



REPORT TO THE PRESIDENT

Modernizing Wildland Firefighting to Protect Our Firefighters

Executive Office of the President
President's Council of Advisors on
Science and Technology

February 2023



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EXECUTIVE OFFICE OF THE PRESIDENT
PRESIDENT'S COUNCIL OF ADVISORS ON SCIENCE AND TECHNOLOGY
WASHINGTON, D.C. 20502

President Joseph R. Biden, Jr.
The White House
Washington, D.C.

Dear Mr. President,

More than 100 million Americans now live in areas threatened by wildfires. The risk of catastrophic wildfires is growing at alarming rates in the West and the South, with disproportionate impacts on low-income and rural communities as well as communities of color. Your Administration has already taken important steps to prioritize community resilience to wildfires within a broader effort to prepare the American people for present and future impacts of climate change.

PCAST has sought to complement those efforts by focusing specifically on the role that science and technology can play in supporting our wildfire first-responders: the tens of thousands of state and federal wildland firefighters as well as thousands of additional local firefighters who risk their lives protecting the American people, property, and infrastructure from the devastating impacts of wildfires. With your encouragement during our meeting at the White House last summer, we have engaged extensively with dozens of wildland firefighters, from frontline hand crews and smokejumpers to incident commanders and resource allocators. Their perspectives have been complemented by discussions with subject matter experts throughout the federal government, the private sector, and academia.

Based on this outreach, we see exciting new opportunities to make the job of wildland firefighting safer and more effective. The recommendations that follow in this report highlight immediate needs that can be addressed with existing technology, and strategic, long-term investments in new science and technology to ensure that our firefighters do not have to face tomorrow's fires with yesterday's tools.

The needs of our wildland firefighters overlap substantially with those of America's warfighters. Whereas we have a national commitment ensuring that our warfighters are not sent into harm's way without the best of American science and technology at their disposal, no similar organizational framework exists to protect and empower wildland firefighters. We recommend that you establish a new joint executive office with Cabinet-delegated authorities to implement a unified S&T strategy for wildfires, similar to the joint strategies that have been achieved for national defense.

These recommendations can only deliver their full potential with your Presidential action designating a clear, empowered, and accountable leader to drive them forward throughout the federal government, e.g., via the proposed new joint-agency executive office. Our success confronting the wildfire challenge can demonstrate the possibilities enabled by science and technology to improve the lives of the American people and provide global leadership in confronting the impacts of climate change.

Sincerely,

The President's Council of Advisors on Science and Technology

The President's Council of Advisors on Science and Technology

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Executive Summary

The linchpin of our country's effort to combat wildfires is a dedicated corps of tens of thousands of state and federal wildland firefighters, who risk their lives to defend over 1.5 billion acres of fire-prone land in the United States.^{1,2} Thousands of additional local firefighters are also called upon to protect communities at the wildland urban interface,³ areas that now collectively house nearly one-third of the U.S. population.⁴ PCAST aims to identify opportunities for science and technology to make the job of wildland firefighting safer and more effective. Progress in this arena can complement and amplify actions already taken by the Biden-Harris Administration to strengthen the firefighting workforce via enhancements to job salary and classification levels⁵ and the 14% increase in wildland fire suppression and prevention funding included in the Fiscal Year (FY) 23 Omnibus Appropriations Law.⁶ Our recommendations highlight immediate needs that can be addressed with existing technology as well as strategic, long-term investments in new science and technology to ensure that our firefighters do not have to face tomorrow's fires with yesterday's tools.

Forest management and similar long-term investments in wildfire prevention are also critically essential to reducing the burden on firefighters in the future. But technology needed to improve wildfire response is ready to help today. Hence, in this report we have intentionally trained our focus on critical aspects of wildfire response that are stuck—technologically and organizationally—in the last century. Several actions recommended in this report can be taken immediately to support the needs of today's wildland firefighters and vulnerable communities nationwide, as we also pursue the longer-term actions recommended here that can ensure an enduring focus on wildland firefighting science and technology development for decades to come.

¹ National Association of State Forestry (NASF) State Forestry Statistics Survey. (2021). *State Foresters by the Numbers*. <https://www.stateforesters.org/wp-content/uploads/2022/01/2020-State-Foresters-by-the-Numbers-01272022.pdf>

² The White House. (2022, July 28). *The Biden-Harris Administration Continues Efforts to Address Growing Wildfire Threat [Fact sheet]*. <https://www.whitehouse.gov/briefing-room/statements-releases/2022/07/28/fact-sheet-the-biden-harris-administration-continues-efforts-to-address-growing-wildfire-threat/>

³ U.S. Fire Administration. (2022). *Wildland Urban Interface (WUI): A Look at Issues and Resolutions*. <https://www.usfa.fema.gov/downloads/pdf/publications/wui-issues-resolutions-report.pdf>

⁴ Radeloff, V. C., Helmers, D. P., Kramer, H. A., Mockrin, M. H., Alexandre, P. M., Bar-Massada, A., Butsic, V., Hawbaker, T. J., Martinuzzi, S., Syphard, A. D., & Stewart S. I. (2018). Rapid growth of the US wildland-urban interface raises wildfire risk. *PNAS*, 115(13), 3314–3319. <http://dx.doi.org/10.1073/pnas.1718850115>

⁵ The White House. (2022, June 21). *The Biden-Harris Administration Announces New Pay Raises & Supports for Wildland Firefighter Workforce from Bipartisan Infrastructure Law [Fact sheet]*. <https://www.whitehouse.gov/briefing-room/statements-releases/2022/06/21/fact-sheet-biden-harris-administration-announces-new-pay-raises-supports-for-wildland-firefighter-workforce-from-bipartisan-infrastructure-law/>

⁶ Committee on Appropriations, Chairman Patrick Leahy. (2022). *Fiscal Year 2023 Omnibus Appropriations Bill: Highlights*, 5. <https://www.appropriations.senate.gov/imo/media/doc/HIGHLIGHTS%20DOCUMENT%20FY%202023.pdf>

