—that are the goal of landscape management actions and change how different actions can store more ecosystem carbon in the long-term, reducing climate change…. Scientific research and appropriate modeling tools, ideally specific to a site or region and in collaboration with fire managers, should consider climate change, drought, invasive species, insect pests, traditional ecological knowledge and other factors that allow estimation of potential future reference conditions under a range of scenarios."
- B9: "New management options for climate change address how these altered conditions change the reference conditions—fire frequency by vegetation type—that are the goal of landscape management actions and change how different actions can store more ecosystem carbon in the long-term, reducing climate change…. Scientific research and experimentation can improve understanding of how climate change is altering ecosystems, fire regimes, fire behavior, post-fire vegetation regeneration and water quality; and test the effectiveness of field solutions."
- B10: "Use predicted future conditions under climate change as potential reference conditions for the proactive use of wildland fire. Current fire management practices in the U.S. primarily use estimates of pre-European settlement vegetation and fire frequency as reference conditions. Yet, scientific research shows that climate change is altering vegetation and fire regimes, possibly preventing the return to previous conditions."

- B11: “Fire regimes and ecosystems (e.g., chaparral and lodgepole pine) that require stand replacement fire may create complicated situations because of subsequent vulnerability to invasive species (e.g., chaparral) or hazardous burning conditions (e.g., lodgepole pine). Other ecosystems have too much fire because of fire-adapted invasive species (e.g., sagebrush steppe, southwestern deserts) or a changing climate (e.g., tundra). Strategies for these systems should be an important part of pre-fire, fire response and post-fire management.”
- B12: “Additionally, understanding pre-European settlement indigenous cultural burning regimes as natural background is important in furthering the use of traditional ecological knowledge.”
- B13: “New construction and rebuilding in wildfire-prone areas is often occurring without employing codes and standards that address wildland fire, and development is further exacerbated by the housing crisis many areas are experiencing. Adopting strong WUI and interface building codes is important in addition to stronger codes for municipal and non-municipal areas, as appropriate for each community.”
- B14: “New data-based and artificial intelligence models along with remote-sensing and field-based warning systems offer opportunities to help build community resilience by predicting post-wildfire impacts on infrastructure (e.g., communities, transportation corridors, and water supplies).”
- B15: “Ensure communities are provided with information about differences between prescribed/cultural burning and wildfire-related events, including mitigating smoke impacts so they can make informed decisions about reducing the impacts to vulnerable residents. This includes consideration for acute versus chronic exposure as tradeoffs.”
- B16: “The health impacts of smoke on populations from both wildfire and prescribed fire can be reduced by ensuring notification of prescribed fires, awareness of smoke health effects and providing options for reducing or mitigating smoke exposure (e.g., reduction of outside activity when air quality index (AQI) is moderate or higher, use of HEPA air purifiers in homes of people who are at increased risk of experiencing health effects of exposure to smoke), and instituting communication systems about the causes and tradeoffs due to smoke, and on planned activities for both prescribed fire and wildfires.”

C. *ON FIRE: The Report of the Wildland Fire Mitigation and Management Commission* (2023)

- C1: “A number of agencies play critical roles in supporting the wildfire mitigation and management mission through science support, decision support

tools, and predictive modeling. The U.S. Geological Survey, for example, produces tools to support decision-making before, during and after wildfires and generates information about the causes of wildfires, the impacts and benefits of fire, and prevention and management of larger, high-severity fires."

- C2: "In support of the wildfire response mission, these agencies also support central coordinating entities, provide predictive services to better support decision-making, and support research that promotes overall efficacy… Significant funding is needed to support and increase the full suite of wildfire mitigation and management activities undertaken by these agencies, especially proactive work to reduce the risk of high-severity wildfire."
- C3: "Congress should ensure that mission-critical support agencies, such as the U.S. Geological Survey, National Oceanic and Atmospheric Administration, and Environmental Protection Agency have the necessary resources to support wildfire risk reduction, recovery, and response efforts. A number of agencies play critical roles in supporting the wildfire mitigation and management mission through science support, decision support tools, and predictive modeling."
- C4: "Utilize wildfire detection systems, which can provide automated early warning detection."
- C5: "Incentivized and improved fire detection technologies including along electric utility corridors."
- C6: "Upon the request of Tribes, entities gathering data and providing dispatch information regarding fire ignitions should have the authority to enter into agreements with such Tribes to protect the privacy and confidentiality of ceremonial and other fire use… Data protection agreements that are put in place before such detections and occur though early and meaningful engagement between governments can help to prevent the inadvertent observation and interference with cultural or ceremonial fire and avoid the misallocation of response resources to an assumed "incident" that does not require attention."
- C7: "While these trends in wildfire have broadly followed what was projected by researchers, the behavior of individual fires is exceeding our existing models (Hurteau 2023). Losing our ability to predict the behavior of any given fire—or worse, predicting it incorrectly—has potentially dire impacts for firefighters, communities, and landscapes."
- C8: "The predictive modeling functions that are housed on the National Interagency Fire Center campus, while co-located, do not rise to the level of interorganizational (federal, Tribal, state, and local) coordination, nor do they fully integrate services across the pre-fire mitigation and post-fire recovery

phases of an incident. They have also failed to keep pace with developing technology and research."

- C9: "Potential Operational Delineations (PODs) are a relatively recent, but increasingly important, example of pre-fire response planning that supports proactive wildfire response planning and the measurement of effective and efficient response. PODs combine the use of spatial analytical tools and consultation with local fire management practitioners to develop potential control lines that can be used to manage future fires (Colorado Forest Restoration Institute 2020)…. Additionally, there are opportunities to expand the use of PODs for a broader set of resource goals before, during, and after wildfires."
- C10: "Along with new funding, the Commission recommends Congress request periodic updates or develop a performance measure to track the development and use of pre-fire planning on federal land management units."
- C11: "Federal agencies should build on the successful model of Rangeland Fire Protection Associations and provide more federal surplus equipment to RFPAs and other volunteer fire response entities… While an important mechanism for added local-level capacity, RFPAs could benefit from improved equipment access, increased federal grant funding, additional training, and more supplies."
- C12: "Accessible, actionable tools and information are needed in all aspects of the wildfire environment and all phases of the fire continuum—before, during, and after incidents. Services addressing these aspects and phases would help inform and guide investments and activities that have the greatest chance of success and positive impact with the least risk, cost, and negative impact to the public. In this work, the center should strive to continuously incorporate new information, data, and models to drive decision-support functions. Specific areas that the center would inform include: … Fire response and management, including response preparedness and initial attack readiness for new fires, deployment of response resources, and firefighter movement decisions during active fire management."
- C13: "Some Commission members called for the use of "standards of cover" for wildfire response. Such standards, widely in use in structure firefighting, amount to a performance measure and promise to respond to an incident within a given geography within a fixed amount of time. Core to this concept is the opinion of some Commission members that wildland fire response should be more holistically considered as a part of emergency management writ large."
- C14: "Functionally, completion of the NWCG practicum process requires access to assignments and dispatching. Therefore, to improve access, both the fire

qualifications management system (the Incident Qualifications and Certification System, or IQCS) and resource ordering system (the Interagency Resource Ordering Capability, or IROC) also must be more inclusive of non-federal entities and individuals."

- C15: "The IROC system is open to any interested and qualified entity, including state and local fire agencies and departments. However, the Commission sees the need for an evaluation of the strengths and limitations of the current system and identification of any needed improvements to ensure that it is functional and inclusive of the diverse array of state, local, Tribal, and non-governmental entities needed to respond to wildfire more holistically."
- C16: "In addition, cultural training and integration of Indigenous Knowledge is important for many mitigation and management activities, including to ensure understanding of areas and resources important to Tribes, like culturally significant plants or sacred sites, that may be impacted by fire or fire management decisions."
- C17: "Expanded adoption of interoperable communication systems and extended field connectivity to all firefighting resources."
- C18: "Enabling the USFA to increase its ability to support, train, and equip the existing structural fire protection workforce for wildfire response will significantly improve the level of service provided by local fire and emergency medical services organizations…. Additional work may include code and standard development, data management, and national communications."
- C19: "Lack of certainty may disincentivize contractors from investing in improved safety and delivery systems while other competitors keep costs lower by continuing use older systems. DOD contracting authorities may offer alternative models that are longer-term and more stable. These models may allow for greater certainty and enable contractors to invest in new technologies over time. Given the rapidly changing nature of technology, partnerships with private industry are important to the successful adoption of new technology for wildfire mitigation and management."
- C20: "Change the system of land management agency performance metrics beyond acres treated or timber volume output to measure success. Reorienting performance measures to focus on outcomes grounded in ecological resilience, values at risk, and social outcomes such as collaboration, community empowerment, partnership, and equity would better incentivize work toward more meaningful measures of success and improve accountability…Change the system of land management agency performance metrics beyond acres treated, timber volume output, or acres burned to measure success. Success should be

measured by outcomes such as the number of protected assets, values, and resources, and the degree to which forests and rangeland are returned to and maintained in a more resilient state."

- C21: "A prescribed fire target should be based on fire regimes and fire return intervals and, given that fire regimes vary by area and ecosystem, should be determined locally.[xvi] However, consideration should be given for climate change, invasive species, and other factors altering historic fire regimes (Brooks et al. 2004; Enright et al. 2015; Halofsky, Peterson, & Harvey 2020)."
- C22: "To increase prescribed fire capacity, there is a need for more training opportunities, all of which should be open and accessible to any interested party, including contractors, non-governmental organizations, and Tribes. Federal funding should be made available to establish and expand prescribed fire training centers and programs throughout the country to increase the accessibility of this important skillset."
- C23: "In forest ecosystems, developing commercial wood processing industries that utilize materials from fuels reduction and ecological restoration projects can defray the costs of this work and incentivize the removal of woody byproducts that are usually left on the landscape due to lack of viable markets. To ensure these commercial wood processing facilities are able to acquire financing, maintain operations, and remain economically viable, they must have a sustainable, dependable source of forest products."
- C24: "Incentivize the adoption of new technologies and processing systems to produce value-added, and demand-driven innovative wood products. When biomass utilization technologies become available for commercial use, there is also a role for the federal government to support their broader adoption. This support could take the form of subsidies to mechanical treatments or the use and authorization of longer-term contracts in order to generate longer-term supply of harvestable timber that is ecologically appropriate and aligned with wildfire risk reduction. Pilot projects in particular should be emphasized."
- C25: "Other mechanisms for advancing this recommendation include supporting the analytical work needed to establish biomass facilities and expanding DOE funding to support bioenergy with carbon capture and storage, biochar production, and cogeneration using waste biomass from fuels reduction treatments. The existing Biomass Research and Development Initiative could also support this effort.[xviii]"
- C26: "Forest resilience represents a crucial component of watershed resilience. The Commission found that proactive and ecologically appropriate forest restoration and resilience treatments are needed to improve the function of

watersheds across the country. To better protect these watersheds and the critical water supplies they contain, programs that support fuels reduction and other ecological restoration work should include a greater focus on source watersheds, riparian areas, and protection of drinking water infrastructure (Jones et al. 2017; Niemeyer, Bladon, & Woodsmith 2020).

- C27: "Consider increasing the use of remote sensing to improve targeted grazing, in part through the use of virtual fencing. These technologies will initially require financial support but may later lead to cost savings by reducing the need to build and maintain physical fences."
- C28: "Develop a periodic quantitative review of the comprehensive wildfire environment to assist adaptive management…. Adaptive management is especially critical given the rapid pace of change in numerous facets of the wildfire environment, including changes driven by rising global temperatures. A periodic review of the wildfire mitigation and management system should include a quantitative analysis of changes in both the built and natural environments, the intersection between wildfire and public health, and the impact of those changes to pre-fire mitigation, incident response, and proactive recovery. Such a review should assess anticipated changes over the coming decades (two decades was one suggested timeline) and identify the need for future adjustment and adaptation. This undertaking should include both qualitative and quantitative assessments of progress and should include a feedback mechanism to the relevant committees of Congress to ensure that needed policy changes are elevated to decision-makers."
- C29: "Furthermore, Indigenous Knowledge related to fire management need to be included, respected, and—when needed—kept confidential."
- C30: "Specifically, the Commission recommends expanding existing, and developing new, authorities for federal agencies to engage in co-management and co-stewardship; enabling Tribes to expand prescribed and cultural burning programs; providing funding to enable this work; and enhancing the ability of Tribes to share information without risking compromising confidentiality… When working with Tribes, care should be given to ensure data sovereignty and confidentiality where requested."
- C31: "Adequate training programs should be developed to ensure that workers have access to necessary background and information to do their jobs well and with respect for Indigenous burning practices. Efforts should be made to ensure that incorporation of Indigenous Knowledge into training programs is not appropriative. Instead, the incorporation of Indigenous Knowledge must come with recognition of and support for Tribal sovereignty."

- C32: “Increase funding for research and development on topics such as engineering principles, identification of best practices for reducing risk to the built environment, and foundational components of establishing codes and standards.”
- C33: “Research, guidance, and standard development related to remediation of buildings affected by a fire or smoke event.[xxxi] … Building codes are also important tools to encourage ignition-resistant construction and other strategies that reduce the risk of future disaster-driven structure loss. These types of resilience-focused building codes should be encouraged during rebuilding, especially in areas where FEMA and other agencies provide sheltering and permanent housing solutions.”
- C34: “Existing scientific research, much of which has been encoded in model codes and standards, can provide the baseline for architects, designers, planners, and others to create the kind of certifications, contests, or other incentives that will spur more innovation toward ignition-resistance and wildfire resilience.”
- C35: “The Commission feels engagement of the private sector, through innovation prizes (e.g., XPRIZE) for wildfire-resilient design and construction, or “seal of approval” for ignition-resistant structure designs or subdivision designs would help spur advancement, similar to the current Leadership in Energy and Environmental Design (LEED) green building certification implemented by the US Green Building Council which sets a globally recognized standard for high-performance green buildings (United States Green Building Council n.d.).”
- C36: “Support for building code or standard adoption and enforcement: Increase financial support and technical resources to state, Tribal, and local jurisdictions to hire staff and enhance capacity to adopt, enforce, and maintain science-based building codes or standards that govern construction, design, and site development in all ‘wildfire-prone’ regions, not only locations identified as high-risk.”
- C37: “Support data procurement and analytic systems that enable intelligence-informed decision-making to inform building codes and standards, and promote ignition-resistant construction and defensible space…. It has become increasingly common for communities to experience repeated wildfire events or other disasters, making it critical to expand post-fire rebuilding and repair strategies that reduce future potential for damage and loss. Rebuilding without upgrading structures to better withstand future wildfire is a lost opportunity that perpetuates individual and community vulnerability to ignition.”

