

An aerial photograph of a forest during a prescribed burn. The trees are mostly dark green and brown, with some bright orange and red foliage. Thick white smoke rises from the ground, partially obscuring the trees. The overall scene is dramatic and captures the intensity of the controlled fire.

Beyond the Burn

**How New Technologies Can Grow
the Use of Prescribed Burns,
Creating Better Land Outcomes,
Peace of Mind, and New Markets**

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PRELUDE

2023: The Summer of our Wildfire Discontent

Unsounded alarms. Uncontrolled wildfires from Maui to the Maritimes, in Europe, and beyond. Lost lives, destroyed habitat and property, crushed communities. Hazardous air quality stifling Chicago, New York, Washington DC, and cities across the once spared Midwest and East Coast. On top of this, if wildfires were a country, their carbon emissions would rank fourth in the world, behind China, the US, and India. And if wildfires were a war, we would never put our first responders in harm's way without adequate technology, tools, and automation. In this paper, we show that the world is about to change, zooming in on prescribed burns – a critically important but underutilized fire prevention strategy and describing how policy, technology, and investment can help grow its use. Stay tuned for more.

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Sounding The Alarm

Orange skylines, smoke-tinged air, emergency “go bags” packed—these are becoming all too familiar as extreme wildfires become regular occurrences amid the climate crisis. Today, we are living through Canada’s worst fire season in modern history, which has burned nearly 60 million acres and released 335 megatonnes of carbon dioxide emissions to date,¹ with hundreds of fires still burning. As more than 1,000 blazes actively burned in Canada, the deadliest US fire in a century ripped through the island of Maui. As news of the destruction and loss of life in the Lahaina community emerged and hit the world stage, much like Paradise, California in 2018, it portended a harrowing and painful harbinger of what a potential future with increasingly destructive fires looks like, particularly for those located in the high-risk urban-wildland interface. New research has found that air pollution, like the sustained

exposure to wildfire smoke seen in recent years, is the greatest external threat to life expectancy on this planet.² The need to prevent catastrophic wildfires has never been so urgent, and expanding the use of prescribed burns, which have been used by Indigenous Tribes for millennia to manage fire-prone landscapes, will play a central role. While the ecological and wildfire mitigation benefits of prescribed burns are widely recognized, there are several challenges preventing their widespread adoption, from the fear of a fire escaping and causing a wildfire to limited workforce capacity and limited weather windows when it is safe to burn. This paper highlights how new technologies in wildfire mitigation, vegetation management, and forestry can help overcome these barriers, and explores how a variety of innovative funding models could be harnessed to scale the ability to use prescribed burns safely and effectively in the future.



The need to prevent catastrophic wildfires has never been so urgent

We Didn't Start The Fire...And That is a Problem

When European settlers arrived in North America, they saw what they thought was a pristine, untouched wilderness.³ What they didn't realize was that much of the American landscape had been shaped by Indigenous Tribes, who, combined with lightning strikes, had been setting fires for millennia to help manage the landscape to keep forests and grasslands healthy and resilient. Beginning in the late 1800s through most of the 20th century, US federal fire policy shifted course and instead viewed fire as a destructive force, calling for total fire suppression to protect communities, watersheds, and timber resources.⁴ By 1935, the US Forest Service established its infamous "10 am Policy," requiring that all fires be suppressed by 10 am the day after they were first reported.⁵ It wasn't until the 1970s when scientific consensus began to emerge that fire plays an important role in forest ecology, and that by eliminating all fires, we had disrupted the natural regenerative cycle of the ecosystem, allowed forests to become overcrowded, and enabled an extremely dangerous buildup of fuel for wildfires.⁶ 100 years ago,

forests in California had about 60 trees per acre, whereas, today, there are nearly 170.⁷ When this increased tree density and fuel