Recommendations

- **Recommendation 1: Given the vulnerabilities and shortfalls in wildland firefighter communications, connectivity, and technology interoperability, immediately assess, adapt, and field currently available technologies.** 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. U.S. Department of Agriculture (USDA) and Department of Interior (DOI) should also develop a program to begin training all federal wildland firefighters on the use of the new technologies immediately. Staff within the National Interagency Fire Center (NIFC) could lead these efforts if allocated a significant increase in their personnel and budget capacity to identify improvements in communications concepts, technology, and delivery systems to support wildland firefighter stakeholders. NIFC could lead the effort with support from National Aeronautics and Space Administration (NASA), National Oceanic and Atmospheric Administration (NOAA), Federal Communications Commission (FCC), and Federal Aviation Administration (FAA).
- **Recommendation 2: Reverse the current trend of rapidly growing wildfire suppression costs by establishing a joint-agency executive office (hereafter Joint Office) that can accelerate enterprise-level development and deployment of new technologies that enhance situational awareness and initial attack capabilities.** This Joint Office would serve to advance coordination, streamline authorities, and drive progress in enabling technology adoption across the numerous federal agencies with equities for wildland firefighting science and technology (S&T) within NIFC. It is imperative that the Joint Office leader have Cabinet-delegated decision-making authorities as well as the mandate and budget needed to develop and execute a unified technology roadmap. Once operational, the Joint Office could assume responsibility for activities in Recommendations 3 through 5 below.
- **Recommendation 3: 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.
- **Recommendation 4: Accelerate improvement of predictive wildfire modeling tools by expanding research community access to archived satellite data from defense and other government sources.** 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. 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.

- **Recommendation 5: 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. Emerging private sector efforts can be dramatically accelerated in partnership with federal agencies. One key facet of this task will be to develop a cross-jurisdictional regulatory and operations framework and concept of operations governing land access, aircraft and airspace operations, and other operational factors. We recommend that the Aeronautics Research Mission Directorate within NASA lead this effort until the Joint Office is established, in close coordination with DOI, the United States Forest Service (USFS), and the FAA. NASA could also help to develop and assess technology prototypes for eventual transition to respective organizations and industry.

Modernizing Wildland Firefighting to Protect Our Firefighters

Introduction

Wildfires are a severe and growing threat to American lives, property, and infrastructure. The confluence of a changing climate, urbanization, and constraints on forest management has added urgency to the need to enhance our strategy to address this threat. The Biden-Harris Administration has taken key steps to marshal a whole-of-government response to wildfires.^{7,8,9,10,11} These efforts have focused on protecting the communities most vulnerable to wildfires, reducing wildfire frequency and severity through more effective land management, and supporting firefighters through increased wages and additional mental and physical health resources. The Executive actions, along with historic investments made possible by the American Rescue Plan (ARP), Bipartisan Infrastructure Law (BIL), and Inflation Reduction Act (IRA), have created the foundation for what can develop into an enduring national resilience to wildfires.

To strengthen these efforts, PCAST has identified opportunities for science and technology to make the job of wildland firefighting safer and more effective. Indeed, the linchpin of our country's effort to combat wildfires is a dedicated corps of tens of thousands of state and federal wildland firefighters, who risk their lives to defend over 1.5 billion acres of fire-prone land in the United States.^{12,13} In the words of one fire chief:

“We fight fire with humans on the ground and hand tools primarily. Some are squirting water, some are swinging axes... We are nowhere near a technological solution to the human aspect... Either work on solving that at some point... or

⁷ The White House. (2022, July 28). The Biden-Harris Administration Continues Efforts to Address Growing Wildfire Threat [Fact sheet]. <https://www.whitehouse.gov/briefing-room/statements-releases/2022/07/28/fact-sheet-the-biden-harris-administration-continues-efforts-to-address-growing-wildfire-threat/>

⁸ U.S. Fire Administration. (2022). Wildland Urban Interface (WUI): A Look at Issues and Resolutions. <https://www.usfa.fema.gov/downloads/pdf/publications/wui-issues-resolutions-report.pdf>

⁹ Executive Order 14008, 86 FR 7619 “Executive Order on tackling the climate crisis at home and abroad,” (January 27, 2021). <https://www.federalregister.gov/documents/2021/02/01/2021-02177/tackling-the-climate-crisis-at-home-and-abroad>

¹⁰ White House Briefing Room. (2021). The Biden-Harris Administration Acts to Address the Growing Wildfire Threat [Fact sheet]. <https://www.whitehouse.gov/briefing-room/statements-releases/2021/06/30/fact-sheet-the-biden-harris-administration-acts-to-address-the-growing-wildfire-threat>

¹¹ White House Briefing Room. (2022). The Biden-Harris Administration Announces New Pay Raises & Supports for Wildland Firefighter Workforce From Bipartisan Infrastructure Law [Fact sheet]. <https://www.whitehouse.gov/briefing-room/statements-releases/2022/06/21/fact-sheet-biden-harris-administration-announces-new-pay-raises-supports-for-wildland-firefighter-workforce-from-bipartisan-infrastructure-law/>

¹² National Association of State Forestry (NASF) Statistics Survey. (2021). State Foresters by the Numbers. <https://www.stateforesters.org/wp-content/uploads/2022/01/2020-State-Foresters-by-the-Numbers-01272022.pdf>

¹³ The White House. (2022, July 28). The Biden-Harris Administration Continues Efforts to Address Growing Wildfire Threat [Fact sheet]. <https://www.whitehouse.gov/briefing-room/statements-releases/2022/07/28/fact-sheet-the-biden-harris-administration-continues-efforts-to-address-growing-wildfire-threat/>

focus on how you can help the tired, dirty, hungry, firefighter who's been up for 36 hours do his or her job better.”¹⁴

PCAST aims to address both immediate and long-term needs embodied in this call. In the process of developing our recommendations, we have engaged extensively with dozens of wildland firefighters, from frontline hand crews and smokejumpers to incident commanders and resource allocators. Their perspectives have been complemented by discussions with subject matter experts from state fire authorities and more than a dozen federal agencies; current and former defense and intelligence community personnel; researchers from academia and national laboratories; and additional stakeholders from philanthropic and other civilian organizations. Our recommendations highlight immediate needs that can be addressed with existing technology, and strategic, long-term investments in new science and technology to ensure that our firefighters do not have to face tomorrow's fires with yesterday's tools.

These recommendations cannot deliver their full potential without Presidential action designating a clear, empowered, and accountable leader to drive them forward. A 2015 assessment by the National Science and Technology Council (NSTC) found a “lack of coordination, collaboration, and integration of fire science and technology, both among the various producers and between the producers and the community of users.”¹⁵ We find that this is still the case, but the root of the problem runs deeper. Despite a proliferation of coordinating bodies, no single entity has successfully marshaled the diverse expertise needed across multiple agencies to address this extremely complex challenge with focus and persistence. Meanwhile, the social and economic impacts of wildfires in some parts of the United States have increased dramatically since that report. In California, for example, the eighth largest fires recorded since reliable record-keeping began in 1932 all occurred in just the last six years.¹⁶ Hence, we recommend designating a single office with a senior leader responsible for a unified course of action to identify, develop, and deploy wildland firefighting technologies across participating federal agencies.