- C38: “Require all-hazard risk disclosures for real estate transactions, including both sales of newly constructed homes and existing homes, involving all federally backed mortgages such as Fannie Mae and Freddie Mac…. Establishing a national requirement for all-hazard risk disclosures as a part of real estate transactions would promote a common level of awareness among buyers, though efforts would still need to be made to reach renters and buyers who do not obtain a federally backed mortgage.”
- C39: “Establish and maintain designated shelter areas in communities that build on recent research from the National Institute of Standards and Technology for shelter design details.”
- C40: “However, there is no uniform or standard set of best practices for permitting risk reduction work in the rights-of-way for many of the utility lines that crisscross the country and pass through multiple federal jurisdictions in addition to other public and private land. Federal land management agencies each have different processes, timelines, and requirements for management of transmission corridors across the lands they administer. State and local governments also have varying approaches to vegetation maintenance adjacent to distribution lines within their jurisdictions. Several states, including California, Oregon, Washington, and Nevada require or incentivize electric utilities to develop plans to guide the preparation for, and mitigation of, fire risk to infrastructure and service provision. However, the variation between state regulations and utilities’ development of wildland fire mitigation plans creates an inconsistent environment for utilities, state energy offices, and land management agencies.”
- C41: “This may include, but is not limited to, parcel assessment and evaluation tools, mapping technologies, database development, and risk and hazard modeling. The resourcing of this work could include support for updates to, and ongoing maintenance of, hazard and risk maps. Updates and maintenance are critical given that community risk profiles shift over time with changes in climate, development, mitigation actions, and major wildfires or other natural disasters. Where possible, mapping efforts should look across scales and jurisdictional boundaries, incorporate collaborative processes in their development and identification of risk, and support better connection and interface with one another.”
- C42: “Support data procurement and analytic systems that enable intelligence-informed decision-making to inform building codes and standards, and promote ignition-resistant construction and defensible space…. Pre-fire mitigation and risk reduction activities for landscapes and communities, including through

assessments and modeling of climate conditions, fuels, home ignition, structure-to-structure spread, and values at risk."

- C43: "The Commission sees a strong need for better data procurement and analytics in the built environment… Support data procurement and analytic systems that enable intelligence-informed decision-making to inform building codes and standards, and promote ignition-resistant construction and defensible space."
- C44: "USFA training could also help address public education for community planning and preparedness activities for wildfires that originate in or move into the built environment. This includes education regarding building codes and standards, use of ignition-resistant building materials, evacuation preparedness and planning, and reduction of vegetation around structures."
- C45: "Congress should provide funding and other support to enable state, local, and Tribal governments, and other partners to undertake data collection, analysis, and application or deployment of systems at the appropriate scale to inform up-to-date, local decision-making and risk reduction regulations and activities. This may include, but is not limited to, parcel assessment and evaluation tools, mapping technologies, database development, and risk and hazard modeling."
- C46: "Mapping and analytical tools, which enable the geospatial identification of wildfire hazard or risk,[viii] are foundations for locally relevant, well-informed decision-making. These tools can also assist in prioritization processes for risk reduction practices, including codes and ordinances, land use policies, hazard disclosures, and allocation of resources. Well-designed mapping and decision support tools can also enable better communication about hazards and risk, support transparency and shared understanding around risk-related decision-making and outcomes, and provide a venue for greater local engagement and the incorporation of local knowledge in these actions."
- C47: "The Commission therefore strongly endorses the need for community-level action and the retention of policy decision authority for land use and development at the state and local level. Where a need exists—and where the Commission felt federal government should play a role—is in ensuring that those entities have the right tools, resources, and incentives, to make well-informed decisions that will proactively reduce the risk to communities from wildfire. Examples of federal support include financial incentives for communities and individuals, technical assistance, technological innovations, data acquisition and access, and, in particular, directed support for low-capacity communities located in high-hazard areas."

- C48: “Support greater adoption of interoperable communication systems…. Expand siren alarm systems as an alternative tool in the absence of, or in the case of, lost cell phone coverage. Ensure there is clear communication about what a siren is intended to signal…. Utilize NOAA Weather Radio as a backup system.”
- C49: “Federal financial and technical support should be made available to local emergency managers to help improve evacuation communications systems and bring them up to national standards. These improvement efforts should seek to create systems that bridge the digital divide and function in remote areas with little communications coverage and in the event of a loss of power or telecommunications networks…. Fill in cellular coverage gaps and harden existing infrastructure to prevent loss of cellular service. Ensure redundancy of coverage should communication equipment lose function during a fire.”
- C50: “Transition existing “opt-in” alert systems to systems in which people are automatically enrolled with the option to opt out. Enable Emergency Operations Centers and NWS to serve as dissemination points to utilize Wireless Emergency Alertsxxxii through the IPAWS for the issuance of nonweather emergencies, such as standard wildland fire Evacuation Immediate…. In addition to these options, the Commission recommends a broader assessment of existing wildfire communication and alert systems that could produce best practices and effective alert system for wildfires…. Congress should initiate the adoption of a single, standardized approach to communicating wildfire-related evacuations, with language that is descriptive of the action or level of threat. This could be a combined interagency effort of the NOAA, U.S. Fire Administration, and land management agencies. Specifically, a national standard for immediate evacuation within FEMA’s Common Alerting Protocol[xxxiii] should be established for notification of wildland fire related evacuation notices. The “Ready, Set, Go!”[xxxiv] terminology, which is already being utilized in many communities, offers an excellent, easy-to-understand model. This terminology should be integrated into a national all-hazard standard. Additionally, NWS should be able to engage the IPAWS Wireless Emergency Alerts to issue standard wildland fire Evacuation Immediate for non-weather emergencies.”
- C51: “Local police, sheriffs, and emergency managers are responsible for making and carrying out warning and evacuation orders for wildfires and other disasters, an authority that the Commission feels should remain at the municipal and county level. However, these local entities may lack the tools and resources needed to effectively plan for and implement warnings and evacuation processes that alert the public and help them move out of harms’ way…. This includes mapping services and data provision to support evacuation decisions in

communities at risk and air quality monitoring data to support health risk information that helps protect the public from smoke impacts associated with fire."

- C52: "As communities grow, they also should look to create evacuation planning that incorporates pre-fire spatial planning and evacuation drills, including the identification and communication of a shelter, safe exit route, post-fire recovery, and re-entry plan."
- C53: "As part of implementation of a new standardized approach, a national campaign should be developed to promote consistent use of "Ready, Set, Go!" terminology. Congress also should make additional funding available to local jurisdictions for public messaging, outreach, and engagement. The Commission notes that within the "Ready, Set, Go!" framework, there will need to be local flexibility to determine specific evacuation and preparedness actions associated with various terms."
- C54: "USFA training could also help address public education for community planning and preparedness activities for wildfires that originate in or move into the built environment. This includes education regarding building codes and standards, use of ignition-resistant building materials, evacuation preparedness and planning, and reduction of vegetation around structures."
- C55: "Federal financial and technical support should be made available to local emergency managers to help improve evacuation communications systems and bring them up to national standards."
- C56: "The development of a near real-time prescribed fire database for federal, Tribal, state, and local agencies to promote the coordination of ignitions so as to minimize smoke impacts."
- C57: "Additional research into the health effects of wildland fire smoke, including comparative studies of smoke from prescribed fires, wildfires and fires that involve the built environment. Additional research into the health effects of wildland fire smoke, including comparative studies of smoke from prescribed fires, wildfires and fires that involve the built environment."
- C58: "Provide the NWS with the access and ability to collect all air quality forecasts, public notifications, and alerts for smoke issued by federal, state, local, Tribal, and territorial air agencies and disseminate them through Weather Forecast Office networks. This approach would enable the successful NWS alert system for weather hazards to be extended to support smoke communications to protect public health and visibility. Improve coordination between the USDA, DOI, EPA, CDC, NOAA, and NWS to establish a public county-resolution

smoke alert system for public health and roadways safety in addition to the current NWS Dense Smoke Advisories, which are based on visibility."

- C59: "Invest in a nationally consistent smoke monitoring and alert system to provide consistent, real-time information and forecasts on air quality impacts from wildland fire."
- C60: "Increase availability of smoke sensors to ensure adequate and accessible data. Increase use of speciation monitors for research purposes to distinguish wildfire smoke from other forms of pollution."
- C61: "Bolster the underlying EPA AirNow framework and technology and enhance AirNow.gov and AirNow-Tech, including improvements to the AirNow EPA and Forest Service Fire and Smoke Map, AirNow Forecast Submittal System and the AirNow mobile app. Include resources to continue modernizing and sustaining AirNow as a state-of-the-art, real-time resource for providing robust and actionable information to protect public health from smoke."
- C62: "The Commission also underscores the need for a parallel increase in measures to protect the public from the adverse health impacts of smoke emissions, including smoke from beneficial fire. The Commission recognizes the significant public health impacts of smoke which have been well-documented in the scientific literature and stressed the need to address these impacts, particularly as they affect historically marginalized communities… While enabling proactive use of beneficial fire, Congress should increase the capacity of federal agencies, including Environmental Protection Agency, Health and Human Services, the U.S. Department of Agriculture, and Department of the Interior to work with state, local and Tribal governments to ensure that air quality, public health, and land management programs work toward minimizing impacts of smoke to human health and to ensure communities and individuals are better prepared for anticipated smoke from all forms of wildland fire."
- C63: "Research into effective public health communication approaches and intervention strategies to promote community preparedness and reduce smoke exposures, with a specific emphasis on targeting those population groups at highest risk and with most frequent or prolonged exposure."
- C64: "In parallel to this review and revision effort, federal, Tribal state and local authorities must be provided adequate resources to undertake the activities needed to expand beneficial fire use via existing regulatory pathways. That includes resources for data tracking to identify and exclude wildfire and beneficial fire smoke from determinations of regulatory significance as well as

the administrative capacity necessary to utilize the Exceptional Events Rule and manage the regulatory compliance process."

- C65: "While there are robust studies about the health risks faced by structural firefighters, current research is limited regarding wildland firefighter physical and mental health and occupational exposures, including smoke and dermal exposure. There are considerable differences between the experience of structural firefighters and the wildland firefighting environment, culture, fuel types, and available protective technologies. Those differences include the potential duration of smoke exposure, with wildland firefighting assignments lasting up to 14 days and repeating for the length of a fire season…. Support strategies for respiratory and thermal protection, as well as decisions that can be made administratively to protect firefighters…. The chemical characterization of smoke and ash, which would provide valuable information about firefighter exposure (inhalation and dermal) and would aid development of best practices for decontamination of personal protective equipment. The effects of cumulative, long-term smoke exposure…. Differences in impacts from exposure to prescribed fire smoke as opposed to wildfire smoke. The effectiveness of mitigation and adaptations or both acute and cumulative exposures."
- C66: "Similarities and differences in the mental and physical health risks and exposures faced by structural firefighters, wildland firefighters, and firefighters working on fires that burn in both the natural and built environment."
- C67: "While there are robust studies about the health risks faced by structural firefighters, current research is limited regarding wildland firefighter physical and mental health and occupational exposures, including smoke and dermal exposure. There are considerable differences between the experience of structural firefighters and the wildland firefighting environment, culture, fuel types, and available protective technologies. Those differences include the potential duration of smoke exposure, with wildland firefighting assignments lasting up to 14 days and repeating for the length of a fire season. Unlike structural firefighters, wildland firefighters do not wear personal protective equipment to reduce smoke exposure due to the challenging and dynamic environment in which they work."
- C68: "Firefighters in particular face prolonged exposure, the impacts of which are still poorly understood, as do agricultural workers and others who work outdoors (Navarro et al., 2019; Navarro, 2020)."
- C69: "There is also need for more research about compounding vulnerabilities, such as frequent smoke inhalation, the combined effects of heat and smoke, and

lack of access to healthcare and the ability to address health impacts as they occur."

- C70: "While there are robust studies about the health risks faced by structural firefighters, current research is limited regarding wildland firefighter physical and mental health and occupational exposures, including smoke and dermal exposure…. Wildland firefighter mental health, on and off season, including the impacts of nutrition and fatigue."
- C71: "Unlike structural firefighters, wildland firefighters do not wear personal protective equipment to reduce smoke exposure due to the challenging and dynamic environment in which they work. In fact, no such personal protective equipment is approved for use in this environment (Navarro 2020)…. Personal protective equipment to protect against hazards from both the natural and built environment as well as physiological effects of this equipment…. The chemical characterization of smoke and ash, which would provide valuable information about firefighter exposure (inhalation and dermal) and would aid development of best practices for decontamination of personal protective equipment."
- C72: "The effectiveness of mitigation and adaptations or both acute and cumulative exposures."
- C73: "Tribal, state, and local public health agencies need increased support to promote community readiness and risk reduction in the context of fire. For example, healthcare providers may need training to better understand the public health impacts and resources to communicate with patients, particularly those with pre-existing conditions such as cardiovascular and pulmonary disease, about potential health risks related to smoke from wildland fires and fires within the built environment, as well as actions that can be taken to reduce smoke impacts…. As wildfires impact increasing numbers of people both near and far from the event itself, there continue to be important gaps in fire-related public health knowledge, including the health implications of repeated smoke inhalation over multiple days, weeks, and fire seasons; public and worker health effects in the post-fire environment; and other long-term and chronic health effects associated with smoke…. Research into effective public health communication approaches and intervention strategies to promote community preparedness and reduce smoke exposures, with a specific emphasis on targeting those population groups at highest risk and with most frequent or prolonged exposure."
- C74: "Tribal, state, and local public health agencies need increased support to promote community readiness and risk reduction in the context of fire. For example, healthcare providers may need training to better understand the public

health impacts and resources to communicate with patients, particularly those with pre-existing conditions such as cardiovascular and pulmonary disease, about potential health risks related to smoke from wildland fires and fires within the built environment, as well as actions that can be taken to reduce smoke impacts. Agencies also need resources to train and equip community healthcare providers to work effectively with patients affected by fire…. In addition to the considerable impacts to the landscape and associated hazards to downstream or downslope communities, communities in the post-fire period can experience challenges resulting from economic losses, damage to infrastructure, increased housing costs and demands, and more. Mental health impacts can also occur. After the 2016 Fort McMurray wildfire in Canada, children aged 11–19 years experienced mental health impacts for at least three years after the fire (Brown et al. 2021)…. Invest in a comprehensive approach that addresses mental and physical health."

- C75: "While the negative health impacts of smoke are well known, there are no standard recommendations or guidance specific to protecting workers, including firefighters, from these impacts. Due to the lack of a wildland fire-specific standard, the Occupational Safety and Health Administration (OSHA) uses the standard for "particles not otherwise regulated" as an occupational exposure limit for smoke. However, this approach does not account for unique attributes of wildland fire smoke or from wildfires burning in the built environment, including the particle size make-up (largely PM2.5 and smaller) and the presence of other pollutants of concern. For these reasons, this existing standard is not an appropriate equivalent for smoke from wildland fires or wildfires burning in the built environment and does not provide an adequate threshold for assessing exposure mitigations or health effects from exposure to smoke. States, including Oregon, Washington, and California, have taken action to set occupational smoke standards, but without national guidance, all are slightly different and are based on public health studies rather than firefighter exposure profiles. They also contain exemptions for firefighting."
- C76: "Invest in a nationally consistent smoke monitoring and alert system to provide consistent, real-time information and forecasts on air quality impacts from wildland fire. … Invest in the completion of a human health risk assessment for worker exposure to wildland fire smoke and smoke from wildfires in the built environment to estimate the nature and probability of adverse health effects in humans who may be exposed to hazards from smoke with the intent of creating best management practices to mitigate the extent and duration of exposure."