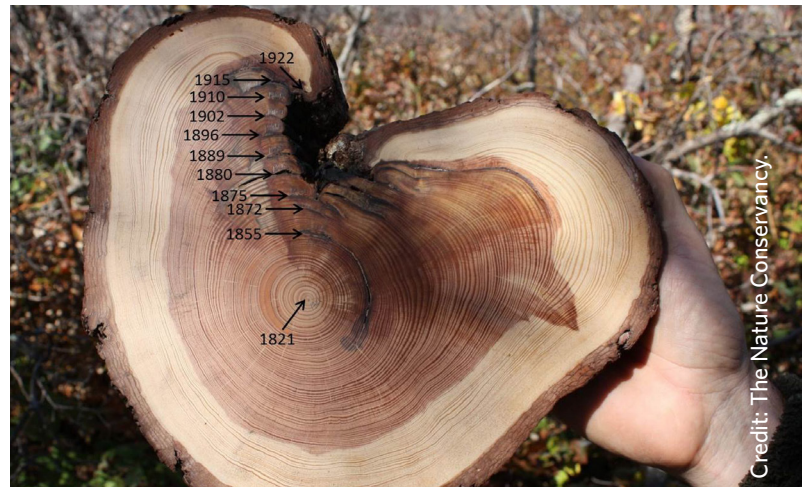


FIGURE 1: Tree rings showing regular fires until 1922.



FIGURE 2: Prescribed Burn in Plumas County, CA, 2023.

buildup are combined with the warming climate and dryer landscapes, anytime a fire breaks out, a much higher risk exists that the wildfire will become catastrophic. We are experiencing this intensity today, with five of the ten worst wildfires in US history occurring in the last decade.⁸

Today, it is widely agreed that we not only need to reduce fuels through vegetation management, but that we also need to reintroduce fire into the landscape through intentionally set, low-intensity fires—known as prescribed or controlled burns—so that we can both reduce wildfire fuel and restore landscapes to improve biodiversity, soil carbon sequestration, and overall resiliency. Slowly, over the past few decades, prescribed burns have become more widely adopted across the US. And yet, experts say the urgency of the climate crisis requires a massive increase in the number of burns performed each year, particularly in the

West, where there is the highest risk of catastrophic wildfires and where millions of people live adjacent to forests in the wildland-urban interface.^{9,10} To confront the wildfire crisis, we need an all-hands-on-deck approach, harnessing tools and innovations to not only suppress uncontrollable fires rapidly, but also to conduct proactive and restorative measures, like prescribed burns, safely. While prescribed burns go according to plan over 99% of the time, there have been incidents where prescribed burns escaped and caused wildfires, such as how an uncontained prescribed burn triggered the largest wildfire in New Mexico's history in 2022.¹¹ Fortunately, there are new emerging technologies available to help grow the use of prescribed burns and prevent them from going out of control, along with innovative funding models to help catalyze a new market for increasing burns.



We not only need to reduce fuels through vegetation management; we also need to reintroduce fire into the landscape

Fighting (Catastrophic) Fire with (Prescribed) Fire

Better Ecological Outcomes

At least half of the world’s landscapes are “fire adapted,” meaning they need regular fire to stay healthy and resilient.¹² In North America, fire-adapted ecosystems range from the boreal forests across Canada and the conifer forests of the Sierra Nevada to the grasslands of the Great Plains and the longleaf pine forests in the Southeast. In these fire-dependent landscapes, prescribed burns have been shown to

increase biodiversity, maintain healthy natural habitats for plants and animals, improve forage for cattle, prevent invasive or non-native species and pests, and improve soil health, which improves carbon sequestration.¹³ As an example, California’s giant sequoias need fire to reproduce. Fires help dry out their cones and release seeds, create ideal growth conditions by returning nutrients to the soil through ash, and increase sunlight exposure by removing