Closing Persistent Technology Gaps for our Wildland Firefighters

“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.”¹⁷

“In many places we’re using radio systems that have been around for 50 years. There’s simple push-to-talk devices, but they’re not able to handle the large amounts of bandwidth that’s required in sharing this type of information.”¹⁷

“We’re using a resource ordering and tracking system that was developed in the 1940s and it was developed primarily to move military equipment for World War II...Every one of your cellphones sitting on your desk in front of you can

¹⁴ Porter, T. (March 20, 2019). [Breakout Session] Wildfire Technology Innovation Summit, Sacramento, CA. <https://www.youtube.com/watch?v=OA5h9Kx-3RE>

¹⁵ National Science and Technology Council. (2015). *Wildland Fire Science and Technology Task Force Final Report*, p. 13. <https://www.hsdl.org/?view&did=789991>

¹⁶ California Department of Forestry and Fire Protection. (2022). *Top 20 Largest California Wildfires*. https://www.fire.ca.gov/media/4jandlhh/top20_acres.pdf

¹⁷ Triplett, S. (2022, March 24). [Public Session] PCAST Meeting: Detecting, Tracking, Mitigating, and Preventing Wildfires, Washington D.C. <https://www.youtube.com/watch?v=nNRKDXlkqU>

*order whatever you need and have it delivered to your house tomorrow. I don't understand why as incident commanders, we can order resources and not have them be processed for two days."*¹⁸

*"We could put real-time fire perimeters—and by that I mean one minute from collection to firefighters' mobile phones—in the hands of almost every firefighter in the country right now if we pointed and wrote a few checks."*¹⁹

Recommendation 1:

Given the vulnerabilities and shortfalls in wildland firefighter communications, connectivity, and technology interoperability, immediately assess, adapt, and field currently available technologies²⁰.

The most pressing technological need for wildland firefighting is improved situational awareness on the scene of an active fire. Firefighters rely on a variety of technologies—including aircraft and satellites for real-time operations support, ground-based sensors for fire detection and monitoring, GPS and cellphone-based systems for location tracking, and radio systems for on-the-ground communications—to coordinate their response. This array of systems plays a crucial role in providing incident awareness and assessment, helping to guide operations, and ultimately keeping firefighters safe. However, situational awareness in wildland firefighting currently suffers from persistent vulnerabilities as a result of antiquated and failing infrastructure, a lack of integration/interoperability among the agencies, and outdated technologies. We found that concerns related to the lack of situational awareness were a common refrain, as reflected in the quotes above from wildland firefighters. Action to address this concern is urgently needed and is the top priority in this report.

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. Staff within the National Interagency Fire Center (NIFC) could lead these efforts if allocated a significant increase in their personnel and budget capacity to identify improvements in communications concepts, technology, and delivery systems to support wildland firefighter stakeholders. NIFC could lead the effort with support from NASA, NOAA, FCC, and FAA.

Additionally, the Office of Management and Budget (OMB) should include in the President's Budget sufficient additional funding (dedicated to wildland fire response) above current base levels to sustain these lifesaving technological improvements.

¹⁸ Gardner, D. (2022, March 24). [Public Session] PCAST Meeting: Detecting, Tracking, Mitigating, and Preventing Wildfires, Washington D.C. <https://www.youtube.com/watch?v=nNRKDXlkIqU>

¹⁹ Dargan, K. (2019, March 20). [Breakout Session] Wildfire Technology Innovation Summit, Sacramento, CA. <https://www.youtube.com/watch?v=OA5h9Kx-3RE>

²⁰ Such commercially available technologies might include temporary base stations that leverage firefighters' official or personal mobile devices; satellite internet connectivity for messaging and downloading of tactical image and other situational awareness information; and mode-translating relays (e.g., devices that can relay mobile phone signals to aerial assets).

“Technology is evolving faster than we can keep up with it.”²¹

“We’ve got so much in technology that’s coming at us, in the fire service we’ve been slow to react to that...I’ve never seen the technology like we are seeing now.”²²

“Not enough attention is being paid to those who are trying to bring awareness to new, better technology and solutions that could help keep some of these disasters from happening.”²³

Wildland firefighters such as those quoted above recognize the value that new technologies could bring for improving the safety and effectiveness of their work. 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. Their efforts are further constrained by budget structures, which specify what work they must be doing when using various funding lines, such as fire suppression or hazard reduction. As another fire chief put it:

“There’s many chief officers that don’t have the time to invest into looking at all the technology and reviewing all the products and learning about data collection...they’re looking for someone to come to them and say, ‘look this is what’s possible, we’re going to be able to provide this to you for a reasonable cost, and you can learn to do this in 30 seconds’...I think our major goal needs to be educate the fire service on what technology is available and how we can adopt that technology.”²⁵

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.

²¹ Marshall, B. (2019, March 20). [Breakout Session] Wildfire Technology Innovation Summit, Sacramento, CA. <https://www.youtube.com/watch?v=OA5h9Kx-3RE>

²² Woodbeck, B. (2019, March 20). [Breakout Session] Wildfire Technology Innovation Summit, Sacramento, CA. <https://www.youtube.com/watch?v=OA5h9Kx-3RE>

²³ Ramos, J. A. (2016). *Smokejumper: A Memoir by One of America’s Most Select Airborne Firefighters*. Mariner Books. Ch 15.

²⁴ Jontz, S. (2014, June 11). *DARPA Modifies Military Equipment to be Used by Firefighters*. Signal. AFCEA International. <https://www.afcea.org/signal-media/darpa-modifies-military-equipment-be-used-firefighters>

²⁵ Munsey, D. (Host). (2019, Jan 18). Assistant Fire Chief Dan Munsey on the Future of Fire Service Technology (No. 16) [Audio podcast episode]. Public Safety First Podcast. First Responder Network Authority. https://www.youtube.com/watch?v=nwMXBV7_2wQ

Why hasn't this already occurred given the needs expressed by wildland firefighters? We identified several barriers. Wildfire is one of the more intensively interagency environmental hazards facing the federal government. Responsibilities spanning basic research and technology development, land management, fire detection, and emergency response are scattered across roughly a dozen federal departments and agencies, including USDA (and USFS), DOC, DoD, DOE (and the National Laboratories), DOI, HHS, DHS (and FEMA), EPA, NASA, and NSF (and NCAR and UCAR). The plethora of consensus-driven coordinating bodies²⁶ that have been established over the years to foster coherence of strategy and effort have been unable to deliver the kind of enterprise-level S&T strategy that our firefighters desperately need. Each of these bodies also lacks the institutional mandate, personnel, and budget authority needed to bring new science and technology into wildland firefighting operations in a timely fashion.