- C77: “In the post-fire realm, several agencies also conduct assessment of burned landscapes and undertake reforestation and revegetation activities to promote ecological recovery. Though less frequently associated with wildfire mitigation and management, the USDA Natural Resources Conservation Service also supports wildfire mitigation via conservation practices funded through its private lands programs and post-fire recovery on non-federal land through its Emergency Watershed Protection program. Significant funding is needed to support and increase the full suite of wildfire mitigation and management activities undertaken by these agencies, especially proactive work to reduce the risk of high-severity wildfire.”
- C78: “Importantly, existing post-fire assessments are largely focused on federally administered and Tribal trust lands, vary by agency, and often need additional funding support. Federal BAER teams do not typically assess state or private land or downstream risk and while USGS has the authority to work on non-federal lands, funding may not be adequate to meet the needs. While there are some state and local efforts that are based on the BAER model, these efforts are not consistent throughout the nation.”
- C79: “Extending burned area assessments to encompass federal and non-federally administered land would provide a powerful tool for state and local jurisdictions, Tribes, and other partners such as non-governmental organizations that largely lack the ability to obtain such data for non-federally administered lands or values at risk. While communities or local jurisdictions may be able to technically access tools that are available for post-fire assessments, the effectiveness of these tools can be limited by the need for the user to possess specialized knowledge or the tools’ requirement of complex data inputs (Driscoll & Friggens 2019). Postfire maps and analyses are especially critical to inform risk assessments for localities, which are often required by federal agencies to move forward with implementing certain protection and risk reduction actions.”
- C80: “Wherever possible, integrate analyses of changed post-fire conditions and any necessary recovery actions into planning documents (e.g., environmental analysis completed under the National Environmental Policy Act, land management plans, Community Wildfire Protection Plans, Hazard Mitigation Plans) to expedite and improve post-fire recovery. When wildfires impact areas that have already been considered in environmental planning and analysis processes, agencies must often redo analyses to account for changed conditions and postfire recovery actions that weren’t contemplated in original plans. This is time and resource-intensive and delays important and often time-sensitive work.

Considering the potential for wildfire and post-fire impacts at the outset of planning processes can enable more timely recovery actions."

- C81: "As a part of this collaborative data environment, the Commission encourages the establishment of a cross-federal departmental clearinghouse for information regarding post-fire impacts including information on available programs and funding opportunities, short- and long-term mitigation best practices, ecological recovery, assessment science, emergency declaration processes, and other relevant topics."
- C82: "Federally-established guidelines could help support consistent implementation through standardized resources, roles and responsibilities, and process descriptions. If implemented, federal guidance also would need to clarify metrics used to deploy these teams and length of deployment, given that the post-fire period is both difficult to define and, at times, lengthy."
- C83: "Congress should request a comprehensive study on the relationship between financial protection solutions available through the private market and federal disaster recovery to support federal efforts to modernize federal post-disaster recovery benefits that ensure resources are complementary rather than conflicting…. A comprehensive study on the relationship between private market financial protection solutions and federal disaster recovery can support individual recovery."
- C84: "Additionally, the study should explore incentives that encourage individuals and communities to obtain sufficient financial protection to support post-disaster recovery."
- C85: "In addition to incorporation of demographic data that is currently available for assessing social vulnerability, additional research is likely needed to better understand the existing gaps in who is served by federal resources compared to expectations for program outcomes. Program criteria should then be aligned to those underserved groups and their capabilities to undertake funded activities. As a note, this recommendation applies to the prioritization of wildfire-related projects but does not mean to imply that wildfire must be prioritized over other hazards."
- C86: "Increase accessibility of federal grants for community wildfire risk reduction and post-fire recovery efforts…. Technology could also support making applications easier and more accessible, for example by enabling auto-populating fields, or notifying applicants of eligibility and open application seasons."

- C87: “Post-fire research and monitoring work also could be supported through the creation of a new program or expansion of an existing program that could offer competitive grants for climate-informed strategy development and implementation. The Joint Fire Science Program could host this grant program through expanded funding, or new categories of eligible activities could be added to other existing programs.”
- C88: “Federal agencies should work with state emergency management partners that administer or manage FEMA multi-hazard mitigation planning grants to improve such programs. Technical support from universities, consulting firms and agencies with science and modeling skills to conduct planning postfire could be used to support these efforts.”
- C89: “In addition, FEMA should be directed and funded to create a wildfire module in its Hazus Program[xlvii] that would provide a standardized method for estimating potential post-wildfire-related losses to the built environment.”
- C90: “Funded activities should include work with permitting and utility providers to pre-establish surge capacity needed to support disaster sheltering and housing, as well as research and development of alternative sheltering solutions.”
- C91: “When developing post-fire restoration plans for federal, state, Tribal, local, and private lands, agency leaders should work collaboratively with interested parties. Planning processes should make sure Indigenous Knowledge and local knowledge are sought out and considered. Social and behavioral science expertise also should be part of this collaborative planning, as social considerations are an important part of recovery. Providing dedicated funding for these assessments, plans, and projects is essential to fostering implementation.”
- C92: “It is important that research and best practices be used to create strategies tailored to diverse ecological conditions while also supporting the landscape-scale action needed to match the size of current and future wildfires. In addition to watershed recovery, reforestation and other post-fire recovery efforts support ecosystem function and integrity, biodiversity, carbon stewardship, and other important ecological recovery needs…. Expand support for the development and application of scientific research into, and monitoring of, post-fire ecological recovery and compounding disturbances, especially for wildfires featuring large high-severity patches where ecosystem type conversion is likely in absence of management interventions.”

- C93: “Post-fire activities, including vegetation recovery, debris flows and flooding, watershed protection, and ecosystem health. Efforts could also support advance planning for the post-fire period.”
- C94: “Authorize and fund the maintenance, deployment and monitoring of a national cache of rapid-deployment rain gauges, stream gauges and weather stations. Timely and strategic installation of these devices is vital for providing advance warning of post-fire flooding events. Risk to downstream locations begins immediately after ignition and the existence of warning systems can make the difference between timely and effective evacuation and loss of life.”
- C95: “Reforestation and revegetation infrastructure in the United States needs additional investment, particularly in seed collection, processing, and storage, and in seedling cultivation…. Develop direction to federal land management agencies about comprehensive seed collection and banking. This direction should seek to better align seed collection, seed use planning, storage, and testing guidelines with current industry standards; build consistency in practices and requirements utilized by seed initiatives as they relate to post-fire long term recovery; and address any limitations in exchanging appropriate seed stock across jurisdictions as may be necessary to support climate-informed reforestation and revegetation approaches.”
- C96: “Develop direction to federal land management agencies about comprehensive seed collection and banking. This direction should seek to better align seed collection, seed use planning, storage, and testing guidelines with current industry standards; build consistency in practices and requirements utilized by seed initiatives as they relate to post-fire long term recovery; and address any limitations in exchanging appropriate seed stock across jurisdictions as may be necessary to support climate-informed reforestation and revegetation approaches…. Support policy and implementation efforts through relevant research and development efforts. For example, advances in research and development, aided by significant investments in monitoring, are critical for developing climate-informed strategies to improve both short- and long-term survival rates for planted seedlings.”
- C97: “Develop direction to federal land management agencies about comprehensive seed collection and banking. This direction should seek to better align seed collection, seed use planning, storage, and testing guidelines with current industry standards; build consistency in practices and requirements utilized by seed initiatives as they relate to post-fire long term recovery; and address any limitations in exchanging appropriate seed stock across jurisdictions as may be necessary to support climate-informed reforestation and revegetation approaches.”

- C98: “Seed data management systems for public nurseries and seed banks should also be modernized to support integration of data from federal and state nurseries and seedbanks.”
- C99: “Above all, the Commission emphasizes the need to ensure that revegetation is ecologically appropriate. Watershed restoration, including channel and riparian area rehabilitation, also represents an integral component of post-fire ecological restoration.”
- C100: “Contamination of potable water supplies creates an immediate public health risk, but little guidance exists regarding how communities should respond. There is a need for greater clarity around the type of testing required and thresholds for replacement or continued utilization of water infrastructure (Proctor et al. 2020)…. The cause of volatile organic compound (VOC) contamination, the primary contaminants of concern, and their occurrence within premise plumbing and distribution systems after a wildfire. Mitigation methods for preventing and controlling VOC contamination.”
- C101: “Increased capacity investments may include training and equipment for testing water quality for contaminants and toxins, implementing interventions to prevent and control harmful impacts, and assessing source water and watershed infrastructure. Public health entities and water providers also need support to provide guidance and direct assistance to community members that rely on federally unregulated drinking water and onsite wastewater systems.”
- C102: “Short-term and long-term changes in source waters (both ground and surface waters) that might impact a drinking water utility’s ability to treat and produce safe drinking water.”
- C103: “In addition to investigation into these topics, the Commission felt there would be value in conducting risk assessments and modeling efforts to determine which water and wastewater utilities are most likely to be impacted by wildfires to help prioritize resources for treatment upgrades and source water protection. This assessment should consider both the direct and indirect impact of wildfire on utility facilities, source water intakes, wellheads, distribution systems, collection systems, and other infrastructure.”
- C104: “Congress should ensure that mission-critical support agencies, such as the U.S. Geological Survey, National Oceanic and Atmospheric Administration, and Environmental Protection Agency have the necessary resources to support wildfire risk reduction, recovery, and response efforts…. The Environmental Protection Agency provides guidance and information about smoke impacts from wildland fire as well as disposal of disaster debris that is produced when wildfires burn through the built environment (EPA n.d.b). Funding is needed for

these agencies and others that support various aspects of wildfire mitigation and management."

D. *NASA Science Mission Directorate (SMD) Wildfire Stakeholder Engagement Workshop: Summary and Key Findings* (2022)

- D1: "There is a need to integrate forecast and climatology at a reasonable resolution. Fine resolution data (fire-scale; less than 0.25 or 0.5 degree) are needed to resolve microclimates (e.g., under canopy deviates from seasonal) in all aspects of fire including but not limited to weather, fuel, soil moisture, and fire danger, that influence fire conditions near and below the surface."
- D2: "Global partnerships to deliver fuels status (e.g., SMAP, Optical data, NRT Fuel moisture) would be beneficial."
- D3: "Notable gaps in timely and integrated weather-to-fuels information includes: understory and canopy data; green-up; snow cover; accurate land cover types (agriculture/cropland -distinguish orchard vs. brush); and soil moisture data, especially in connection to organic soils and deep duff."
- D4: "Thus, knowledge of pre-fire vegetation composition along with the capability to characterize the composition of vegetation regrowth and regrowth trajectories at various spatial scales is central to determining both future fire risk and post-fire management decisions."
- D5: "It can be difficult to distribute new types of information to government agencies and to integrate experimental data into national weather forecasting tools that favor established data streams. Collaboration between government, university, and industry partners can help expedite R2O transitions, but support for technical approaches including co-development of shared code and data repositories and workflow tools is critical."
- D6: "Real-time, accurate geolocation of fire detections is especially critical in the Wildland-Urban Interface (WUI), where tens to hundreds of meters matter."
- D7: "Satellite-based Earth Observation (EO) instruments provide routine coverage to help identify and track active fires, and current capabilities provide either moderate spatial resolution and infrequent coverage (e.g., VIIRS, MODIS) or coarse spatial resolution and frequent coverage (e.g., GOES). Gaps in moderate resolution coverage currently limit advances in fire science and applications needed to support the management of extreme fire events and their unprecedented impacts on communities, ecosystems, and air quality."
- D8: "Ground-based camera networks provide rapid detection information for the WUI and other high-value infrastructure but require improved analytics

techniques for rapid data reduction and then incorporation into operational decision-making processes with other observation / information sources."

- D9: "Developing Decision Support Systems (DSS) integrating ground-based and remote sensing data with advanced artificial intelligence (AI) algorithms and models could help fire detection, tracking, evacuation, assessment of post-fire impacts, and restoration measures."
- D10: "Machine learning (ML) and artificial intelligence (AI) show great promise for rapid analysis of data across a range of platforms and may accelerate the delivery of downscaled products for specific end users, including climate data needed to forecast fire spread in complex terrain."
- D11: "In another example, the LANDFIRE fuel model has a latency of 2 years, but fire managers require an update at least every 6 months."
- D12: "Finally, key gaps remain in fire detection and tracking in the WUI, where current models do not fully account for fuels in the built environment."
- D13: "Insufficient resolution of data products remains a barrier for many potential users. Air quality managers would benefit from updates throughout the day to help local communities plan for smoke events and at spatial scales capable of representing gradients within urban areas and fire perimeters. Long latencies typical of many satellite data products are a major barrier limiting their integration into fire weather forecast models."
- D14: "The impact of fire weather and climate on wildland fires represents a multiscale problem, where microscale meteorology can influence how a fire moves across a landscape, synoptic scale meteorology drives regional-scale severe multiple fire scenarios, and climate determines wildland fire trends over the next year to decades. Given this level of complexity in the data products and information needed to inform decision-making activities, the integration of fire weather, climate, and fuels data into useful, accessible information and tools is essential."
- D15: "Smoke and wind data offer complementary information about fire spread, including stereo-derived estimates of smoke plume height to identify and respond to PyroCB events…. Though multiple observations provide information on total column aerosol and trace gases, the lack of vertical information identifying the height of a plume makes it difficult to accurately incorporate this information into forecast models and can greatly reduce predictive skill. Insufficient information about boundary layer height and its diurnal evolution also limits the ability of air quality managers and fire weather forecasters to provide reliable information about near surface impacts of smoke plumes,

particularly at night…. Fire behavior information is also critical to understand the conditions under which PyroCBs form and collapse, as both conditions represent critical events for fire management and public safety."

- D16: "Mechanisms and capabilities to validate cutting-edge research and emerging tools to support Research-to-operations (R2O) processes and procedures is "embarrassingly slow." Recognizing that 'new' is not necessarily useful, a need exists to validate short- and long-term fire-related forecasts (all areas fire - weather, fuel, fire potential, etc.) with truth. Otherwise, enhancements are near impossible and leads to a lack of confidence in data and information by fire and land management."
- D17: "Advances in fire detection and tracking can benefit from a range of new and emerging data sources and analytic techniques…. Smoke and wind data offer complementary information about fire spread, including stereo-derived estimates of smoke plume height to identify and respond to PyroCB events."
- D18: "Currently wildfire is managed across its life cycle by state and federal agencies who leverage various information sets to make informed management decisions. However, these information sets are sometimes of limited utility for a myriad of reasons including accuracy, resolution, latency, effectiveness, and degree of technical innovation, among others…. Source data systems and applications need to continue to improve the ease of access/use of data and help users better understand limitations/caveats of data products."
- D19: "Satellite-based Earth Observation (EO) instruments provide routine coverage to help identify and track active fires, and current capabilities provide either moderate spatial resolution and infrequent coverage (e.g., VIIRS, MODIS) or coarse spatial resolution and frequent coverage (e.g., GOES). Gaps in moderate resolution coverage currently limit advances in fire science and applications needed to support the management of extreme fire events and their unprecedented impacts on communities, ecosystems, and air quality."
- D20: "A spatially explicit long-term dataset on building footprints, defensible space, and demographics is needed to address WUI fires during preparatory, recovery, and post-recovery phases."
- D21: "Addressing fires in wildland urban interface (WUI) areas requires immediate attention within minutes to hours to save lives and infrastructure; thus, essential demographics and infrastructure information are necessary in advance. Developing Decision Support Systems (DSS) integrating ground-based and remote sensing data with advanced artificial intelligence (AI) algorithms and models could help fire detection, tracking, evacuation, assessment of post-fire impacts, and restoration measures…. More detailed, better resolution and

faster data are essential for effective fire management. Their absence currently constitutes a barrier. The data should be linked to freely accessible decision support systems (DSS) useful to land managers and the public."