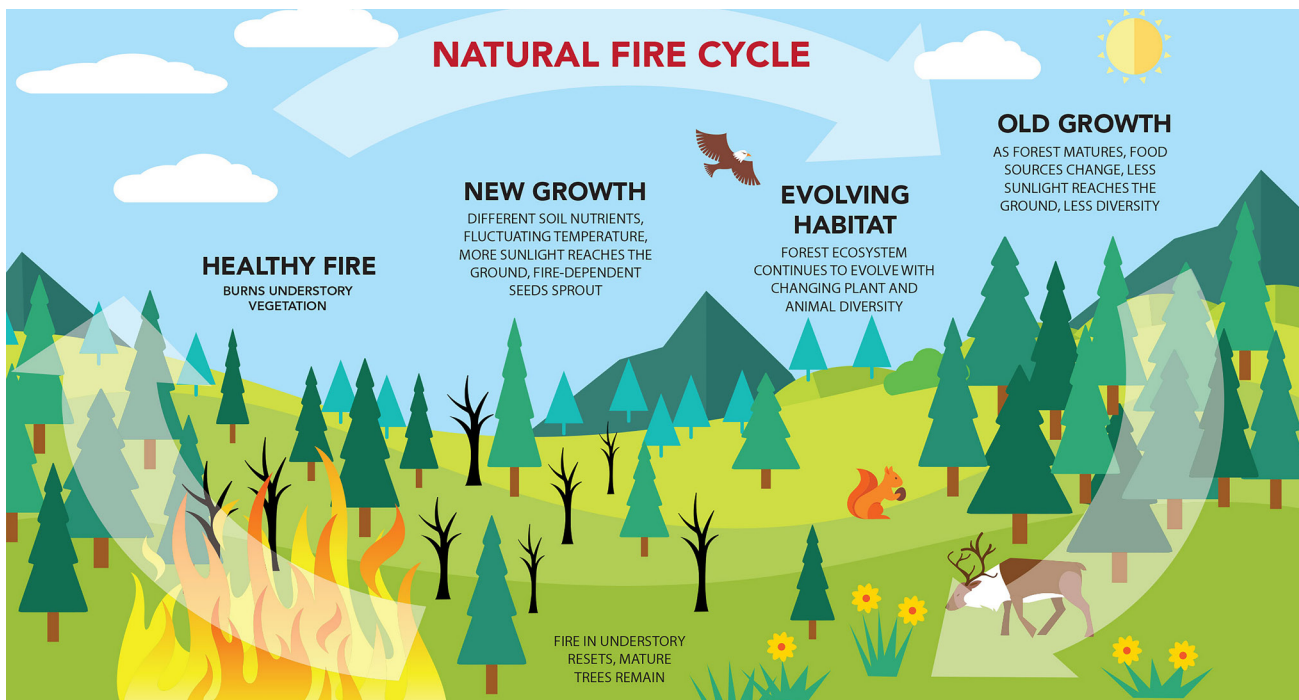


FIGURE 3: Natural Fire Cycle. Credit: Open Space Authority Santa Clara Valley.



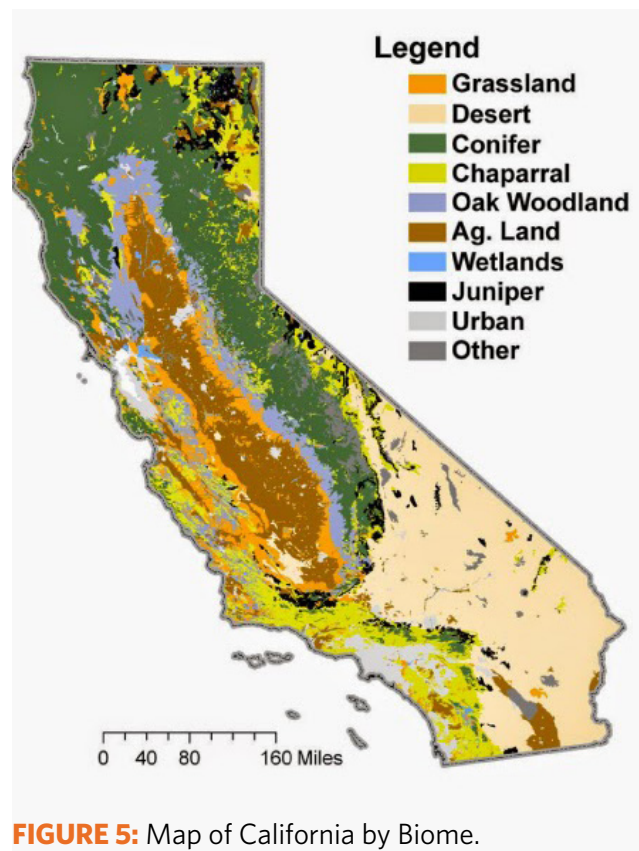
Credit: Lenya Quinn-Davidson.

FIGURE 4: A prescribed burn in Humboldt County, CA was used to halt a woody encroachment and maintain grasslands. The picture on the right is seven months after a burn in Fall 2018.

competing trees.¹⁴ On grasslands, prescribed burns warm up the soil, increasing microbial activity that releases nutrients that new grasses and flowers need to grow. Healthy grasslands provide food for wildlife and nutritious forage for livestock, with grazing animals naturally attracted to the lush re-growth. Indigenous Tribes have recognized these ecological benefits for thousands of years, using prescribed burns to clear the land for agriculture, attract game for hunting, clear brush for ease of travel, and promote the growth of food sources and basketry materials.¹⁵

Granted, not all landscapes are suitable for prescribed burns and the technique should not be used indiscriminately. For example, the story is a little different in coastal southern California where the landscape is dominated by native chaparral shrublands that ignite easily, burn intensely, and spread rapidly. According to the California Chaparral Institute, overly frequent fires of chaparral can kill the shrub and promote the growth of non-native species which are less fire-resilient.¹⁶ The National Park Service, which is responsible for much of

the Santa Monica Mountains, does not carry out prescribed burning there, explaining that burns would not fill ecological needs in chaparral or coastal sage scrub and would increase the probability of a damaging wildfire.¹⁷ However, in some chaparral regions, prescribed burns are performed to build fuel breaks; these are conducted during the wet season when soil and fuel



Credit: California Chaparral Blog.