NIFC is the one interagency coordinating location focused solely on firefighting operations. It is where the primary federal fire agencies—USFS, DOI and NOAA (for fire weather and environmental intelligence more broadly)—convene with state partners to coordinate firefighting efforts in real-time, something they do exceptionally well. As an entity consisting of firefighters and focused squarely on safe and effective fire operations, NIFC should be the obvious and rightful driver of improved wildland firefighting technologies across the federal firefighting force. It is, however, unable to do this in its present state for three main reasons:

- NIFC is a physical facility, not an executive body, meaning it lacks the authority to direct the actions of any agency.
- It is staffed so thinly that during peak fire season, NIFC requires a surge of temporary, loaned personnel.
- There is no dedicated funding for such activities. The USDA and DOI funds supporting NIFC are designated for either “preparedness” or “suppression.”

Because of these three barriers, NIFC lacks both the authority and the organizational capacity to drive improvements in firefighting technology and cross-agency interoperability (e.g., setting data or equipment standards) that could improve firefighter safety and effectiveness in the field.

Research over several decades^{27,28,29} suggests that investments in technology for early wildfire detection and more effective initial attack could reduce the costs of wildfire suppression—precisely the budget category that is straining forest management resources and preventing the aforementioned technology investments.

Recommendation 2:

Reverse the current trend of rapidly growing wildfire suppression costs by establishing a joint-agency executive office (hereafter Joint Office) that can accelerate enterprise-level

²⁶ These include the National Wildfire Coordinating Group (NWCG), National Interagency Fire Center (NIFC), Joint Fire Science Program (JFSP), and Wildland Fire Leadership Council (WFLC), among others.

²⁷ Steele, T.W. & Stier, J.C. (1998). An Economic Evaluation of Public and Organized Wildfire Detection in Wisconsin. *International Journal of Wildland Fire*, 8(4), 205-215. <https://doi.org/10.1071/WF9980205>

²⁸ Hirsch, K.G., Podur, J.J., Janser, R.F., McAlpine, R.S. & Martell, D.L. (2004). Productivity of Ontario Initial-Attack Fire Crews: Results of an Expert-Judgement Elicitation Study. *Canadian Journal of Forest Research*, 34(3), 705-715. <https://doi.org/10.1139/X03-237>

²⁹ Arienti, M.C., Cumming, S.G. & Boutin, S. (2006). Empirical Models of Forest Fire Initial Attack Success Probabilities: The Effects of Fuels, Anthropogenic Linear Features, Fire Weather, and Management. *Canadian Journal of Forest Research*, 36(12), 3155-3166. <https://doi.org/10.1139/X06-188>

development and deployment of new technologies that enhance situational awareness and initial attack capabilities.

To drive progress and enable technology adoption across the numerous federal agencies with wildfire equities, we recommend creation of a new Joint Office for wildland firefighting S&T. It is imperative that the Joint Office leader have Cabinet-delegated decision-making authorities as well as the mandate and budget needed to develop and execute a unified technology roadmap. Once operational, the Joint Office could assume responsibility for activities in the remaining recommendations in this report.

We further recommend the Joint Office be housed in NIFC and its senior executive have the mandate and authorities needed to develop and execute an integrated, user-centered, cross-agency roadmap for technology validation, acquisition and deployment. We believe that the end of FY 2024 is realistic target date for creation of the necessary governance structure and budget plan and is in keeping with the need for timely action to support the crucial needs of wildland firefighters. The Office of Management and Budget (OMB) should include in the President's Budget additional funding above current base levels that is sufficient to sustain activities within the Joint Office. We estimate that an annual budget of \$5 million would provide incremental full-time employees sufficient to sustain an impactful level of activity in this office. To put this sum in context, the 2022 appropriation for federal wildland fire suppression activities is \$1.01B.³⁰

Precedent for the recommended joint office structure with Cabinet-delegated, shared authorities exists, such as the joint effort between the Department of Energy and Department of Transportation to build out the nation's electric vehicle infrastructure.³¹

Creating a Comprehensive Wildland Firefighting Technology Roadmap

The technology revolution that has occurred over the last 25 years and benefitted nearly all aspects of American life should be leveraged to help wildland firefighters. There have been sporadic efforts to integrate technology into wildland firefighting to improve effectiveness and reduce risk to firefighters. Operation Firestop, a one-year pilot study in 1954, is an early example credited with adapting World War II and Korean War bombers and helicopters to deliver fire retardants, water hoses, and other equipment in support of wildland firefighting.³² Surprisingly, many of those same technologies are still in use today, despite several generations of improvement to warfighting technology since then.

On the whole, federal agencies that have been tasked with managing wildfires have not had the opportunity to take full advantage of the possibilities that technology can offer to wildland firefighting safety and effectiveness. Staff within NIFC have begun their own assessment of technologies that can modernize wildland firefighting, with a primary focus on information technologies. These include aviation coordination, satellite monitoring, integrated data services, data standards and processing, situational awareness tools, and last mile connectivity (see Figure 1). A

³⁰ 2022 Consolidated Appropriations Act, Public Law 117-103. <https://www.congress.gov/117/plaws/publ103/PLAW-117publ103.pdf>. 345.

³¹ Department of Energy. (2021, Dec. 14). *DOE and DOT Launch Joint Effort to Build Out Nationwide Electric Vehicle Charging Network*. <https://www.energy.gov/articles/doe-and-dot-launch-joint-effort-build-out-nationwide-electric-vehicle-charging-network>

³² Richardson, S. D. (1959). Operation Firestop. *Empire Forestry Review*, 38(1 (95)), 26-34. <http://www.jstor.org/stable/42600576>

more comprehensive, user-centered evaluation of this type would provide a strategic vision for development of wildland firefighting technologies within the proposed Joint Office, while also helping to guide the dramatically increasing private sector and philanthropic interest and funding directed toward wildfire S&T.