- D22: "Fundamentally, there is two-tiered need: 1) incident fire teams are often active in remote locations, without access to updated information [(e.g., no cell towers and only communicate by radio (VHF) - possible link to iridium satellites, balloons]; and 2) fire management teams, making decisions in the field, are hampered by an overabundance of data, often without perspective, rather than useful information….Communicating life-saving information to the front lines will require improvements in communications to remote crews with limited connectivity (cellular, radio, WiFi) to data/information sources and services (Incident Command Center, web-services, etc.). Specific needs include regular updates on the fire location and behavior, forecasts, and other management activities."
- D23: "R2O requires mutual agreement on how to verify and validate fire and land products, a single-source share for particular applications, and an acceptable hand-off from operational management (e.g., operational resources) to fire spread, prevention, and control (e.g., planning tools) management. There are three distinct, requisite times scales: short-range safety and immediate fire management (hours, day); mid-range forecasts for longer-term strategies and resources (days, weeks); and long-range forecasts (pre-season, climate), where probability, risk assessments, and confidence are requirements."
- D24: "In addition to communication during a fire event, closing the communication gaps between data producers and data users will require further training and support for new data products and a two-way sharing of data between research and analysis teams and fire suppression efforts. For example, fire spread forecasts could be more accurate if they account for planned fire suppression efforts."
- D25: "Fundamentally, there is two-tiered need: 1) incident fire teams are often active in remote locations, without access to updated information [(e.g., no cell towers and only communicate by radio (VHF) - possible link to iridium satellites, balloons]; and 2) fire management teams, making decisions in the field, are hampered by an overabundance of data, often without perspective, rather than useful information. The information and forecasts from predictive services are not targeted at the appropriate scale, which when compounded with the lack of available communication systems leads to a disconnect between available and actionable information."

- D26: “To safely identify ‘windows of burn opportunities’, requires allocated personnel, enhanced computing resources and integrated fuels-meteorology-smoke transport models at the required micro-landscape scale. At a larger scale, enhanced forecasts for seasonal/monthly planning that integrate climate-weather and fuels are necessary, while balancing Air Quality (AQ).”
- D27: “An integrated solution is one that requires: accurate and useful risk assessments; enhanced computing resources and science for model development at both local and regional scales; and social science to enhance community understanding of prescribed smoke and to provide a basis to motivate local building codes and political will….Despite the evidence supporting the use of prescribed fire as a fuels management strategy, it is still largely underutilized in fire-prone regions because of negative community perceptions of fire and smoke. A monumental shift in these negative perceptions is required before treatment can be realized at scales large enough to make significant impacts, and this ultimately requires communication strategies that build trust among communities and between communities, scientists, and land managers.”
- D28: “Fires will burn, so the choice is whether we burn under controlled prescribed conditions or when fire danger is extreme, leading to unhealthy extreme smoke and fires that are uncontrollable. Here is where agencies must work together to allow ecosystem-dependent local decisions, where the knowledge exist. To safely identify ‘windows of burn opportunities’, requires allocated personnel, enhanced computing resources and integrated fuels-meteorology-smoke transport models at the required micro-landscape scale. At a larger scale, enhanced forecasts for seasonal/monthly planning that integrate climate-weather and fuels are necessary, while balancing Air Quality (AQ). Comprehensive risk assessments that convey to fire management and communities fall into two categories: static (current community risk); and dynamic (changing fuel/fire over next days). Probabilistic forecasts were suggested as valuable to accurately assess future risks. An integrated solution is one that requires: accurate and useful risk assessments; enhanced computing resources and science for model development at both local and regional scales; and social science to enhance community understanding of prescribed smoke and to provide a basis to motivate local building codes and political will.”
- D29: “Debate continues about pre-settlement fire regimes, the natural occurrence of megafire and the role of indigenous fire management. This means that management of both red zone, urban-wildland interfaces and extensive forest or range land involves multiple stakeholders, multiple worldviews and priorities, indigenous values and knowledge and a host of other competing

positions. Building a fire-resilient landscape involves science, but equally culture, values, and community priorities."

- D30: "This means that management of both red zone, urban-wildland interfaces and extensive forest or range land involves multiple stakeholders, multiple worldviews and priorities, indigenous values and knowledge and a host of other competing positions. Building a fire-resilient landscape involves science, but equally culture, values, and community priorities."
- D31: "For infrastructure issues, psychology and economics are likely as important as traditional fire science; thus, socioeconomic surveys are a must for successful management. Further, community-level adaptation and policy studies can help understand post-fire impacts and improve responses to wildfire at the WUI."
- D32: "An integrated solution is one that requires: accurate and useful risk assessments; enhanced computing resources and science for model development at both local and regional scales; and social science to enhance community understanding of prescribed smoke and to provide a basis to motivate local building codes and political will."
- D33: "First, tools and models for assessing fire risk, and how much mitigation action might reduce that risk need to be more robust, especially in the case of changing climate, changing ecological communities, and changing settlement patterns…. A spatially explicit long-term dataset on building footprints, defensible space, and demographics is needed to address WUI fires during preparatory, recovery, and post-recovery phases. Very high-resolution remote sensing data could be helpful here. Approaches that promote defensible space, coupled with home hardening, are essential to improve any home's chance of surviving a wildfire."
- D34: "A spatially explicit long-term dataset on building footprints, defensible space, and demographics is needed to address WUI fires during preparatory, recovery, and post-recovery phases. Very high-resolution remote sensing data could be helpful here. Approaches that promote defensible space, coupled with home hardening, are essential to improve any home's chance of surviving a wildfire."
- D35: "Providing uniform warnings and services for fires across the country, which face geographic differences, complex regulatory environments that span federal to local agencies, and varying levels of fire expertise in field office staff, is a major challenge. Improving communication of existing tools and services is critical in making sure that advances truly serve the communities they are intended to support. The panel strongly emphasized the value of working closely

with social scientists to find better ways to communicate risk and inform the public without creating panic and to address equity and social justice concerns."

- D36: "Specifically, owners of tribal lands and cultural heritage do not have proper early warning systems (EWS) before the fire hits them; thus, developing EWS should be a priority."
- D37: "Developing Decision Support Systems (DSS) integrating ground-based and remote sensing data with advanced artificial intelligence (AI) algorithms and models could help fire detection, tracking, evacuation, assessment of post-fire impacts, and restoration measures."
- D38: "Trends in Burn Severity (MTBS) and Burned Area Emergency Response (BAER) systems are beneficial for post-fire management and restoration efforts; however, more such programs with better data latency are needed to address wildfire problems."
- D39: "Developing Decision Support Systems (DSS) integrating ground-based and remote sensing data with advanced artificial intelligence (AI) algorithms and models could help fire detection, tracking, evacuation, assessment of post-fire impacts, and restoration measures."
- D40: "The group made a strong case for the need for a centralized database of wildfire related data. They would like this database to mention the types of data available and how they could be used on the front page to increase the "discoverability" of data types they may not be familiar with. To increase accessibility of the data, the group suggested the database be formatted similar to existing well-known mapping portals such as: GWIS-Current Situation."
- D41: "Harmonizing different types of data represents a significant gap in the wildfire community. These different types of data could be integrated as layers that with a data mapping platform. The data types mentioned by the group that would be useful in post-fire analysis were: vegetation data, geologic map information, burn severity maps, high resolution imagery, soil type and moisture information, above ground structure locations, as well as spectral, photogrammetry, and topographic data."
- D42: "Remotely acquired wildfire data are typically stored locally and need to be directly shared with those requesting access. However, many wildfire agencies suffer from a lack of resources and little to no dedicated remote sensing personnel that can process, classify, and share these data. This result in delays to scientific and public data access and can limit capacity to fully utilize actionable information to identify post-fire risk within the period where data are needed…. There is a need for a clear and well-established communication pathway to

requesting information that agencies and researchers can utilize to better understand what data are available and how to acquire these data. These lines of communication need to connect groundcrews and those researching and monitoring post-fire cascading hazards with the existing databases and networks of data."

- D43: "Further, community-level adaptation and policy studies can help understand post-fire impacts and improve responses to wildfire at the WUI."
- D44: "The vegetation regrowth and plant succession after fires will depend on various factors such as fire severity, disturbance history, topography, site characteristics, and local weather. Ecological studies combined with remote sensing data can provide valuable information on these variables useful for restoration efforts."
- D45: "High severity and high-intensity fires can alter vegetation structure and function at rapid timescales (<week to a month). Vegetation regrowth and plant succession after fires can depend on various factors such as local weather, topography, ecological site characteristics, fire disturbance history, and fire severity (intensity, duration, type, size, season). In particular, fire-adapted invasive species can expand and degrade natural ecosystems. Also, the regenerated vegetation can be fuel for the next wildfire. Thus, knowledge of pre-fire vegetation composition along with the capability to characterize the composition of vegetation regrowth and regrowth trajectories at various spatial scales is central to determining both future fire risk and post-fire management decisions."
- D46: "In addition, new vegetation can govern water infiltration capacities, affecting downstream water supply, but we lack details on the timing and scale of these impacts."

E. *Wildland Fire Science and Technology Task Force Final Report* (2015)

- E1: "There is a need to support fire prevention educational efforts as well as for states and local jurisdictions to develop adequate and enforceable ordinances related to wildfire prevention. There is clear evidence that small investments in fire prevention help reduce the high cost of fire suppression, as well as associated wildfire damages.18 Such programs are most effective when they focus on the underlying causes of these human-caused ignitions in each location and tailor the prevention programs to specific causal factors and community dynamics."

- E2: “Use Earth observation systems (ground and remote sensing) to develop and regularly update fuels, weather, and other data bases needed for fire prediction and monitoring.”
- E3: “Implement continuity missions for moderate-resolution satellite data (15–30 m) for characterizing fuels and burn severity and for active fire remote sensing.”
- E4: “Develop national databases of burn severity and fire perimeters for both wildland and wildland-urban-interface fires.”
- E5: “Use Earth observation systems (ground and remote sensing) to develop and regularly update fuels, weather, and other data bases needed for fire prediction and monitoring.”
- E6: “Integrate new process understanding into improved 3-D fire behavior models that incorporate complex fuels (including structures), terrain, and fire/atmosphere interactions into predictions of fire probability, fire behavior, fire severity, fire emissions, smoke transport, and ecosystem fire effects.
- E7: “Use Earth observation systems (ground and remote sensing) to develop and regularly update fuels, weather, and other data bases needed for fire prediction and monitoring.”
- E8: “Implement continuity missions for moderate-resolution satellite data (15–30 m) for characterizing fuels and burn severity and for active fire remote sensing.”
- E9: “Develop and deliver real-time decision support tools during fire incidents to help managers identify wildlands, communities, and structures most at risk and the most appropriate tactical responses.”
- E10: “Develop and deliver real-time decision support tools during fire incidents to help managers identify wildlands, communities, and structures most at risk and the most appropriate tactical responses…. Despite this capacity, the WFDSS does not yet meet the need for real-time data to support the wildland-fire fighter on the ground who has to make fast and informed decisions.”
- E11: “Establish methods to assess the adequacy of community resources for a successful response to a likely fire hazard.”
- E12: “Study the effectiveness of resource management and firefighter response and alternative management strategies at altering outcomes, including benefits to safety, costs, natural resources, and communities.”

- E13: “Implementation of new technologies for situational awareness, communications, and protective equipment to improve safety during wildfire response activities.”
- E14: “Finding innovative ways to contain large wildfires more efficiently is an ongoing and continuous struggle for both fire-science producers and users, and it represents a significant research priority going forward.”
- E15: “Implementation of new technologies for situational awareness, communications, and protective equipment to improve safety during wildfire response activities.
- E16: “The ecological benefits of wildland fire often outweigh the negative effects, and as such, prescribed fire is one of the most effective means for controlling the rate of spread and severity of undesired wildfire. A more unified and effective messaging strategy among the fire- and health-management agencies is needed to relay these benefits to the public in a clear and understandable way.”
- E17: “Fuel treatments near homes and communities are also an effective way to reduce the likelihood of structure ignition and enhance the safety of fire fighters and the public. With so many variables and options, maximizing the effectiveness of fuel treatment is a major challenge, and additional research is needed to explore the full range of conditions and consequences…. Use remote sensing and burn severity mapping to monitor fuel treatment effects and effectiveness…. Develop risk-based methods for deciding on the best strategies for mitigating the negative effects of wildland fire on ecosystems and communities.”
- E18: “Assess the benefits of fuel treatments, other preparedness activities, societal attitudes and decision-making processes in reducing potential impacts…Improve understanding of costs and benefits of wildland fire and fuel management.
- E19: “Understand the factors that motivate individuals to undertake risk mitigation activities.”
- E20: “To avoid further habitat degradation, action must be taken by Federal fire-science users and producers to improve capabilities to effectively suppress fire as well as actively manage vegetation, including fuels treatment, post-fire stabilization, and habitat restoration actions.”
- E21: “Link fire safe community information with geospatial data for evaluating and predicting local to national impacts of fuel and fire management and community design.”

- E22: “Understanding and anticipating trends in, and impacts from, climate change is necessary in order to most effectively manage changes in fire regimes and fire behavior and meet all three national goals of the Cohesive Strategy…. Poor understanding of wildland fire in the context of changing baseline conditions such as climate change as outlined in the National Climate Assessment…. Develop methods to model recovery of fire-impacted ecosystems under various climate change scenarios.”
- E23: “Poor understanding of the relationship between wildland fires and adjacent structures and a lack of science-based building codes, standards, and guidance.”
- E24: “The concept of fire-adapted communities needs to be supported by data documenting the performance of risk-mitigation technologies for wildlands, communities, and structures…. To this end, research is needed to improve the current mitigation guidelines and regulations, both for new construction and for retrofitting existing communities. Improving building resilience should be a high priority, along with parallel science-based fuel treatments.”
- E25: “Federal fire science producers and users should focus efforts on protecting life and property and reducing risks to WUI property, residents, and responders.”
- E26: “To this end, research is needed to improve the current mitigation guidelines and regulations, both for new construction and for retrofitting existing communities. Improving building resilience should be a high priority, along with parallel science-based fuel treatments…. Link fire safe community information with geospatial data for evaluating and predicting local to national impacts of fuel and fire management and community design.”
- E27: “Assess the fire safe characteristics of community designs, including layout, landscaping, and structure design and building materials, and make recommendations for improved fire safety.”
- E28: “Improve information and tools for homeowners and planners on fire-safe construction, landscaping, and community planning.”
- E29: “Develop and implement integrated landscape and larger-scale modeling and analysis systems for wildland fire planning and wildland-urban-interface community design that incorporate risk mitigation, fuels, fire behavior, smoke transport, resource and social values…. Develop risk-based methods for deciding on the best strategies for mitigating the negative effects of wildland fire on ecosystems and communities.”

- E30: “Link fire safe community information with geospatial data for evaluating and predicting local to national impacts of fuel and fire management and community design.”
- E31: “Evaluate effectiveness of alternative approaches to risk communication, emergency warning, and decision-making on fire management, prevention, and mitigation… Integrate with multi-hazard risk communication systems for emergency warning.”
- E32: “Evaluate effectiveness of alternative approaches to risk communication, emergency warning, and decision-making on fire management, prevention, and mitigation… Integrate with multi-hazard risk communication systems for emergency warning.”
- E33: “Assess logistical needs and evacuation plans for a variety of fire scenarios, including wildland and wildland-urban-interface fires.”
- E34: “Understand why individuals evacuate or choose to stay.”
- E35: “Poor understanding of the human elements of wildland fire, including firefighter safety, long-term health effects of smoke, individual and organizational performance and risk perception, and public perceptions and attitudes towards both fire and fire management.”
- E36: “Develop improved systems to assist homeowners and communities to recover from impacts of wildland fire.”
- E37: “Develop data and validated models to assess how well different community and landscape designs and post-fire restoration activities mitigate fire risk and damage, including offsite effects such as flooding and erosion, and damage to transportation and energy infrastructure.”
- E38: “Develop methods to model recovery of fire-impacted ecosystems under various climate change scenarios.”
- E39: “Improve and apply validated methods to enable consistent, rapid, and accurate fire severity mapping and assessment of the benefits of natural wildland fire and the risk of severe erosion, flooding, and other ecosystem damage.”
- E40: “Create common tools for assessing impacts of wildland fire as well as validated methods to enhance resilience to wildland fire and restore fire-impacted ecosystems and communities.”