FIGURE 5: Map of California by Biome.

moisture levels are higher to keep the fire's intensity low.^{18,19}

Better Catastrophic Wildfire Mitigation

In addition to the numerous ecological benefits prescribed burns offer fire-adapted landscapes, prescribed burns are also an essential tool to reduce the risk of catastrophic wildfires. Strategic controlled burns decrease the amount of fuel sources available in a fire and prevent the growth of invasive or non-native species, which are often less fire-tolerant. For instance, regular prescribed burns in forests help ensure enough space between mature trees and limit fuel such that if a wildfire occurs, it only burns the surrounding brush and tree bases but does not extend up the tree's canopy. When fires rise into the canopy, the fire spreads rapidly to nearby trees at a much higher intensity. As seen in Figures 6 and 7, the 2021 Bootleg Fire in Oregon visibly demonstrated the effectiveness of prescribed burns in limiting wildfire spread and damage, with areas treated

with prescribed burns by the US Forest Service and Klamath Tribes surviving the wildfire significantly better than areas with only thinning or no treatment. The Bootleg Fire burned over 400,000 acres in an area experiencing extreme drought, and over two-thirds of the fire's footprint burned at high severity with very few, if any, living trees remaining.²⁰

Better Carbon Outcomes

Reducing catastrophic wildfires has never been more urgent than today amid the climate crisis, with wildfires serving as a massive driver of carbon emissions. A 2022 UCLA study estimated that the 2020 wildfire season in California emitted twice as many greenhouse gas emissions as the state had reduced between 2003 to 2019, effectively erasing two decades of Californians' hard work decarbonizing the power, transport, and industrial sectors in a single year of wildfires.²¹ Recent estimates suggest that if wildfires were a country, they would be the world's fourth largest emitter —meaning total emissions from global wildfires are larger

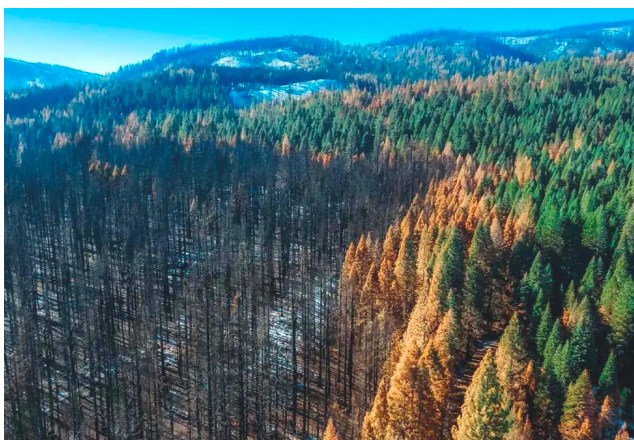


FIGURE 6: Where treated forests in Oregon stopped the Bootleg Fire. Credit: Stanford Law School and Bezos Earth Fund, Measuring the Carbon (and Other) Benefits of Climate-Smart Forestry Practices.



FIGURE 7: Fremont-Winema National Forest After the 2021 Bootleg Fire. Credit: Klamath Tribes Natural Resources Department.

than the national emissions of every other country except China, the US, and India.²²

While prescribed burns do emit some greenhouse gas emissions and cause smoke pollution, by helping to prevent catastrophic wildfires, they can avoid millions of tons of carbon from being released from trees and soil. Forests in the US are removing and storing nearly 800 million tons of carbon dioxide per year, the equivalent of around 15% of US emissions.²³ Unfortunately, status quo forest management practices are leading to fires that cancel out much of this climate-friendly carbon storage each year. The California Air Resources Board estimates that the 2020 wildfire season alone emitted a record-breaking 107 million tons of carbon dioxide.²⁴ Through August 2023, the ravaging Canadian wildfires released the equivalent of 1.1 billion tons of carbon dioxide.²⁵ Though this trend is discouraging, other research shows that prescribed burns

can reduce these massive carbon emission events. A 2010 study by Northern Arizona University found that widespread prescribed burns could reduce carbon emissions in the US West by an average of 18 to 25 percent, and as much as 60 percent in certain forests.²⁶