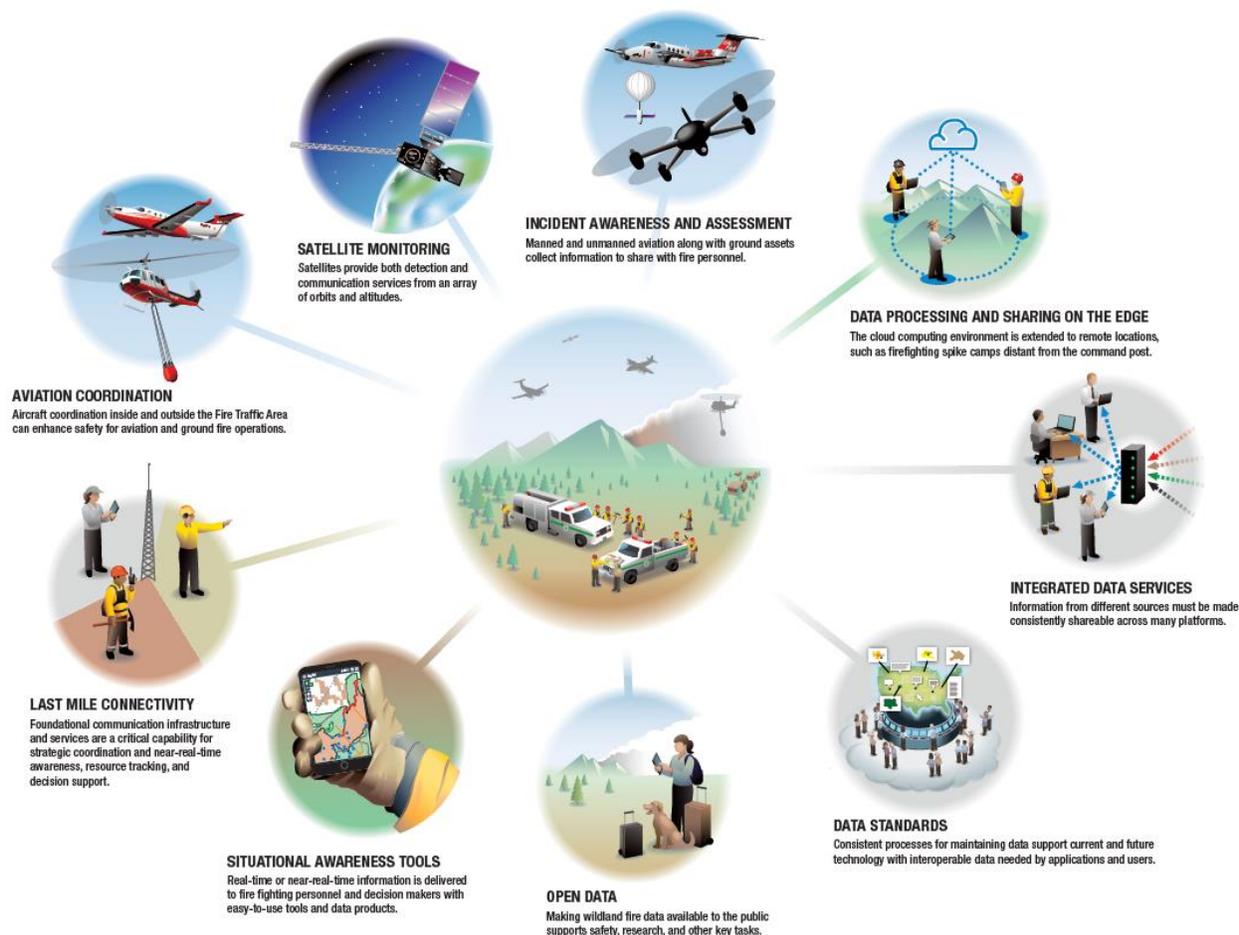


Figure 1. Schematic of key tools and technologies identified in a 2022 assessment by the USFS Wildland Fire Tools and Technology Group. Courtesy of NIFC.

Recommendation 3:

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. In addition to the information technologies described above, this broader assessment should identify existing technologies such as uncrewed aerial and ground vehicles, commercial satellite data feeds, 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 Joint Office is established. We believe it is feasible to complete the assessment by the end of FY 2024.

Defense Satellite Data for Wildfire Modeling and Prediction

“As a firefighter, understanding what a fire does—and more important, being able to predict what it’s going to do—is a matter of life and death.”³³

“If we could have that ability to monitor fires, to then forecast their growth, to then lay that on top of a data source we could share with other fire ground commanders, with other emergency responders, with other emergency managers, and most importantly, the public to make them aware there is a fire and aware of the path of that fire—it will help us make smart decisions and it will help us get people out of the way.”³⁴

“We really have to use the technology, be it artificial intelligence or machine learning,...and see where these next big large fires are going to occur.”³⁵

The ability of incident commanders to track wildfire progression relative to firefighter positions in real time has been described as the “Holy Grail of Firefighter Safety.”³⁶ Recent advances in artificial intelligence (AI) make much more accurate prediction of the future course of a wildfire a realistic possibility. These new tools require data from numerous previous fire events in diverse conditions (e.g., topography, vegetation, weather, soil moisture, and other factors) to make accurate forecasts. In the United States alone, there have been more than 1.5 million wildfires since 2000.³⁷ Tens of millions of additional wildfires have occurred outside of our country in that period. Many of these wildfire incidents—occurring in the diversity of conditions required for data-driven modeling—may have been captured incidentally by defense-related space-based assets. These assets offer more consistent coverage and substantially more frequent observations than civilian and commercial systems, resulting in a more detailed picture of a fire’s evolution. Archival defense satellite data can potentially provide the much-needed quantity and diversity of wildfire observations necessary to enable breakthroughs in wildfire modeling and prediction.

At this time, however, the data are not available to researchers (with a few exceptions) due to security classification. We can dramatically accelerate progress toward predictive wildfire modeling tools by engaging the broader community of researchers—in national labs, universities, and in the private sector—with expertise in AI, atmospheric science, remote sensing, advanced computational methods, and other disciplines central to our understanding of wildfires. By providing them access

³³ Ramos, J. A. (2016). *Smokejumper: A Memoir by One of America’s Most Select Airborne Firefighters*. Mariner Books. Ch 9.