F. *Wildland Urban Interface Fire Operational Requirements and Capability Analysis: Report of Findings* (2019)

- F1: "R15 – Need real-time and continuous identification of heat sources and smoke to detect ignition location. R17 – Need integrated data for baseline risk factors (e.g., weather, fuel, topography, fire history) with real-time updates. R18 – Need to exploit all source information (e.g., social media) for ignition detection."
- F2: "Insufficient dissemination of ignition detection data to all response partners…. Moreover, power companies/utilities have access to data using proprietary systems which could include ignition detection and communities without power. Participants noted that they have been unable to access this potentially life-saving data."
- F3: "R16 – Need widespread, automatic dissemination of detection data. R19 – Need to deconflict and process ignition data into actionable information. R20 – Need standardized format for ignitions that can be easily distributed and understood by emergency responders."
- F4: "Non-traditional, crowdsourced information and communications (e.g., social media) are not frequently incorporated into the WUI fire common operating picture…. Social media posts, pictures, and videos provide important information for modeling, but there is not a clear, repeatable process to analyze and disseminate the information in a way which emergency responders in the field can easy utilize."
- F5: "Many wildfire models attempt to recreate fire characteristics and require an operator to manually enter inputs, but that does not adequately account for the threatened or burning landscape and is an inefficient use of time. No known automatic technology solutions track and account for fire characteristics in WUI Fire modeling."
- F6: "Fire models also do not always match fire behavior on the ground due to challenges predicting WUI fires. Existing models do not accurately forecast fires when certain factors are involved, such as fire-induced winds and multiple structures serving as fuel. Participants reported often needing to apply ad hoc improvisations to models for them to match observed conditions (e.g., change true fuel conditions to dry brush)… Fire models do not currently account for the unique nature of WUI fires; Fire models do not account for ignitions of structures and urban fuels across the WUI or extreme weather. Existing fire models have known and unknown limitations and are not consistent or accurate in predicting WUI fires, resulting in uncertainty in where the models will fail….

R29 – Need to acquire WUI Fire modeling inputs (e.g., fuel, meteorological conditions, wind)."

- F7: "There are a number of fire models used for risk assessment. There is no standard usage or methodology, nor are these models validated for WUI planning."
- F8: "The fire community has many tools to track the perimeter of a fire, including drone or fixed wing flyovers, but current systems are not frequent or accurate enough to relay the real-time fire perimeter. Current capabilities may not penetrate through smoke cover, giving an inaccurate picture of the WUI fire perimeter."
- F9: "Fire modeling and critical information dissemination are not timely enough to support effective decision-making for emergency managers…. R28 – Need timely fire behavior modeling (i.e. updated hourly or less)."
- F10: "R27 – Need WUI Fire modeling that generates actionable and reliable data outputs…. Participants reported that modeling results do not arrive in time to impact decision-making—modeling can take upwards of eight hours to receive results. WUI fires evolve too quickly for such long turnaround times…. R28 – Need timely fire behavior modeling (i.e. updated hourly or less)."
- F11: "Participants reported it would be beneficial to have an up-to-date inventory of all available resources in one repository…. R9 – Need a catalog of local, state, and federal WUI firefighting resources."
- F12: "R62 – Need to know sensitive site (Environmental and Cultural) locations and specific requirements for first responders during WUI fires."
- F13: "Participants reported frequent challenges maintaining telephone and internet connection during WUI incidents. Telecommunication and radio connectivity are essential to maintaining a common operating picture; communicating incident information, warning, and evacuation notices to affected populations; maintaining continuity of operations of affected jurisdictions and maintaining data feeds from operational partners."
- F14: "Participants reported an incomplete common operating picture due to agencies and neighboring counties failing to share vital information with one another. This is partially due to inherent siloed responsibilities, but also due to the different systems and programs that cannot communicate with one another, as well as the complex problem of protecting proprietary data…. Current response resource tracking systems in the fire community track vehicles, but not individual emergency responders…. Emergency responders are eager to obtain all the necessary information, but because information is not compiled from the

field and disseminated out in a coherent, complete, or expeditious manner they do not always receive a complete picture."

- F15: "Participants reported the fire community has not sufficiently adapted to threats associated with WUI fires. Meanwhile, the frequency and breadth of WUI fires has steadily increased with no sign of the threat reducing. For example, emergency responders highlighted that current wildland firefighting doctrine of morning briefings is insufficient for the information needs for fighting WUI fires; emergency responders need more frequent briefings to match the volatility of WUI fires."
- F16: "Insufficient location planning for critical infrastructure to account for WUI fire threat (e.g., cell towers and emergency operations centers)…. R7 – Need to identify risk to and from critical infrastructure and plan accordingly (e.g. site communications appropriately)…. More accurate models would allow for infrastructures to be prioritized for relocation and/or hardening."
- F17: "Best practices of fire mitigation efforts for communities in a WUI area include the following: 1) Defensible space—a buffer zone between a building and fuel (grass, trees, leaves, etc.) that helps decrease the risk that a home will ignite as well as assist firefighters who are protecting the structure. 2). Building and maintenance codes to include an ignition resistant exterior, noncombustible decking and stairs, and tile or metal roofing; and 3). Fuel mapping and condition testing to ensure fire behaviorists understand the location of high-risk areas due to the type and extent of fuel in the area."
- F18: "R64 – Need resilient critical infrastructure prepared to avoid cascading impacts. R65 – Need to know status of critical infrastructure necessary to respond."
- F19: "Infrastructure that is critical to response (e.g., cell towers and radio towers) are often situated in hazardous locations which makes them susceptible to damage from a WUI fire…. R7 – Need to identify risk to and from critical infrastructure and plan accordingly (e.g. site communications appropriately)."
- F20: "Participants indicated a pressing need for accurate modeling of fire behavior in WUI conditions. However, subject matter experts in fire behavior stated that current fire models do not account for extreme wind and weather conditions nor structure fires and may not produce accurate results…. Fire models also do not always match fire behavior on the ground due to challenges predicting WUI fires. Existing models do not accurately forecast fires when certain factors are involved, such as fire-induced winds and multiple structures serving as fuel. Participants reported often needing to apply ad hoc improvisations to models for them to match observed conditions (e.g., change

true fuel conditions to dry brush)…. R27 – Need WUI Fire modeling that generates actionable and reliable data outputs. R30 – Need WUI Fire modeling that matches specific WUI conditions…. In addition, by integrating census and assessor data, WFRAS can quantify potential impacts of fires, including estimates for economic and social impacts such as the dollar value of exposed structures, commodity agriculture, plantations, etc."

- F21: "Participants reported that, during major WUI fire incidents, they did not have enough personnel to maintain Public Information Officers (PIO) on full-time social media duty. As a result, emergency responders are often unable to communicate warnings and up-to-date incident information through common channels and incorporate information from survivors into the common operating picture. PIOs must be more than simply social media literate, they need to be able to vet the message, determine reliability, time of origin, source, etc. … R38 – Need to disseminate information and warnings through social media."
- F22: "R43 – Need multi-platform messaging with a single source capable of national reach."
- F23: "Public information and warning are hindered by telecommunication carrier limitations… R36 – Need tele-communication carriers to loosen limitations and improve service delivery of emergency messages."
- F24: "The fire community is cautious of disseminating frequent warnings fearing that the public will become desensitized to their importance. However, the fire community also does not want to avoid informing the public. Participants recommended further study into the tradeoffs of over warning—especially false positives—and under-warning their jurisdictions.
- F25: "Participants reported dispatch centers do not have a connection between the early incident command centers and communication centers, which can result in missing information. Participants emphasized the information's source is not important during response, only how it may influence response decisions. Furthermore, many dispatch centers are currently unable to integrate information coming from sources beyond 911 calls."
- F26: "The AFN population must be provided with accommodations to typical text/visual/audible notifications and warnings, should successful message and delivery occur. such as translation into a different language or alerts that vibrate/shake instead of make noise."
- F27: "Participants cited a high rate of delivery failure due to hang ups, lack of landline/cell, telecommunications network down, and other factors which all contributed to messaging not arriving to the intended recipient. Respondents

noted the need for messaging across a wide variety of platforms to improve delivery rate…. R31 – Need geographically targeted notification and warning to specific areas."

- F28: "Participants reported the need for consistent warning terminology; the lack of consistency leads to confusion among emergency responders and the public. For example, California fire fighters reported requesting a reverse 911—an alert to go out to everyone in the jurisdiction; however, the dispatch used a different term for the same procedure, which delayed the warning."
- F29: "Participants across multiple jurisdictions reported a range of authorities that order notification and warnings, occasionally causing confusion during a WUI event, especially for multi-jurisdictional events. While not common, the general lack of clarity on important decisions has a high impact on life-safety…. Participants reported the lack of clear thresholds on when to send out information and warnings delayed or prevented distribution. For example, participants cited numerous issues in distributing wireless emergency alerts (WEA) due to the lack of pre-defined thresholds."
- F30: "Hazardous condition warnings (e.g., the red flag system) are not integrated with fire departments and emergency manager's assessment of risk…. Fire communities and emergency managers have their own assessment of risk, but WUI hazardous condition warnings often do not account for these risks."
- F31: "Current public education programs (e.g., Ready, Set, Go) have not resulted in marked changes in behavior and have not effectively integrated with similar programs for other types of disasters…. R10 – Need the public to have more realistic expectations for protection in high-risk areas."
- F32: "Participants reported limited insight on whether evacuations should occur from the farthest away to the closest to the hazard, or in a different organizational pattern. In addition, emergency responders highlighted that evacuations have typically resulted in traffic and chaos. Evacuations schema need to account for the vehicles and traffic—for example, one participant cited an instance of an evacuation destination located too close to the incident causing a line of cars still in the hazard zone…. R51 – Need to identify best practices for evacuation patterns and schema."
- F33: "R46 – Need public-private partnerships to support evacuation efforts…. Social media platforms (i.e. Facebook) use a check-in feature which allows people to share when they have successfully escaped the danger-area of an incident. These check-ins are typically not real-time. Crowdsourced navigation apps (i.e. WAZE) leverage social media data to inform the response common operating picture during evacuation, but more development is required.

Additionally, coordination with the hospitality and advertising industries to ensure transient populations are aware of evacuation procedures and receive all necessary evacuation guidance is necessary."

- F34: "Jurisdictions have plans in case of emergency, but neighboring counties, cities, and towns do not always communicate plans with one another, leading to evacuation into each other or insufficient resources (i.e. transport vehicles for AFN)."
- F35: "R44 – Need identification of multiple evacuation routes, safe zones, shelter-in-place facilities and alternatives."
- F36: "R55 – Need an inventory of evacuation capabilities and available resources."
- F37: "R2 – Need pre-incident public education, including understanding of actions associated with notifications and warnings."
- F38: "Participants reported current evacuation models have trouble calculating evacuation times, especially for AFN and transient populations. Participants wanted to use evacuation modeling to determine the most effective evacuation route…. R52 – Need reliable modeling of evacuation routes, population behavior, and safety areas."
- F39: "Participants reported the lack of clear triggers for evacuation and/or shelter in place orders. In addition, participants recommended creating multiple evacuation thresholds where possible (e.g., lower evacuation threshold for AFN population). Participants recommended the creation of federal evacuation guidelines that could be adapted to each particular incident."
- F40: "R47 – Need standards and guidelines to evacuate individuals with disabilities and others with access and functional needs population."
- F41: "The fire community is becoming more aware of the extra attention needed for the AFN population, but there are no common systems that track AFN population data, such as their communication and medical needs, and mobility requirements or location."
- F42: "Participants reported the inability to monitor the status of evacuation routes and safety zones in real time. For example, a camera system on a major evacuation route would allow emergency responders to address blockages and reroute the public quickly. Further, participants reported that they lacked a common platform to track inhabitants who have successfully evacuated, not yet evacuated, or refused to evacuate. This platform would allow emergency responders to target their operations and reduce duplication of effort…. The fire community strives for clear evacuation routes and procedures but struggle to

monitor the status of evacuation routes and safety zones in real-time. Some mass notification systems allow recipients to reply and may allow follow-ups to better assess response to evacuation notices. Some features may be add-ons to basic service, thus increasing cost."

- F43: "Participants noted that many citizens care deeply about their animals and risk their lives, and inadvertently the lives of others, when trying to evacuate or save animals. Pet owners may fail to evacuate because of their pets or evacuate without their pets and go back for them, causing road congestion and/or the potential need for rescue."
- F44: "Participants reported they have no system to measure or track the harmful particulate in the air—caused by smoke—that may affect the AFN population and/or be a public health risk…. Existing technology solutions focus on monitoring smoke plumes and air quality near the fire source but are unable to assess transported and/or dispersed smoke in the atmosphere. Transported smoke worsens air quality and poses serious risk to public health."
- F45: "Participants reported they have no system to measure or track the harmful particulate in the air—caused by smoke—that may affect the AFN population and/or be a public health risk. Additionally, smoke desensitizes people; many people do not understand their immediate risk after prolonged smoke exposure…. There exist systems to monitor smoke and air quality, but they are not currently used to detect extremely small and harmful particulates that may affect the AFN population…. R39 – Need to warn about air quality levels (e.g. smog, smoke)."

G. *Fire Science Strategy* (2014)

- G1: "In particular, given the prevalence of the use of prescribed fire by DoD managers to mimic low intensity surface fires, a desired outcome is improved understanding of the processes involved in fine fuel heat exchange, ignition, and fire spread and how they may be affected by fuel condition, incorporation of this understanding into fire behavior models, and subsequent validation of those models."
- G2: "Improve model validation, testing, and identification of uncertainties of physics-based fire behavior and effects models. Specifically, we need to improve our understanding of why fires spread or don't spread, including relationships between fire spread and wind speed and moisture conditions and mechanics that drive fire brands (generation, transport and ignition)."
- G3: "In particular, given the prevalence of the use of prescribed fire by DoD managers to mimic low intensity surface fires, a desired outcome is improved

understanding of the processes involved in fine fuel heat exchange, ignition, and fire spread and how they may be affected by fuel condition, incorporation of this understanding into fire behavior models, and subsequent validation of those models.