As reporting and measurement protocols for the impacts of wildfire on forest carbon improve, the case for prescribed burns will continue to be strengthened. In July 2023, Stanford Law School and the Bezos Earth Fund published a report authored by David J. Hayes, former Special Assistant to President Biden on Climate Policy, on the carbon benefits of climate-smart forestry tools including prescribed burns. The report called for a more robust and routine accounting of the carbon benefits from prescribed fire to help better inform governments on the value of such mitigation efforts.²⁷ The benefits extend beyond carbon emissions, as shown

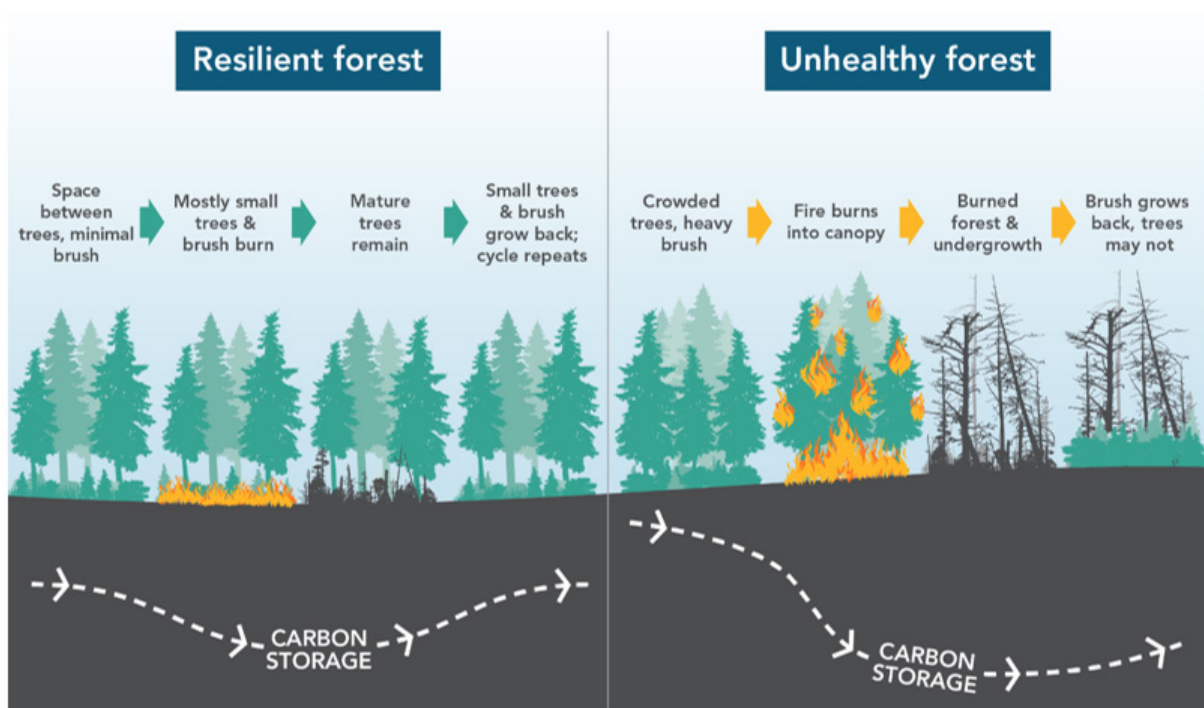


FIGURE 8: Resilient Forests vs Unhealthy Forests During a Wildfire. Credit: California Air Resources Board.

by a 2021 EPA Study, which concluded that prescribed burns can not only reduce the size and emission of future wildfires, but also lessen smoke-related public health impacts.²⁸

Lower and Avoided Costs

In addition to their ecological, carbon, and risk mitigation benefits, prescribed burns are one of the most affordable forms of fuel management, costing significantly less than mechanical thinning or mastication (i.e., crushing or chopping fuels), with the exact cost depending on a variety of factors such as location, season, size, fuel type, and existence of fire breaks. The US Forest Service estimates that a prescribed burn costs the agency around \$1,000 per acre, on average.²⁹ In contrast, it can cost up to \$7,000 to clear an acre of land using a bulldozer in heavily forested areas without any of the additional ecological and land restoration benefits that prescribed burns provide.³⁰ In fact, using heavy machinery like bulldozers or excavators for fuel management can actually cause ecological harm, disrupting topsoil, interrupting the water cycle, causing soil erosion, and releasing stored carbon.³¹