³⁴ Gardner, D. (March 24, 2022). [Public Session] PCAST Meeting: Detecting, Tracking, Mitigating, and Preventing Wildfires, Washington, D.C. <https://www.youtube.com/watch?v=nNRKDXlkJqU>

³⁵ Martin, K. in NatureBridge. (2020, November 20). *Campfire Chat: Fighting Fire with Fire* [Video]. YouTube. <https://www.youtube.com/watch?v=osYK0vroBqM>

³⁶ Gabbert, B. (2014, July 12). *What is the Forest Service Doing About Tracking Firefighters and Fires in Real Time?* Wildfire Today. <https://wildfiretoday.com/2014/07/12/what-is-the-forest-service-doing-about-tracking-firefighters-and-fires-in-real-time/>

³⁷ Hoover, K., & Hanson, L. A. (2022). *Wildfire Statistics*. (CRS Report No. 10244). Congressional Research Service. <https://crsreports.congress.gov/product/pdf/IF/IF10244/65>

to archival space-based detections of wildfires and observations of their spread and by ensuring regular updates from new measurements, the deep and diverse pool of talented researchers across the United States could rapidly advance the state-of-the-art and realize the possibilities afforded by predictive wildfire modeling. This community is poised to use the declassified data immediately, and the federal government has recently made strategic investments in the computational infrastructure required to take full benefit from the new data streams.³⁸ The foresight provided by a reliable, “tried-and-tested” predictive capability can save lives and property by enabling better-informed decisions by incident commanders in response to active fires.

In the absence of this knowledge, firefighters and civilians face much greater risk of catastrophic loss of life and property when confronted with fast-moving wildfires. The Yarnell Hill Fire in 2013 (19 firefighter fatalities,³⁹ \$660M cost⁴⁰) and the Camp Fire in 2018 (85 civilian fatalities, \$16.6B cost⁴¹) are just two of many recent examples.

Recommendation 4:

Accelerate improvement of predictive wildfire modeling tools by expanding research community access to archived satellite data from defense and other government sources.

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. We recommend that DoD, with the support from partners in the intelligence community, NOAA, and NASA, lead a review of the classification level of the archived data.

To accomplish this, DoD, along with its partners in the intelligence community, should complete a review of the classification level of all archived space-based data likely to contain incidental wildfire observations in the defense-related archive of space-based sensors, with the intent of expanding raw data access to the research community where possible. Additionally, DoD should provide an expert technical assessment of the potential value of currently classified wildfire data for predictive modeling, as well as a technical analysis of potential risks to national security created by release of the wildfire data. The previous instances of environmental data declassification noted below lead us to believe this could reasonably be completed by the end of FY 2024.

Similar releases of previously-classified, government satellite data have taken place, from the much-praised Executive Order 12951 (1995) release of CORONA photographic images for environmental studies,⁴² to the release of data from radio-frequency and radiation sensors on Global Positioning

³⁸ See, for instance, WIFIRE. (n.d.). WIFIRE Commons. <https://wifire.ucsd.edu/commons>

³⁹ FEMA. (2023, January 10). *Yarnell, Arizona Wildfire Recovery*. <https://www.fema.gov/case-study/yarnell-arizona-wildfire-recovery>

⁴⁰ Associated Press. (December 31, 2013). Yarnell Hill Fire Damage Claims Total \$662 Million. *Arizona Capitol Times*. <https://azcapitoltimes.com/news/2013/12/31/yarnell-hill-fire-damage-claims-total-662-million>

⁴¹ Maranghides, A., Mell, W., Hawks, S., Wilson, M., Brewer, W., Vihnanek, B., & Walton, W. (2021). *A Case Study of the Camp Fire*. National Institute of Standards and Technology. <https://nvlpubs.nist.gov/nistpubs/TechnicalNotes/NIST.TN.2135.pdf>

⁴² Earth Resources Observation and Science (EROS) Center. (2018, July 13). *USGS EROS Archive - Declassified Data – Declassified Satellite Imagery-1*. United States Geological Survey. <https://www.usgs.gov/centers/eros/science/usgs-eros-archive-declassified-data-declassified-satellite-imagery-1>

System (GPS) satellites^{43,44} and, most recently, U.S. Space Command’s release of a decades-long series of meteor event detections. The Space Command’s process for release, which led soon thereafter to breakthroughs in planetary defense science⁴⁵, could be emulated for wildfire data dissemination.

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. This research can, therefore, further support proactive fuels management practices, such as prescribed burns. The incident of escaped prescribed fires in New Mexico⁴⁶ demonstrates the importance of leveraging the best tools science can offer to properly plan and execute these interventions. 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. In addition, better modeling of wildfires near the built environment can inform advance planning for evacuations, particularly of vulnerable populations within such communities. The NOAA National Centers for Environmental Information (NCEI) could be a useful platform for the sharing of data with the research community in national labs, academia, and the private sector.

In cases where the classification review determines that release of the archived raw data would represent an unacceptable risk to national security, we recommend that DoD should establish a mechanism to release technically obfuscated data in a timely fashion to the research community by the end of FY 2025.

Mechanisms of technical obfuscation of the raw data—for example, release of derived fire perimeter polygon data—have already been established to enable access by the research community as Controlled Unclassified Information (CUI). DoD should explore additional means to release archival wildfire data in formats that maximally preserve the scientific value. For example, numerous tools now exist for AI training that facilitate the use of sensitive data without compromising the original sources. Successful examples exist, e.g., in healthcare⁴⁷ and finance, that we believe demonstrate the plausibility for DOD to engage domain experts to establish this alternative data pipeline to the wider research community by the end of FY 2025.

As President Biden told a group of wildland firefighters during his visit to the National Interagency Fire Center in 2021:

⁴³ Los Alamos National Laboratory. (2021, Oct. 6). *Newly Available GPS Data Helps Scientists Better Understand Ionosphere*. <https://discover.lanl.gov/news/1006-gps-ionosphere-data/>

⁴⁴ Voosen, P. (2017, Jan. 30). Los Alamos Releases 16 Years of GPS Solar Weather Data. *Science*. <https://www.science.org/content/article/los-alamos-releases-16-years-gps-solar-weather-data>

⁴⁵ NASA. (2022, April 7). *US Space Force Releases Decades of Bolide Data to NASA for Planetary Defense Studies*. Asteroids and Comets. <https://www.jpl.nasa.gov/news/us-space-force-releases-decades-of-bolide-data-to-nasa-for-planetary-defense-studies>

⁴⁶ United States Forest Service. (2022). *Gallinas-Las Dispensas Prescribed Fire Declared Wildfire Review*. https://sourcenm.com/wp-content/uploads/2022/06/Las-Dispensas-Review_Final_6_19_22-508.pdf

⁴⁷ Kaissis, G.A., Makowski, M.R., Rückert, D., Braren, R. F. (2020). Secure, Privacy-Preserving and Federated Machine Learning in Medical Imaging. *Nature Machine Intelligence*, 2, 305–311. <https://doi.org/10.1038/s42256-020-0186-1>

“We have a commitment at the Department of Defense to defend home, as well as abroad, and that includes the fire service.”⁴⁸

The Biden-Harris Administration has already acted on this commitment by providing DoD aircraft and personnel to support wildfire detection and monitoring, as well as firefighting operations. The present recommendation of wider satellite data access represents a potentially transformative opportunity to use archival defense-related wildfire observations to do even more to keep firefighters safe on the front lines.