- G4: "Fire behavior remains an elusive area of inquiry with few studies that comprehensively define basic heat transfer processes (e.g., radiant or convective heat release and consumption) and few tools capable of integrating and advancing science in the other dependent core areas. Predictive modeling tools that describe the pyrolysis and combustion processes have been dominated by empirical and semi-empirical approaches, whose integration into the other core research areas that depend on first understanding fire behavior has been problematic…. They identify four potential areas of inquiry: (1) fuel particle exchange; (2) role of convection; (3) definition of, and criteria for, ignition; and (4) burning of live fuels (as distinct from dead fuels)."
- G5: "Modeling of fire behavior has recently been advanced by the development of coupled fire-atmospheric numerical models that capture the fluid dynamics of the fire environment, but a lack of comprehensive datasets still limit real-world validation of such models."
- G6: "In addition, although a number of fire behavior models are available that are supposed to provide managers predictive capabilities, no inter-model comparisons have been conducted to assess limitations, cost, and performance capabilities across fuel types represented on DoD lands. Models also need to be validated against multiple vegetation types and conditions (e.g., regularly burned versus fire suppressed). Finally, usability by the manager has not been evaluated…. Fire behavior models need to be tested across multiple scales, and it will be important to characterize model limitations across a range of relevant scales and scenarios"
- G7: "These objectives include a focus on prescribed fire versus suppression, sustaining the military mission through fire management, indirect suppression tactics, and sustaining particular ecosystems, specifically the recovery and maintenance of the longleaf pine ecosystem in the southeastern U.S. for which DoD is a significant land manager…. As a result, associated ecosystem-level research must consider the dynamics of the carbon cycle per se and how that cycle relates to carbon sequestration goals and the trade-offs involved with other ecosystem services (including supporting the military mission)."
- G8: "In addition, the consequences of deciding not to burn are key data gaps as well, especially if prescribed fire is viewed from a risk management perspective in which the risks of burning are balanced against the risks of not burning."

- G9: “To develop, demonstrate, validate as appropriate, and transition the science needed by DoD fire and resource managers to understand and apply fire behavior as a management tool for those ecosystems of management concern to DoD.”
- G10: “To support DoD’s continued use of fire as a management tool, SERDP has funded efforts to address how best to characterize the emissions associated with fire and their dispersion in the atmosphere, as well as to understand how fire acts as a disturbance process that resets ecological communities.”
- G11: “Unmet needs for vegetation/fuel bed information for the dominant fire ecotypes and purposes represented on DoD lands remain a critical data gap. These include the concentrations of DoD lands in the Southeast and arid and semi-arid Southwest that are represented by system types of open canopy pine/oak stands with surface fire regimes, grasslands, and shrub types such as pocosin and chaparral.”
- G12: “Improve characterization, monitoring, modeling, and mapping of fuels to support enhanced smoke management and fire planning at DoD installations.”
- G13: “In addition, new regulatory environments should be anticipated as current compliance constraints will not likely remain static. For example, although a mandate for carbon management, especially sequestration, does not currently exist, land management agencies certainly should prepare for that eventuality.”
- G14: “The research also must incorporate the future uncertainty of climate change on processes that drive the carbon cycle. In particular for DoD, understanding how managed disturbances such as fire—with an emphasis on using the principles of ecological forestry and prescribed fire—affect carbon cycle dynamics is a priority.”
- G15: “As a result, associated ecosystem-level research must consider the dynamics of the carbon cycle per se and how that cycle relates to carbon sequestration goals and the trade-offs involved with other ecosystem services (including supporting the military mission).”
- G16: “In addition, new regulatory environments should be anticipated as current compliance constraints will not likely remain static. For example, although a mandate for carbon management, especially sequestration, does not currently exist, land management agencies certainly should prepare for that eventuality. These types of data, along with research on the carbon cycle of DoD forest ecosystems and the relationship to ecological forestry, would provide DoD and other fire and resource managers the information and tools they need to manage their forests for multiple land management and ecosystem services benefits.”

- G17: “A carbon footprint tool—preferably one that is flexible with respect to data quality and transferable across ecosystems—is needed to estimate stocks and fluxes under different management trajectories.”
- G18: “In particular, synthesizing the implications of the numerous studies, demonstrations, and research projects associated with longleaf pine restoration and management—an ecosystem of critical interest to DoD—is a pressing need.”
- G19: “For wildland fire emissions and carbon accounting, improved characterization and mapping of fuels is needed that accounts for all fuelbed components from canopy to surface fuels and characterizes diverse fuel complexes (e.g., masticated fuels, homes and landscapes within the wildland-urban interface, and invasive species assemblages). To address this, evaluation of new, spatially explicit fuel measuring protocols and tools (e.g., LiDAR and SAR) is needed with field sampling verification. Development of a central data repository for fuel datasets would also benefit fuel consumption and fire behavior modeling efforts.”
- G20: “What remains to be determined are: … (2) an understanding of the critical ecosystem function of nutrient cycling under non-stationary conditions in the context of fire management; (3) an understanding of community assembly, disassembly, and novel reassembly in a fire-managed, no-analogue future.…”
- G21: “Emissions factors enable estimating the amount of regulated gaseous and aerosol constituents that are released during a fire. They are needed to address permitting requirements associated with meeting air quality requirements and if inaccurate and overly conservative could result in activity restrictions, such as the ability to conduct prescribed burns…. Moreover, the presumed dichotomy between wildfire versus prescribed burn emissions—given its focus on distinguishing purposeful versus natural or unintended ignition—may miss the point between distinguishing emissions that are of an air quality concern versus those that are not or are a necessary trade-off to meet resource management objectives, but in a manner that can be planned and controlled and the negative impacts minimized. This may require a new complementary way of classifying fires and their associated emissions factors along a continuum independent of their ignition source that instead considers fuel and weather conditions at the time of a fire and the resultant intensity and subsequent severity of the fire.”
- G22: “Under current conditions, the presence of insects, disease, and drought affect forest health and the degree to which fire can be applied as a management tool and its effectiveness.”

- G23: “With the advent of climate non-stationarity, simulation modeling tools will prove valuable in understanding future sensitivity to swings in climate variability that lead to forest changes and altered fire consequences, but these models must be evaluated (validated) in ecosystems and regions of DoD interest to accurately capture relevant dynamics.”
- G24: “Specifically, in regards to the development of a fire science strategy, it is critical to understand where and when fire can be a primary tool for meeting future management needs and how fire-adapted ecosystems will respond under a changing climate regime and novel stressors.”
- G25: “What remains to be determined are: … (4) the relationship of fuel hazard reduction techniques to protect built infrastructure and training/testing missions to their ecological effects.”
- G26: “Although related to emissions characterization in fundamental ways (e.g., aging of smoke plumes with dispersion and the secondary formation of aerosols), the core area of fire plume dispersion contains several unique sub-elements that are of critical research focus. These elements include fire plume development and rise phenomena, plume chemistry, local and regional day- and night-time smoke transport, super fog formation, and predicting and preventing visibility impairments from prescribed fires that potentially impact the military mission and public safety…. The review concluded with an overview of key areas of uncertainty that required additional research attention. These include improved: (1) understanding of the plume structure that results from the buoyant phase of plume development as it relates to the vertical distribution of plume constituents, (2) quantification of the number of cores contributing to an updraft plume for a given fire as a way to improve dispersal simulations, (3) linkage of smoke transport and dispersion models to fire behavior models to better capture the space-time variability of heat and emissions release rates across the landscape, (4) linkage of plume structures to prescribed fire ignition patterns, (5) fully resolved canopy sub-models within atmospheric models to improve dispersion predictions for low intensity fires to improve local smoke effect predictions, and (6) quantification of the advantages and limitations through validation of the various models and their components to assist managers with determining which model to use for which purpose (Goodrick et al. 2013).”
- G27: “Visibility impacts have largely been the focus because of safety concerns; however, few night-time modeling tools exist and the dispersion dynamics of night-time smoke dispersion remain largely unstudied.”

- G28: “Design and execute field experiments to validate next-generation smoke models. This will require field experiment partnerships and validation criteria and an increased focus on heavy fuels and high-intensity fire events.”
- G29: “Emissions characterization focused mostly on regulated constituents, such as criteria pollutants, which have established exposure thresholds, and hazardous air pollutants, which do not have established exposure thresholds but instead are regulated on the basis of compliance with using the maximum available control technology.”
- G30: “This includes not only refining specific emissions factors for air constituents of concern for DoD vegetation types under both flaming and smoldering conditions, but also includes improving estimates of fuel consumption to place those factors into context….This may require a new complementary way of classifying fires and their associated emissions factors along a continuum independent of their ignition source that instead considers fuel and weather conditions at the time of a fire and the resultant intensity and subsequent severity of the fire…. In addition, the preceding research requires reconciling the differences between smoldering and flaming combustion—which occur simultaneously during a fire but whose relative contributions to emissions differ in ways based on the type and severity of the fire that need to be quantified—and determining whether our generalized understanding of those processes are adequate.”
- G31: “Although progress has been made (see SERDP/ESTCP Investments to Date below), reconciling laboratory results to field-based emissions estimates and ground-based to airborne-based estimates still remain a challenge.”
- G32: “An important by-product of this work, however, was to provide information on the greenhouse gas (GHG) emissions profiles of fires. Further work on characterizing GHG emissions, along with other climate-forcing agents (e.g., soot carbon and brown carbon; *sensu* Andreae and Gelencsér 2006) generated by fire, and their relationship to fire frequency, intensity, and severity is needed to understand the trade-offs involved.”
- G33: “For prescribed burns, field data are generally more available than they are for wildfires but the quality of the data is variable for both methods and types of data collected.”
- G34: “Continued collection of data and development of models are needed to characterize emissions resulting from prescribed burning and wildfires that occur on and adjacent to DoD lands and to accurately allocate the source contribution of these fires to regional air quality in comparison to other sources. Information is needed for the variety of fire-adapted ecological systems

managed by DoD and via characterization protocols that are standardized, transferable, and accepted by the regulatory community. Such work also should contribute to: (1) information on the types and amounts of emissions that play a role in climate forcing and their fate and (2) our understanding of the differences in emission profiles between fire-maintained stands and fire-suppressed stands that may burn under unfavorable conditions as a wildfire."

- G35: "A better understanding of fire behavior, its purposeful manipulation to achieve desired management objectives, and the consequences of wildfire versus prescribed fire for air quality, ecological effects, human health and safety, and mission support is needed to assist DoD managers not only in the proper use of fire but also in understanding the trade-offs involved in deciding to burn or not to burn…. In addition, effects research, while focusing on ecological effects, also should account for minimizing any adverse consequences to safety, human health, and military training/testing activities."
- G36: "Improve characterization, monitoring, modeling, and mapping of fuels to support enhanced smoke management and fire planning at DoD installations…. Design and execute field experiments to validate next-generation smoke models. This will require field experiment partnerships and validation criteria and an increased focus on heavy fuels and high-intensity fire events. Experimentalists and modelers need to work together to inform validation studies, new measurements, and model refinement through iterative testing and modification. Variables to model and test include 1) fire growth and behavior, 2) fuel consumption, 3) influence of fuel moisture on combustion, 4) plume structure and transport, and 5) ground smoke impacts."
- G37: "Quantify, model, and monitor post-fire effects at DoD installations to improve fire management effectiveness…. This will require coordination with the other fire science agencies to improve the characterization of fuels and post-fire consumption estimates in ways that can serve multiple uses yet improve the standardization, repeatability, and transferability across fuel types of methodological approaches."
- G38: "Fire may have other consequences for DoD, such as impacts to built infrastructure and training/testing missions. These end points are not addressed as separate research areas, but are considered in the context of ecological effects as other constraints."
- G39: "Fire behavior models need to be tested across multiple scales, and it will be important to characterize model limitations across a range of relevant scales and scenarios… Evaluate plausible future climate change scenarios and no analog, novel, and disappearing climates and their implications for fire and

ecosystem-based management. To anticipate a range of outcomes and possible threshold effects under climatic change scenarios, ecosystem process models will need to directly incorporate disturbance models."

- G40: "Under a future of climate change-related perturbations and expanding presence of NIS and native pests and diseases, understanding how fire affects recovery, restoration, maintenance, and resilience of ecosystems on which DoD depends will present new challenges."

H. *Assessment of Indian Forests and Forest Management in the United States* (2023)

- H1: "These tribal cultural burning efforts are being used to restore habitat for culturally important animals, fungi, and plants, which are valued as food, medicine, artisanal, and spiritual uses. In some cases, partnerships with state agencies and/or nongovernmental agencies are proving to be supportive of tribes' efforts to restore cultural burning. However, regulations and delays in receiving burn permits are hampering tribal efforts to restore landscapes and habitats for fishing, gathering, and hunting. Tribes note that the exact timing and methods of burning in one place will not necessarily work in another area."
- H2: "In contrast, wildfires and, in particular, high intensity wildfires are destroying habitat for wildlife, compromising fish habitat, and eliminating populations of culturally important plants. These high intensity fires are making it difficult for affected tribes to meet their goals with regards to fishing, gathering, and hunting. In some cases, medicinal plants have been especially adversely impacted by large wildfires. This places tribal health at risk."
- H3: "Maintenance of planning inventories and Forest Management Plans (FMPs) is not keeping up, especially regarding climate change. FMPs are not updated to include new techniques and ideas such as monitoring, climate change, forest health, modern planning techniques, carbon goals and accounting, sustained yield management practices to promote forest resilience, and new approaches for calculating the AAC…. Treatments such as hazardous fuels reduction, range/forage improvement, fuelwood gathering, food security, and carbon sequestration are not being well coordinated into forest management activities. This can lead to inefficiencies in program implementation."
- H4: "Treatments such as hazardous fuels reduction, range/forage improvement, fuelwood gathering, food security, and carbon sequestration are not being well coordinated into forest management activities. This can lead to inefficiencies in program implementation."

- H5: “During site visits there was the observation that many facilities are in poor (or even worse) condition; some at the point they may need to be condemned…. Facilities on many reservations are presently not adequate to house and provide office capacity for existing workloads and facilities throughout Indian Country need to be assessed.”
- H6: “There is an opportunity to reorient people’s perceptions around income to focus more on the generation of funds to meet more important forest management goals. For example, income generated from timber sales can be viewed as important to foster forest health, climate adaptation activities, and ecosystem restoration…. A survey of the condition of Indian forest lands, including health and productivity levels…. Forest management plans are not being updated to address current forest issues such as climate change, NTFP, forest health, and tribal objectives…. An assessment of institutional capability, staff, equipment, facilities, and organizational components necessary to support landscape scale management.”
- H7: “Unfortunately, there is consensus among tribes that tribal values, goals, and standards regarding NTFPs are often not articulated in current management plans or in cross-boundary landscape planning with neighbors. Likewise, forest and landscape management on and around tribal lands generally falls short of providing healthy, abundant populations of species important to tribes for fishing, gathering, and hunting.”
- H8: “Revise the policies surrounding non-expiring forest management plans to ensure that plans are monitored, reviewed, and updated to meet tribal priorities including the AAC (F1/F6).”
- H9: “Maintaining an active forest monitoring program that can identify when forest density and fuels conditions exceed critical levels. Update plans as necessary based on this information and implementation of treatments.”
- H10: “The impacts from Wild Horse and Burro (WHB) populations on tribal lands is of great concern to tribes across the West…. This issue has not changed over the decades, and in most cases is now getting worse. If these herds are not reduced to sustainable levels, the damage to the land may be beyond repair.”
- H11: “Secretarial Order 3372 directs all BIA Forestry units to expedite active management of forests to reduce wildfire risks, but delayed BIA approval of burn plans have been cited by a number of tribes as a primary reason they have not been able to reach targets for hazardous fuel reduction…. Specify quantitative torching and crowning targets (i.e., acceptable levels of mortality under given fire weather conditions) in all forest plans. Use these targets

systematically to identify hazardous fuel reduction treatment options and priorities."