In addition to the cost advantages relative to other fuel management practices, prescribed burns could avoid a portion of the massive spending that goes toward suppressing fires that go out of control every year. In the US, total spending on fire suppression by federal agencies has more than tripled over the last decade to about \$2.5 billion per year. These costs do not capture the broader economic losses generated by wildfires – including structures destroyed or damaged, forgone

tax revenues, depressed housing prices, and evacuation costs, which research has estimated can range from \$37 billion to \$88 billion annually (in 2020 dollars).³² Further analysis by the Moore Foundation estimated the net economic, fiscal, and environmental costs of wildfires in the State of California over the period 2017-2021 at \$117.4B in average annual losses.³³ In contrast, in 2020, the federal government spent \$194 million on “hazardous fuels/fuels management” on federal land and \$545 million on “other Forest Service wildfire appropriations,” both of which include prescribed burning.³⁴ Of the 2.65 million acres of National Forest Land that the Forest Service treated to mitigate wildfire risk that year, around 44% were treated with prescribed burns.³⁵ In a simulation study, researchers showed that enacting an optimal treatment plan, which includes prescribed burns, had the potential to reduce spending on fire suppression by more than five times, with the cost of prevention and suppression combined in a prevention management case costing less than half the cost of suppression alone in a no prevention management case.³⁶

Policymakers Taking Action

Fortunately, over the last few years, policies and programs recognizing the benefits of prescribed burns have increased significantly. For example, at the federal level, the 2021 Bipartisan Infrastructure Law and 2022 Inflation Reduction Act together allocated nearly \$7 billion in funding to reduce hazardous wildfire fuels through practices like prescribed burns. In 2022, California’s Wildfire and Forest Resilience Task Force released its first Strategic Plan for Expanding the Use of

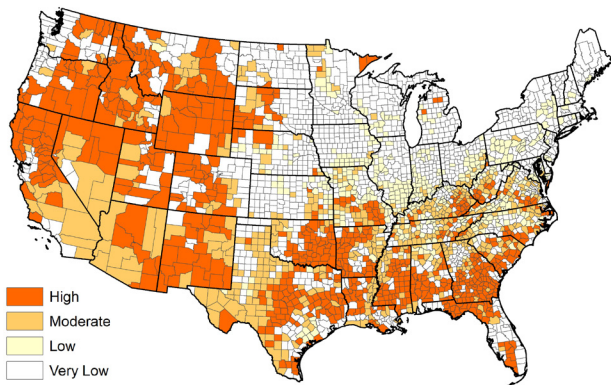


FIGURE 9: Map of national priorities for broad scale fuels management utilizing a mix of options including prescribed burns, 2014. Credit: USDA, DOI, The National Strategy, 2014.

Beneficial Fire. The fire management practices of Indigenous people have increasingly been recognized by fire experts, nonprofits, and policy experts. For example, the Indigenous Peoples Burning Network was formed in 2015 by the Yurok, Hoopa, and Karuk Tribes, and supported by The Nature Conservancy, with the aim of revitalizing cultural burns in Native communities. Similarly, the Cultural Fire Management Council has brought back cultural burning on the Yurok Reservation and ancestral lands.³⁷ In California, tribes are also partnering with federal, state, and local agencies, such as the Forest Service and Cal Fire to share their Traditional Ecological Knowledge and Indigenous expertise with prescribed fire practitioners.³⁸

While policy support is mounting for the use of prescribed burns, this is not to say it is met without challenges. In an autumn irony, one California tribe, the Karuk Tribe, believed so deeply in the value of prescribed fire that they sponsored a state bill (SB-310) that would encourage its use. The problem? In September, the Tribe leaders were busy dealing with an uncontained wildfire burning

through its lands in Siskiyou County where they live, pulling attention away from getting the bill through its legislative steps with the Natural Resources Agency and others, while facing pressure from air pollution officials who opposed the bill.