Enabling Technologies for Next-Generation Wildland Firefighting

“The technology is there. The challenge is educating fire staff and the powers-that-be that UAVs [uncrewed aerial vehicles] are a tool that will increase safety and save money.”⁴⁹

“In the fire service, we’ve been waiting for this [UAV] application for quite a while. Frankly, this is a very safe and effective means of being able to do that transmission of the gear, the water that firefighters need.”⁵⁰

“There’s going to be a lot more use of drones in the future for the fire service, and that’s driven by efficiency...Being able to deploy drones on dispatch to get out and give us situational awareness to be able to modify alarms are things that we’re gonna see in the future.”⁵¹

Technological advances in uncrewed aerial vehicles and other autonomous systems can increase protections for wildland firefighters and expand our nation’s wildfire response capacity. The threat posed by the current trend toward larger and more severe wildfires⁵² is exacerbated by firefighter staffing shortages at state and federal levels. Already in 2021, large proportions of requests for wildland firefighting resources went unfilled, including 40% of requests for hand crews, 29% of requests for fire engines, 30% of requests for tactical water tenders⁵³, and 35% of the nearly 40,000 requests for auxiliary support personnel.⁵⁴ While 2021 was an historically active fire season, it is essential that we prepare for the potential that future fire seasons could be even more challenging.

⁴⁸ The White House. (2021, Sept. 13.). *Remarks by President Biden in Briefing with Federal and State Fire Agency Officials*. <https://www.whitehouse.gov/briefing-room/speeches-remarks/2021/09/13/remarks-by-president-biden-in-briefing-with-federal-and-state-fire-agency-officials/>

⁴⁹ Ramos, J. A. (2016) *Smokejumper: A Memoir by One of America’s Most Select Airborne Firefighters*. Mariner Books.

⁵⁰ Munsey, D. (2022, May 4). [Public comments]. Unpiloted Aerial Vehicle Demonstration. San Bernardino, CA.

⁵¹ Munsey, D. (Host). (2019, Jan 18). Assistant Fire Chief Dan Munsey on the Future of Fire Service Technology (No. 16) [Audio podcast episode]. Public Safety First Podcast. First Responder Network Authority. https://www.youtube.com/watch?v=nwMXBV7_2wQ

⁵² Iglesias, V., Balch, J.K., & Travis, W.R. (2022) U.S. Fires Became Larger, More Frequent, and More Widespread in the 2000s. *Science Advances*, 8(11), eabc0020. <https://doi.org/10.1126/sciadv.abc0020>

⁵³ Vehicles that are specifically designed for bringing suppressants to fire engines in the field

⁵⁴ National Interagency Coordination Center. (2021). *Resource Activity Charts and Tables*. https://www.predictiveservices.nifc.gov/intelligence/2021_statsumm/resource_charts_tables21.pdf

Recent actions by the Biden-Harris Administration have increased federal firefighter pay,⁵⁵ and FY 2023 appropriation legislation⁵⁶ could help attract and retain firefighters; however, the demand for firefighting resources may continue to outstrip the supply. To adequately prepare for long-term workforce needs, the federal government should develop new technologies for enhancing the reach and capacity of our wildland firefighting forces. 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.

DoD possesses deep expertise in drones, robotics, and other relevant technologies, but the present application to domestic wildland firefighting calls for leadership from a civilian agency. The Joint Office proposed in this report's second recommendation could steward this type of activity once it is established. Given the urgency of the wildfire threat, an existing agency should be designated interim leader and charged with driving immediate progress.

The question then is which of the many civilian agencies with wildfire equities is best-suited for this interim role. We assess that NASA is uniquely capable of achieving real-world, field demonstrations of new wildland firefighting technologies that combine remote sensing, environmental modeling, and robotics. NASA has a long legacy of working with frontline firefighters to pioneer and deploy new tools that improve the safety of firefighting, beginning more than 50 years ago in a collaboration with the International Association of Fire Fighters (IAFF) aimed at developing more effective fire protection suits.⁵⁹ Today, the Aeronautics Research Mission Directorate in NASA is actively developing tools needed to support the use of uncrewed aerial systems (UAS) for wildfire response.⁶⁰

Recommendation 5:

Expand our nation's wildfire response capacity by encouraging development and field demonstration of prototype autonomous detection, assessment, and containment systems for wildland fire.

⁵⁵ The White House. (2022, June 21). *The Biden-Harris Administration Announces New Pay Raises & Supports for Wildland Firefighter Workforce from Bipartisan Infrastructure Law [Fact sheet]*.

<https://www.whitehouse.gov/briefing-room/statements-releases/2022/06/21/fact-sheet-biden-harris-administration-announces-new-pay-raises-supports-for-wildland-firefighter-workforce-from-bipartisan-infrastructure-law/>

⁵⁶ 2023 Consolidated Appropriations Act, Public Law 117-328. H.R. 5631 - 117th Congress (2021-2022): Tim Hart Wildland Firefighter Classification and Pay Parity Act.

⁵⁷ DARPA News. (2022, Feb. 8). *ALIAS Equipped Black Hawk Helicopter Completes First Uninhabited Flight*. <https://www.darpa.mil/news-events/2022-02-08>

⁵⁸ Zhou, X., Wen, X., Wang, Z., Gao, Y., Li, H., Wang, Q., Yang, T., Lu, H., Cao, Y., Xu, C., & Gao, F. (2022). Swarm of Micro Flying Robots in the Wild. *Science Robotics*, 7(66), eabm5954. <https://doi.org/10.1126/scirobotics.abm5954>

⁵⁹ International Association of Fire Fighters. (2003, Oct. 13). *Project Heroes: Homeland Emergency Response Operational and Equipment Systems*. <https://www.cdc.gov/niosh/npptl/pdfs/ProjectHEROES-508.pdf>

⁶⁰ Kopardekar, P., & Grindle, L. (2021). *NASA ARMD Wildfire Management Workshop*. NASA. https://www.nasa.gov/sites/default/files/atoms/files/nasa_armd_wildfire_management_workshop_6.1.2021_v13.pdf

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. Emerging private sector efforts can be dramatically accelerated in partnership with federal agencies. One key facet of this task will be to develop a cross-jurisdictional regulatory and operations framework and concept of operations governing land access, aircraft and airspace operations, and other operational factors. We recommend that the Aeronautics Research Mission Directorate within NASA lead this effort until the Joint Office is established, in close coordination with the DOI, the USFS, and the FAA. NASA could also help to develop and assess technology prototypes for eventual transition to respective organizations and industry.