- H12: "Train tribal staff to ensure they can serve in leadership positions within the Incident Management Teams once the delegation of authority has been passed off. Provide special training for personnel assigned as IMT leaders on tribal land to ensure consideration of tribal values and input when implementing wildfire suppression strategies…. Some tribes may also benefit from more workforce related activities such as training and development opportunities including grant management and/or various fire qualifications so that their staff can implement prescribed burn plans, forest measurements and inventory, etc."
- H13: "Cooperative agency training for managed fire program should be implemented similar to The Nature Conservancy Indigenous burning network. Cooperative burn plans need to be developed so multiple agencies can participate in prescribed burn projects."
- H14: "Poor road conditions leading to poor access and a lack of road signage can cause increased response times to wildfires while the fires grow rapidly in size…. Build additional internal capacity (work force, training, and funding) to develop plans for integrating fuels treatments into road network maintenance, harvest plans, silvicultural prescriptions, watershed and wildlife habitat protection, and recreation planning…. Remedial work included all-weather rock surfacing, grading, resurfacing, adding drainage features, cleaning/adding or replacing culverts, bridge needs or repair, cattleguard cleaning/adding or repair, and road signs throughout the reservations."
- H15: "The IFMAT IV team observed examples of regional non-profits assisting villages with securing funding through BIA programs and other sources for firewood processors, biomass heating units and training to manage wood lots for woody biomass. These same nonprofits are also assisting regional and village corporations to enter and maintain carbon projects…. Some areas have used biomass to assist in heating homes and community buildings to provide backup for high fuel costs… Extend contracting periods for the USFS and BLM to provide tribes the ability to secure long-term supply of forest harvest/biomass material."
- H16: "Develop marketing strategies for biomass products… BIA/tribes need to explore other revenue options such as carbon, biofuels, biomass use, water, wildlife, recreation, TFP (e.g., maple syrup), or other natural resource uses…. Consider an ecosystem services perspective that creates subsidies or provides offsets for improving water yield for adjacent urban communities, tap into

markets for biomass, portable sawmills, marketing, and branding opportunities that are unique to tribal enterprises."

- H17: "Coordinate development of annual plans (Task D, Task F) on each reservation for integrating all forest management activities including hazardous fuel reduction activities and creation of operational wildfire containment lines, in anticipation of future large wildfire events and the need to contain those incidents…. Review and streamline Regional Office procedures for burn plan approval implementation of prescribed fire projects and associated silvicultural prescriptions connected to planned operational wildfire containment lines."
- H18: "Coordinate development of annual plans (Task D, Task F) on each reservation for integrating all forest management activities including hazardous fuel reduction activities and creation of operational wildfire containment lines, in anticipation of future large wildfire events and the need to contain those incidents."
- H19: "Site visits to reservations in all regions indicated that the effects of climate change are already evident. In repeated cases, growing seasons are shifting, winter and/or summer temperatures are increasing, fire seasons are longer, precipitation patterns are changing, and tree species are moving higher, or farther north, potentially leaving reservations. Adaptation strategies can be threefold: (1) protect resources from climate change by promoting tree/stand resistance and resilience, (2) promote stand recovery to a prior state or condition after disturbance, or (3) actively facilitate, or accommodate, forest change towards an anticipated future, such as assisted tree migration."
- H20: "Another explanation could be that there is a broad decrease in environmental quality due to climate change, invasive species, drought, wildfire, and other changes that have decreased the effectiveness of forest management…. Tribal lands in the West continue to experience significant mortality from wildfires and other disturbances associated with drought, but typically less than neighboring non-industrial landowners; for example, National Forests currently experience 39-113% greater mortality across all regions…. In repeated cases, growing seasons are shifting, winter and/or summer temperatures are increasing, fire seasons are longer, precipitation patterns are changing, and tree species are moving higher, or farther north, potentially leaving reservations. Adaptation strategies can be threefold: (1) protect resources from climate change by promoting tree/stand resistance and resilience, (2) promote stand recovery to a prior state or condition after disturbance, or (3) actively facilitate, or accommodate, forest change towards an anticipated future, such as assisted tree migration."

- H21: “Land management organizations and agencies adjacent to tribal lands should integrate TEK and indigenous ways of knowing into their land management practices.”
- H22: “In some cases, partnerships with state agencies and/or nongovernmental agencies are proving to be supportive of tribes’ efforts to restore cultural burning. However, regulations and delays in receiving burn permits are hampering tribal efforts to restore landscapes and habitats for fishing, gathering, and hunting…. The Indigenous Peoples Burning Network is one great intertribal organization that promotes the revitalization of traditional fire practices, but more organizations are needed.”
- H23: “Managing tribal forests for forest protection, cultural, and spiritual values, continues to be more important than income for tribal members, tribal council, and natural resource managers. Tribal forest management should account for, and focus on, stakeholder values, including protection and cultural uses.”
- H24: “Tribal forest managers face immense forest health challenges following 100 years of fire suppression policies and historic fire suppression. Current Incident Management Teams (IMTs) who are generally not trained in tribal values, management, and culture are assigned to work on tribal trust lands on incidents. This is a significant issue for tribes due to the conflict between forest health, cultural and archeological sites, and wildfire suppression tactics.”
- H25: “The need for Burned Area Emergency Response (BAER) funds has increased significantly due to more frequent and larger wildfires on Indian lands. However, BAER funding is often insufficient to meet emergency needs and the policies and procedures for administering these funds are not aligned with the timing needs for project implementation. The BIA only has two BAER staff officers (H6)…. Improve the procedures for securing BAER funding and the distribution these funds to meet reforestation needs of lands damaged by wildfire.”
- H26: “Tribes report difficulty in obtaining planting stock given a surge in demand for seedlings without a corresponding investment in seed collection/storage and nursery operations. Regeneration success has fallen in the last decade due to the combination of increased weed competition from delayed planting, harsh post-fire environments, and prolonged drought associated with climate change across many regions; some tribes are testing the effectiveness of herbicides to increase regeneration success.”

Appendix B.
Federal Entities with Equity in Wildfire Science and Technology

The STPI team reviewed reports C and E to create a preliminary list of major Federal entities involved in wildfire S&T. The STPI team then modified this list with additional details as appropriate. The following organizational chart depicts major Federal entities in this field. This chart is intended to depict the breadth and complexity of Federal wildfire management, but is not intended to be a comprehensive list of all relevant entities. This chart is not proportional to the size or budget of each entity. Some offices and programs may have changed names and/or may have been discontinued since the publication of reports C and E.

Department-level Federal entities appear on the left of the chart, with relevant sub-entities on the right. Often, multiple sub-entities are nested within a single parent entity. Certain entities are intra-agency efforts, so those overlap with more than one parent entity (e.g., the Joint Chiefs Landscape Restoration Partnership is depicted as a sub-entity of both the Natural Resource Conservation Service and the U.S. Forest Service).

Table B-1. Federal Entities with Equity in Wildfire Science and Technology

USDA	Natural Resource Conservation Service			Environmental Quality Incentives Program
				Emergency Watershed Protection Program
				Joint Chiefs Landscape Restoration Partnership
	U.S. Forest Service	National Forest System		Burned Area Emergency Response
				Collaborative Forest Landscape Restoration Program
				Technology and Development Centers
				Enterprise Program
				Geospatial Technology and Applications Center
		State, Private, and Tribal Forestry	Fire and Aviation Management	National Infrared Operations
				Community Wildfire Defense Grant
				Interagency Wildland Fire Air Quality Response Program
				Hazardous Fuels
				Information Management
				Risk Management
		Research and Development	Research Stations	Wildland Fire Management Research Development & Application
				Fire Modeling Institute
				AirFire
				Forest Products Lab
				Experimental Forests and Ranges
		Business Operations		Chief Information Office
				Casualty Assistance Program
	Farm Service Agency			Emergency Forest Restoration Program
				Emergency Loan Program
				Livestock Indemnity Program
				Livestock Forage Disaster Program
				Noninsured Crop Disaster Assistance Program
				Emergency Livestock Relief Program
				Disaster Set-Aside Program
				Emergency Conservation Program
				Tree Assistance Program
				Emergency Assistance for Livestock, Honey Bees, and Farm-Raised Fish

USDA	Rural Development		Rural Development Disaster Assistance
	Risk Management Agency		Federal Crop Insurance Corporation
	Climate Hubs		
HUD	Community Development Block Grant Disaster Recovery Program		
DHS	Science and Technology Directorate		Early Fire Detection Project
			Wildland Fire Fighter Advanced Personal Protection System
	Federal Emergency Management Agency	Hazard Mitigation Assistance	Building Resilient Infrastructure and Commnunities Program
			Hazard Mitigation Grant Program
			Flood Mitigation Assistance Program
			HMGP Post-Fire Assistance Program
			Flood Mitigation Assistance Swift Current
			Pre-Disaster Mitigation Program
			Safeguarding Tomorrow Revolving Loan Fund Program
		U.S. Fire Administration	National Fire Incident Reporting System
			Fire and Emergency Services Higher Education Initiative
			National Fire Academy
		National Flood Insurance Program	
		Emergency Management Performance Grant Program	
		HAZUS Program	
		Individuals and Households Program	
		Public Assistance Program	
		Fire Management Assistance Grant	
		Integrated Public Alert and Early Warning System	
		Office of Response and Recovery	
NSF	National Center for Atmospheric Research		
DHHS	Centers for Disease Control and Prevention	National Institute for Occupational Safety and Health	Fire Fighter Fatality Investigation and Prevention Program
			National Personal Protective Technology Laboratory
	Indian Health Service	Office of Environmental Health and Engineering	Division of Environmental Health Services
	National Institutes of Health		National Institute of Environmental Health Sciences
DOE	Advanced Research Projects Agency		
	Office of Science	National Laboratories	
		Office of Biological and Environmental Research	

DOC	National Institute of Standards and Technology	Fire Risk Reduction in Communities Program				
		Fire Risk Reduction in Buildings Program				
		Disaster and Failure Studies Program				
		Fire Fighting Technology Group				
		Engineered Fire Safety Group				
		Flammability Reduction Group				
		Wildland-Urban Interface Fire Group				
	National Oceanic and Atmospheric Administration	National Environmental Satellite, Data, and Information Service				
		National Marine Fisheries Service				
		NOAA Research Laboratories				
		National Weather Service	Office of Dissemination			
			Weather Forecast Office			
			Analyze, Forecast, and Support Office			
			Environmental Modeling Center			
			Storm Prediction Center			
DOL	Office of Workers Compensation Programs	Federal Employees' Compensation Program				
	Occupational Safety and Health Administration					
Government Accountability Office						
SBA	Economic Injury Disaster Loans					
	Home Disaster Loans					
	Business Physical Disaster Loans					
Ameri-Corps	National Civilian Community Corps					
USAID	Bureau for Humanitarian Assistance					
EOP	Office of Science and Technology Policy					
	Office of Management and Budget					
NASA	Science Mission Directorate	Earth Science Division	Research and Analysis	Earth Action	Applied Sciences	Disasters Program
						Wildand Fires Program
						Climate Resilience Program
						Health and Air Quality Program

DOI	Bureau of Indian Affairs	Division of Wildland Fire Management	Wildfire Prevention Program	Youth Fire Intervention Program
				Wildfire Investigations
				Wildfire Prevention Youth Support Coalition
				Youth Fire Education
			Fuels Management Program	Hazardous Fuels Reduction Management Program
				Reserved Treaty Rights Lands Program
			Wildfire Response Program	National Aviation Office
				Hand Crews
			Post-Wildfire Recovery Program	Fire Suppression Repair
				Burned Area Emergency Response
				Emergency Stabilization
	Bureau of Land Management	BLM Fire	Fuels Management Program	
			Office of Fire and Aviation	
	Fish and Wildlife Service	Fire Management Program		
		Partners for Fish and Wildlife Program		
	National Park Service	Division of Fire and Aviation Management	Wildland Fire Program	
			Structural Fire Program	
			Aviation Program	
		Youth Conservation Corps		
	Office of Wildland Fire	Fuel Management Programs		
		Burned Area Rehabilitation		
		Preparedness		
		Suppression		
	U.S. Geological Survey	Natural Hazards Mission Area (MA)	Science Application for Risk Reduction	
			Landslide Hazards Program	
			Emergency Management Program	
			Flood Hazards Program	
		Energy and Mineral Resources MA	Mineral Resources Program	
		Ecosystems MA	Climate Research and Development Program	
			Land Management Research Program	
			Climate Adaptation Science Centers	

DOI	U.S. Geological Survey	Ecosystems MA	Species Management Research Program
			Environmental Health Program
			Biothreats and Invasive Species Program
		Water MA	Ground Water and Streamflow Information Program
			National Water Quality Program
			Water Availability and Use Science Program
		Core Science MA	National Geospatial Program
			National Land Imaging Program
			Science Synthesis, and Analysis Research Program
			Land Change Science Program
	Earth Resources Observation and Science Center		
DOD	National Geospatial-Intelligence Agency		Firefly Program
	Office of the Assistant Secretary of Defense		Environmental Security Technology Certification Program
			Strategic Environmental Research and Development Program
	Army	Army Corps of Engineers	
		Army Installation Management Command	
		Army Natural Resources Conservation	Army Wildland Fire Management
	Air Force	National Guard	FireGuard Program
		Civil Engineer Center	Environmental Directorate / Wildland Fire Branch
	Navy	Marines	
		U.S. Naval Research Laboratory	
	Defense Advanced Research Projects Agency		
EPA	Office of Research and Development	Center for Public Health and Environmental Assessment	Environmental Public Health Division
		Sustainable and Healthy Communities Research Program	
		Air, Climate, and Energy Research Program	
	Office of Air and Radiation	AirNow	
		Office of Air Quality Planning and Standards	

Appendix C.
Interagency Entities with Equity in Wildfire Science and Technology

The following charts depict major interagency efforts in wildfire S&T. These charts build upon Appendix B to demonstrate the breadth and complexity of Federal wildfire management. These charts are not proportional to the size or budget of each entity.

The parent organization name appears at the top of each chart. The next-highest organizational level appears on the left, with relevant sub-entities on the right. Often, multiple sub-entities are nested within a single parent entity.