Increasing the use of prescribed fire is an emerging area of focus for policymakers and government officials. In June, California’s congressional delegation wrote to the US EPA asking for looser standards for particulate matter in order to enable more prescribed fire.³⁹ The Biden administration is also advocating for the use of more prescribed fire. Following a two-year process and the selection of over 50 federal, state, local, and tribal officials, the Wildland Fire Mitigation and Management Commission submitted to Congress one of the most sweeping and comprehensive reviews of the wildfire system to date. The report identified over 148 recommendations and seven key themes. One of the key themes was “enabling beneficial fire to reduce the risk of catastrophic wildfire.”



Over the last few years, policies and programs recognizing the benefits of prescribed burns have increased significantly

The State of Prescribed Burns Today

While 9.4 million acres of forestry and rangeland were treated with prescribed burns across the US in 2020,⁴⁰ over 460 million acres still remain at moderate to very high risk of wildfires, due to a combination of accumulating fuels, a warming climate, and expanding development in fire-prone landscapes. More fuel management practices and prescribed burns are needed in order to address the hazardous level of fuel buildup today, particularly in the highest-risk areas affecting communities in the wildland-urban interface in the West.

Of the 9.4 million acres burned in 2020, only a third were in the West, with the majority taking place in the Southeast. Florida leads the nation with around 2 million acres burned each year, while California burned only around 125,000 acres last year,⁴¹ despite state estimates that around 30 million acres need some kind of fuel reduction.⁴² While burns are less challenging in Florida where it is flat, humid, and surrounded by water, its burn-friendly policies have solidified the state as a national leader in prescribed burns. Landowners and agencies have been conducting burns in Florida for decades, driven in part by landmark legislation

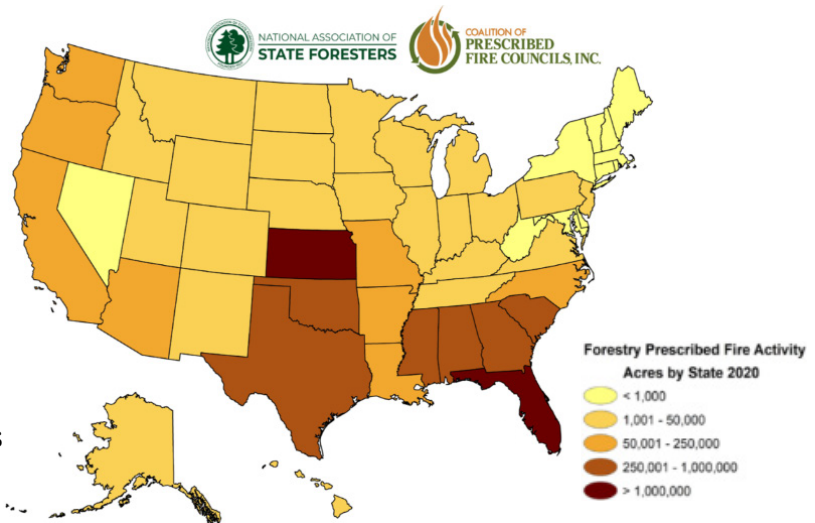


FIGURE 10: Prescribed Fire Activity by State, 2020. Credit: 2021 National Prescribed Fire Use Survey Report.

in 1990 that protected responsible burners from civil liability with the goal of increasing the acreage treated with prescribed burns.⁴³ Moreover, Florida is a leader in prescribed burn infrastructure, opening the nation's first Prescribed Fire Training Center in 1998.⁴⁴ By contrast, California's Governor signed a bill to create the state's first prescribed fire training center in 2021.⁴⁵

Over 80% of prescribed burns across the US are conducted on state or privately-owned land, with the remaining share on federal land (see Figure 11).⁴⁶ As the US Forest Service implements its 10-year wildfire strategy, it is likely that the share of burns on federal lands will gradually

PRESCRIBED BURNS BY LAND OWNERSHIP TODAY

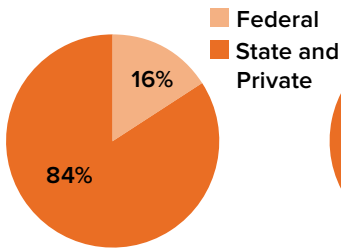


FIGURE 11: Credit: 2021 National Prescribed Fire Use Survey Report.