We believe that the enabling technology and cross-jurisdictional regulatory frameworks for these field demonstrations can be realized by the end of FY 2027. The Director of OMB should identify additional funding required to implement this approach, including additional personnel and training resources.

This federal effort toward autonomous wildland firefighting can also leverage emerging private sector initiatives toward the same goal. For example, the XPRIZE Foundation is a non-profit organization that has previously sponsored prizes to spur progress on significant societal challenges such as human spaceflight and carbon removal. The \$10 million XPRIZE for private spaceflight, launched in 1996, is credited with helping to create⁶¹ the multi-billion-dollar industry that is now led by U.S.-based companies such as Blue Origin, SpaceX, and Virgin Galactic. Planning is underway for a \$15 million prize that will source teams to develop integrated systems that can autonomously detect, assess, and suppress potentially catastrophic wildfires quickly.⁶² An ongoing collaboration with the State of California aims to ensure that these new technologies can protect vulnerable communities and infrastructure throughout the state.⁶³ Coordination between the lead federal agencies and private sector efforts to spur technology innovation, such as the XPRIZE, can ensure that private sector efforts are effectively aimed toward known vulnerabilities in wildfire response and can facilitate effective dissemination of new technologies to wildland firefighters throughout the country, e.g., via NIFC. These tools can support our nation's firefighters both in suppressing unplanned fires and controlling the prescribed burns they conduct to reduce fuels and foster greater wildfire resilience.

⁶¹ NASA. (2010) *Ansari X-Prize: A Brief History and Background*. <https://history.nasa.gov/x-prize.htm>

⁶² XPRIZE Foundation. (n.d.). *XPRIZE Wildfire: Executive summary*. https://assets-us-01.kc-usercontent.com/5cb25086-82d2-4c89-94f0-8450813a0fd3/066a7a7b-5e5b-4e8b-9660-ceaf7168a7b1/XPWILDFIRE_ExecSumm.pdf

⁶³ Office of the Governor. (2019, October 26). *Governor Newsom Announces New Partnerships and Tools to Help California's Most Vulnerable Residents During Power Shutoffs*. <https://www.gov.ca.gov/2019/10/26/governor-newsom-announces-new-partnerships-and-tools-to-help-californias-most-vulnerable-residents-during-power-shutoffs>

Conclusion

“We have fewer available humans to fight fire effectively than we have in the past, and we get stretched. How do we extend a human’s efficacy?”⁶⁴

“Our resources are becoming tired, they’re getting overworked, and it’s a very extensive physical toll on our firefighters, our population.”⁶⁵

“[W]e have a problem in the West and we need help. Tracking resources, monitoring fires, predicting spread, and notifying people. It’ll help us stay safer. It’ll help us keep our responders safer and it’ll help us keep our public safer.”⁶⁶

Implementing the recommendations in this report will leverage our nation’s leading science and technology to better protect wildland firefighters and to modernize our wildfire response enterprise, including the tools used to combat fires and the organizations that develop and deploy those tools. We fully recognize the importance of forest management and similar long-term investments in wildfire prevention, but observe that those activities have received greater attention and investment than new technology development for wildfire response. For example, the recently-passed Inflation Reduction Act provides more than \$2 billion in funding for forest management and wildfire fuels reduction, but no funding for improving wildland firefighting tools and technologies.⁶⁷ A similar differential exists between funds for wildfire prevention and wildfire response technologies in FY 2022 and FY 2023 appropriations.^{68,69}

Hence, in this report we have intentionally trained our focus on critical aspects of wildfire response that are stuck—technologically and organizationally—in the last century. The actions recommended in this report include measures that can be taken immediately to support the technology needs of today’s wildland firefighters. These recommendations also propose efforts for establishing the infrastructure needed to ensure wildland firefighting continues to benefit from advances in science and technology for decades to come. The technological advances spurred by Presidential action on these recommendations can make wildland firefighting safer and more effective, while also addressing growing shortages of firefighting resources. Finally, though these recommendations focus on wildfires, they may also serve as a blueprint to similarly leverage current and future S&T for the broader range of climate resilience challenges that our country faces, such as drought, flooding, heat waves, and severe storms.

⁶⁴ Porter, T. (2019, March 20). [Breakout Session] Wildfire Technology Innovation Summit, Sacramento, CA. <https://www.youtube.com/watch?v=OA5h9Kx-3RE>

⁶⁵ Triplett, S. (2022, March 24). [Public Session] PCAST Meeting: Detecting, Tracking, Mitigating, and Preventing Wildfires, Washington D.C. <https://www.youtube.com/watch?v=nNRKDXlkJqU>

⁶⁶ Gardner, D. (2022, March 24). [Public Session] PCAST Meeting: Detecting, Tracking, Mitigating, and Preventing Wildfires, Washington D.C. <https://www.youtube.com/watch?v=nNRKDXlkJqU>

⁶⁷ Public Law 117-169, <https://www.congress.gov/bill/117th-congress/house-bill/5376>

⁶⁸ Public Law 117-103, <https://www.congress.gov/117/plaws/publ103/PLAW-117publ103.pdf>

⁶⁹ 2023 Consolidated Appropriations Act, Public Law 117-328.

<https://www.congress.gov/117/bills/hr2617/BILLS-117hr2617enr.pdf>

Acknowledgments

The members of PCAST wish to thank the staff in the Office of Science and Technology Policy (OSTP) for their various contributions throughout the preparation of this report. PCAST would like to thank Alondra Nelson, Deputy Assistant to the President, formerly Performing the Duties of Director of the White House Office of Science and Technology Policy. PCAST also expresses its gratitude to Marc Aidinoff, Kei Koizumi, and Asad Ramzanali in OSTP. We especially thank the IDA Science and Technology Policy Institute (STPI) team, especially Chris Cannizzaro, Matthew Ishimaru, Emily Grumbling, Todd Ringler, and Gifford Wong, for assistance with analyses and the report. Finally, we wish to express a heartfelt thanks to the staff at the Department of Energy, particularly Karen Talamini, who have worked tirelessly in administering PCAST.

Appendix A. External Experts Consulted

PCAST sought input from a diverse group of additional experts and stakeholders. PCAST expresses its gratitude to those listed here who shared their expertise. They did not review drafts of the report, and their willingness to engage with PCAST on specific points does not imply endorsement of the views expressed herein. Responsibility for the opinions, findings, and recommendations in this report and for any errors of fact or interpretation rests solely with PCAST.

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