Table C-1. Wildland Fire Mitigation and Management Commission Organizational Structure

Wildland Fire Mitigation and Management Commission			
Federal Members	Environmental Protection Agency		
	Department of Agriculture	U.S. Forest Service	
	Department of the Interior	Bureau of Indian Affairs	
		Bureau of Land Management	
		National Park Service	
		U.S. Fish and Wildlife Service	
	National Wildfire Coordinating Group		
	Department of Homeland Security	Federal Emergency Management Agency	Mitigation Framework Leadership Group
			Recovery Support Function Leadership Group
	Department of Commerce	National Institute of Standards and Technology	
		National Oceanic and Atmospheric Administration	
Non-Federal Members	State Government Representatives	Hazard Mitigation	
		Department of Natural Resources, Forestry, Agriculture, or similar state agency	
		Department of Energy or similar state agency	
		Fire Response	
	Local Government Representatives	County Government	
		Municipal Government	
	Industry Representatives	Public Utilities	
		Property Development	
		Forestry	
	Subject Matter Expertise Representatives	501(c) 3 Organization with expertise in forest management and conservation	
		Science (social and ecological)	
		Prescribed Fire	
		Health Equity	
		Forest Stewardship and Reforestation	
		Innovation	
	Tribal Government Representatives		
	National Wildland Fire Cohesive Strategy Representative		
	Wildland Firefighter Representative		

Table C-2. Wildland Fire Leadership Council

Wildland Fire Leadership Council		
Department of Agriculture	Under Secretary for Natural Resources and Environment	
	Deputy Under Secretary for Natural Resources and Environment	
	Chief of the U.S. Forest Service	
	Under Secretary of Farm Production and Conservation	
Department of the Interior	Assistant Secretary of Policy, Management and Budget	
	Director, Bureau of Indian Affairs	
	Director, Bureau of Land Management	
	Director, National Park Service	
	Director, U.S. Geological Survey	
	Director, U.S. Fish and Wildlife Service	
Department of Homeland Security	Federal Emergency Management Agency	Deputy Administrator for Resilience
		Administrator, U.S. Fire Administration
Department of Defense	Deputy Assistant Secretary of Defense for Environmental Management and Restoration	
	Deputy Assistant Secretary for Homeland Defense Integration and Defense Support of Civil Authorities	
Environmental Protection Agency	Assistant Administrator, Office of Air and Radiation	
Department of Health and Human Services	Centers for Disease Control and Prevention	Deputy Director for Non-Infectious Diseases
National Governors' Association		
Western Governors' Association		
Intertribal Timber Council		
National Association of Counties		
National League of Cities		
State forester representative		
Fire chief representative		
State emergency manager		

Table C-3. National Interagency Prescribed Fire Training Center Organizational Structure

National Interagency Prescribed Fire Training Center	
Department of Agriculture	U.S. Forest Service
Department of the Interior	U.S. Fish and Wildlife Service
Tall Timbers (non-profit organization)	

Table C-4. Interagency Council for Advancing Meteorological Services

Interagency Council for Advancing Meteorological Services			
Co-Chairs	Director of the Office of Science and Technology Policy		
	Under Secretary of Commerce for Oceans and Atmosphere		
Interagency Meteorological Coordination Office			
Committees	Observational Systems	Department of Interior	U.S. Geological Survey
		Department of Commerce	National Oceanic and Atmospheric Administration
		National Aeronautics and Space Administration	
	Cyber Facilities and Infrastructure	Department of Energy	
		Department of Commerce	National Oceanic and Atmospheric Association
			National Institute of Standards and Technology
	Services	Department of Agriculture	
		Department of Commerce	National Oceanic and Atmospheric Association
		Department of Homeland Security	Federal Emergency Management Agency
	Research and Innovation	Department of Commerce	
		Department of Defense	
		Department of Energy	
		National Aeronautics and Space Administration	

Table C-5. U.S. Group on Earth Observations Organizational Structure

U.S. Group on Earth Observations		
Co-Chairs	Office of Science and Technology Policy	
	Department of Commerce	National Oceanic and Atmospheric Association
	Department of the Interior	U.S. Geological Survey
	National Aeronautics and Space Administration	
Members	Executive Office of the President	
	Department of Agriculture	
	Department of Defense	National Geospatial Intelligence Agency
	Department of Energy	
	Department of State	
	Department of Transportation	
	Environmental Protection Agency	
	National Aeronautics and Space Administration	
	Department of Health and Human Services	National Institutes of Health
	Department of Commerce	National Oceanic and Atmospheric Association
		National Institute of Standards and Technology
	National Science Foundation	
	Smithsonian Institute	
	Department of Interior	U.S. Geological Survey
	U.S. Agency for International Development	

Table C-6. Interagency Hotshot Crews Organizational Structure

Interagency Hotshot Crews	
Department of Agriculture	U.S. Forest Service
Department of the Interior	Bureau of Indian Affairs
	Bureau of Land Management
	National Park Service
State Agencies	

Table C-7. National Wildfire Coordinating Group Organizational Structure

National Wildfire Coordinating Group		
Department of Homeland Security	Federal Emergency Management Agency	U.S. Fire Administration
Department of the Interior	Fish and Wildlife Service	
	Bureau of Indian Affairs	
	Bureau of Land Management	
	National Park Service	
	Office of Wildland Fire	
Department of Defense		
Department of Agriculture	U.S. Forest Service	Fire and Aviation Management
Department of Commerce	National Oceanic and Atmospheric Association	National Weather Service
National Aeronautics and Space Administration		
International Association of Fire Chiefs		
Intertribal Timber Council		
National Association of State Foresters		

Table C-8. Joint Fire Science Program Organizational Structure

Joint Fire Science Program	
Department of Agriculture	U.S. Forest Service
Department of the Interior	U.S. Fish and Wildlife Service
	Bureau of Indian Affairs
	Bureau of Land Management
	National Park Service
	Office of Wildland Fire
	U.S. Geological Survey

Table C-9. National Multi-Agency Coordinating Group Organizational Structure

National Multi-Agency Coordinating Group		
Department of Agriculture	U.S. Forest Service	
Department of the Interior	U.S. Geological Survey	
	Bureau of Land Management	
	National Park Service	
	Bureau of Indian Affairs	
	U.S. Fish and Wildlife Service	
Department of Homeland Security	Federal Emergency Management Agency	U.S. Fire Administration

Table C-10. Fire Executive Council Organizational Structure

Fire Executive Council		
Department of Agriculture	U.S. Forest Service	Fire and Aviation Management
Department of the Interior	Office of Wildland Fire	
	Office of Aviation Services	
	Bureau of Land Management	
	National Park Service	
	Bureau of Indian Affairs	
	U.S. Fish and Wildlife Service	
Department of Homeland Security	Federal Emergency Management Agency	U.S. Fire Administration

Table C-11. Fire Management Board Organizational Structure

Fire Management Board		
Department of Agriculture	U.S. Forest Service	Fire and Aviation Management
Department of the Interior	Office of Wildland Fire	
	Office of Aviation Services	
	Bureau of Land Management	
	National Park Service	
	Bureau of Indian Affairs	
	U.S. Fish and Wildlife Service	
Department of Homeland Security	Federal Emergency Management Agency	U.S. Fire Administration

Table C-12. Federal Fire Policy Council Organizational Structure

Federal Fire Policy Council		
Department of Agriculture	Under Secretary for National Resources and Environment	
	Chief of the U.S. Forest Service	
	Deputy Chief of State and Private Forestry	
Department of the Interior	Assistant Secretary for Policy, Management, and Budget	
	Assistant Secretary for Fish and Wildlife Parks	
	Assistant Secretary for Indian Affairs	
	Assistant Secretary for Land and Minerals Management	
	Assistant Secretary for Water and Science	
	Director, Bureau of Land Management	
	Director, U.S. Fish and Wildlife Service	
	Director, National Parks Service	
	Director, Bureau of Indian Affairs	
	Director, U.S. Geological Survey	
	Deputy Assistant Secretary - Law Enforcement, Security and Emergency Management	
Department of Homeland Security	Federal Emergency Management Agency	U.S. Fire Administration
Environmental Protection Agency		

Table C-13. Interior Fire Executive Council Organizational Structure

Interior Fire Executive Council	
Department of the Interior	Office of Wildland Fire
	Office of Aviation Services
	Bureau of Indian Affairs
	Bureau of Land Management
	U.S. Fish and Wildlife Service
	National Park Service
	U.S. Geological Survey

Table C-14. Biomass Research and Development Initiative Organizational Structure

Biomass Research and Development Initiative	
Department of Agriculture	National Institute of Food and Agriculture
Department of Energy	Office of Biomass Programs

References

American Meteorological Society. 2024. "Glossary of Meteorology." https://glossary.ametsoc.org/wiki/Pyrocumulonimbus.

California Department of Insurance. 2018. "Montecito mudslide insurance claims top $421 million." https://www.insurance.ca.gov/0400-news/0100-press-releases/2018/release033-18.cfm.

California Governor's Office of Emergency Services. 2024. "Montecito Mudslides Anniversary, Reflections Through Images." https://news.caloes.ca.gov/montecito-mudslides-anniversary-reflections-through-images/.

Department of the Interior. n.d. "DOI FIRES - Wildland Fire Jobs." https://www.firejobs.doi.gov/glossary#:~.

Kerstein, H. 2021. *Reducing the Destructiveness of Wildfires: Promoting Defensible Space in California*. The Legislative Analyst's Office. https://lao.ca.gov/reports/2021/4457/defensible-space-093021.pdf.

McQuerry, M., C. Kwon, and M. Poley-Bogan. 2023. "Female firefighters' increased risk of occupational exposure due to ill-fitting personal protective clothing." *Frontiers in Materials*. https://www.frontiersin.org/articles/10.3389/fmats.2023.1175559/full.

Mills, J. and L. Clark. 2022. "Interagency Aviation Information Bulletin." https://www.nifc.gov/sites/default/files/document-media/iaib-2022-04%20FTA%20New.pdf.

National Aeronautics and Space Administration. 2022. *NASA Science Mission Directorate (SMD) Wildfire Stakeholder Engagement Workshop: Summary and Key Findings*. https://aam-cms.marqui.tech/aam-portal-cms/assets/ki2yd52vavkccskc.

National Science and Technology Council Committee on Environment, Natural Resources, and Sustainability Subcommittee on Disaster Reduction. 2015. *Wildland Fire Science and Technology Task Force Final Report*. https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/NSTC/sdr_wildfire_st_task_force_final_report.pdf.

National Wildfire Coordinating Group. n.d. *Incident Qualifications and Certification System (IQCS)*. https://iqcsweb.nwcg.gov/incident-qualifications-and-certification-system-iqcs.

———. 2024. "NWCG Glossary of Wildland Fire, PMS 205," (*Stand replacing fire*, p. 43). https://www.nwcg.gov/node/409960.

Northwest Fire Science Consortium. 2023. *Rangeland Fire Protection Associations: An Alternative Model for Wildfire Response*. https://www.nwfirescience.org/rangeland-fire-protection-associations-alternative-model-wildfire-response.

Strategic Environmental and Research Development Program; Environmental Security Technology Certification Program. 2014. *Fire Science Strategy: Resource Conservation and Climate Change*. https://climateandsecurity.org/wp-content/uploads/2020/01/serdp_fire-science-strategy.pdf.

The Fourth Indian Forest Management Assessment Team for the Intertribal Timber Council. 2023. *Assessment of Indian Forests and Forest Management in the United States*. https://www.bia.gov/sites/default/files/media_document/ifmat_iv_report.pdf.

The President's Council of Advisors on Science and Technology. 2023. *Report to the President: Modernizing Wildland Firefighters to Protect our Firefighters*. https://www.whitehouse.gov/wp-content/uploads/2023/02/PCAST_Wildfires-Report_Feb2023.pdf.

U.S. Department of Agriculture. 2024. "Potential Operational Delineations." https://www.fs.usda.gov/research/rmrs/projects/pods.

U.S. Department of Agriculture and Department of the Interior. n.d. "IROC." https://www.wildfire.gov/application/iroc.

U.S. Department of Homeland Security. 2019. *Wildland Urban Interface Fire Operational Requirements and Capability Analysis: Report of Findings*. https://www.dhs.gov/sites/default/files/publications/wui_fire_report_of_findings_july_24_2019v2_508.pdf

U.S. Fish and Wildlife Service. n.d. "Spike camp." https://www.fws.gov/glossary/spike-camp#.

U.S. Forest Service. n.d. *Appendix K: Fire Regime and Condition Class*. https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5435658.pdf.

U.S. Geological Survey. 2022. *Research Spotlight: Vegetation Type Conversion in the Southwest—Observations and Management Takeaways*. https://www.usgs.gov/centers/werc/news/research-spotlight-vegetation-type-conversion-southwest-observations-and.

———. 2024. *Wildfire Decision Support System*. https://wfdss.usgs.gov/wfdss/WFDSS_Home.shtml.

Wildland Fire Leadership Council. 2023. *National Cohesive Wildland Fire Management Strategy Addendum Update*. https://forestsandrangelands.gov/documents/strategy/natl-cohesive-wildland-fire-mgmt-strategy-addendum-update-2023.pdf.

Wildland Fire Mitigation and Management Commission. 2023. *ON FIRE: The Report of the Wildland Fire Mitigation and Management Commission*. https://www.usda.gov/sites/default/files/documents/wfmmc-final-report-09-2023.pdf.

Abbreviations

AI	artificial intelligence
BAER	Burned Area Emergency Response
CEOS	Committee on Earth Observation Satellites
DEIA	diversity, equity, inclusion, and accessibility
DHS	Department of Homeland Security
DoD	Department of Defense
DOE	Department of Energy
DOI	Department of the Interior
DSS	Decision Support System
EOC	emergency operations center
EPA	Environmental Protection Agency
ESTCP	Environmental Security Technology Certification Program
EWS	emergency weather system
FAIR	findable, accessible, interoperable, and reproducible
FEMA	Federal Emergency Management Agency
ICQS	Incident Qualifications and Certification System
IDA	Institute for Defense Analyses
IPAWS	Integrated Public Alert & Warning System
IPT	Integrated Project Team
IROC	Interagency Resource Ordering Capability
JFSP	Joint Fire Science Program
JSON	JavaScript Object Notation
LANDFIRE	Landscape Fire and Resource Management Planning Tools
LiDAR	Light Detection and Ranging
MTBS	Monitoring Trends in Burn Severity
NASA	National Aeronautics and Space Administration
NFPA	National Fire Protection Association
NIEM	National Information Exchange Model
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NSF	National Science Foundation
NSTC	National Science and Technology Council
OGC	Open Geospatial Consortium
OSTP	Office of Science and Technology Policy
PM	particulate matter
POD	Potential Operational Delineations
PPE	personal protective equipment
RFPA	Rangeland Fire Protection Association

S&T	science and technology
SERDP	Strategic Environmental Research and Development Program
SMD	Science Mission Directorate
STPI	Science and Technology Policy Institute
TEK	traditional ecological knowledge
USDA	U.S. Department of Agriculture
USFA	U.S. Fire Administration
USFS	U.S. Forest Service
VOC	volatile organic compounds
WEA	weather emergency alerts
WFDSS	Wildland Fire Decision Support System
WFLC	Wildland Fire Leadership Council
WUI	wildland-urban interface
XML	Extensible Markup Language

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
XX-07-2024	FINAL	

4. TITLE AND SUBTITLE

Gaps, Priorities, and Entities with Equities in Wildland Fire Science and Technology

5a. CONTRACT NUMBER

NSFOIA-0408601

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Miller, Rebecca K.
Kirk, Hannah L.

5d. PROJECT NUMBER

TP-20-1005.FP

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

IDA Science and Technology Policy Institute
1701 Pennsylvania Ave., NW, Suite 500
Washington, DC 20006-5805

8. PERFORMING ORGANIZATION REPORT NUMBER

IDA Product 3002852

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Office of Science and Technology Policy
Executive Office of the President
Eisenhower Executive Office Building
1650 Pennsylvania Avenue, NW
Washington, DC 20504

10. SPONSOR/MONITOR'S ACRONYM(S)

OSTP

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The Wildland Fire Mitigation and Management Commission released a report in 2023 identifying recommendations to Congress and Federal agencies on improving wildfire management and research. Recommendation 110 from "On Fire: The Report of the Wildland Fire Mitigation and Management Commission" states that a wildfire research coordinating body should be established to identify research gaps and science priorities, drawing from a review of existing reports on known wildfire research needs. STPI was charged with identifying wildland fire science and technology gaps and priorities based on eight existing reports in anticipation of a wildland fire workshop held in June 2024.

15. SUBJECT TERMS

Wildland Fire Mitigation and Management Commission; wildfire; wildfire management; wildland fire science and technology; education and training; interagency and cross-sector coordination; practitioner-informed S&T; data management; research leadership; information at appropriate scales; diversity, equity, inclusion, and accessibility

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Ludwig, Kristin
Unclassified	Unclassified	Unclassified	Same as Report	124	19b. TELEPHONE NUMBER *(Include area code)* Kristin.A.Ludwig@ostp.eop.gov

Reset