PRESCRIBED BURNS BY LAND OWNERSHIP IN 10 YEARS

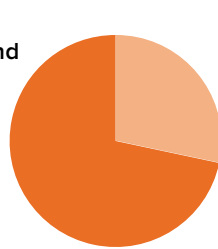


FIGURE 12: The USFS's 10-year wildfire crisis strategy will likely increase the share of burns on federal lands.

increase (see Figure 12*), along with the size of burns conducted, in order to address the significant backlog. In California, Cal Fire and the US Forest Service are responsible for nearly all prescribed burns by acreage across all private, state, Tribal, and federal lands in the state, with the Forest Service treating around 55% of the 80,000 acres burned in 2021, and Cal Fire treating the remaining 45% (see Figure 13). Private landowners can either partner with Cal Fire,

contract a private, state-certified prescribed fire “burn boss” (who plans, obtains permits, and performs the burn), or conduct the burn themselves after obtaining approval from Cal Fire if the burn occurs in fire season.⁴⁷ State agencies partner with Cal Fire, while federal agencies, which own nearly half of California’s land and nearly 60% of all Californian forest land, conduct burns with their own trained personnel.⁴⁸

Prescribed burns performed by private landowners tend to be small, at less than 100 acres, while the Forest Service, Department of Interior, Cal Fire, and other federal and state agencies can conduct larger burns that can exceed 1,000 acres. Today, most burns are small, with nearly 70% of burns in the West occurring on less than 10 acres (see Figure 14). Going forward, as more federal funding and resources are allocated to prescribed fires to address the massive backlog and fuel buildup, larger burns by the Forest Service and Department of Interior will emerge. For instance, the

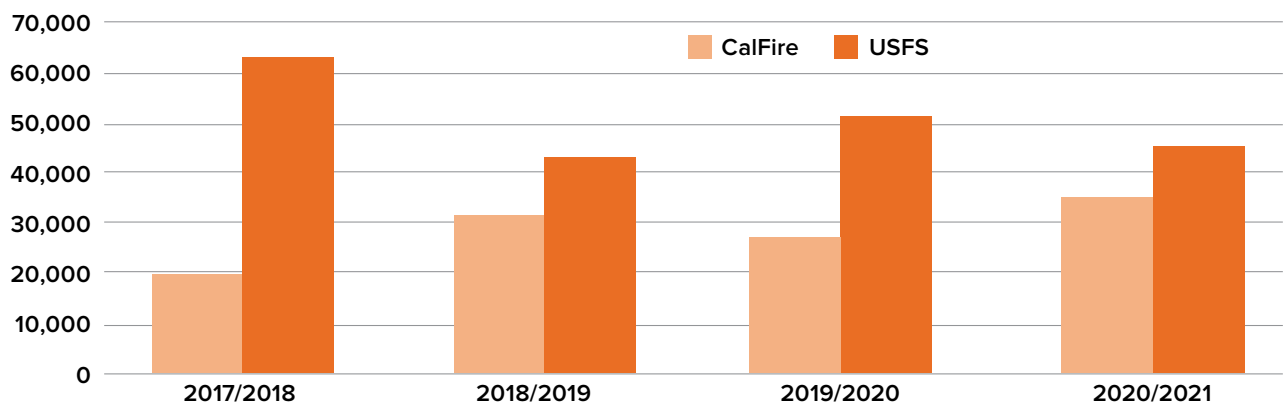


FIGURE 13: California Prescribed Fire Acreage Treated. Credit: California's Strategic Plan for Extending the Use of Beneficial Fire, 2022.

* This figure is for illustrative purposes only. Given that the US Forest Service has received billions of dollars in funding to meet its 10-year wildfire mitigation strategy across 20 million acres of National Forest System Land and 30 million acres of federal, state, private, and Tribal lands, the share of burns on federal lands will likely increase.

Forest Service identified 50 million acres of key “fire sheds” in the West where a wildfire would be most likely to expose homes, communities, and infrastructure to wildfire—i.e., the wildland-urban interface. Over the next decade, it will prioritize fuel treatment on 20 million acres of Forest Service land and 30 million acres of federal, state, and Tribal lands (see Figure 15).⁴⁹

Burns led by private landowners and burn bosses are often performed through Prescribed Burn Associations (PBAs) in which community members pool labor,

equipment, and expertise to carry out burns. PBAs are largely staffed with volunteers using drip torches. Costs include permits, fees for burn planning and a certified burn boss, and volunteer fire department stipends. For example, burns by the PBA in Humboldt County, CA range from \$450 to \$2,500 per day.⁵⁰ In contrast, large federal and state prescribed burns are backed by agency funding and are more heavily resourced, with fire engines and crews. Sometimes helicopters or drones help with ignition across very large landscapes or in terrain that is difficult to access by foot.

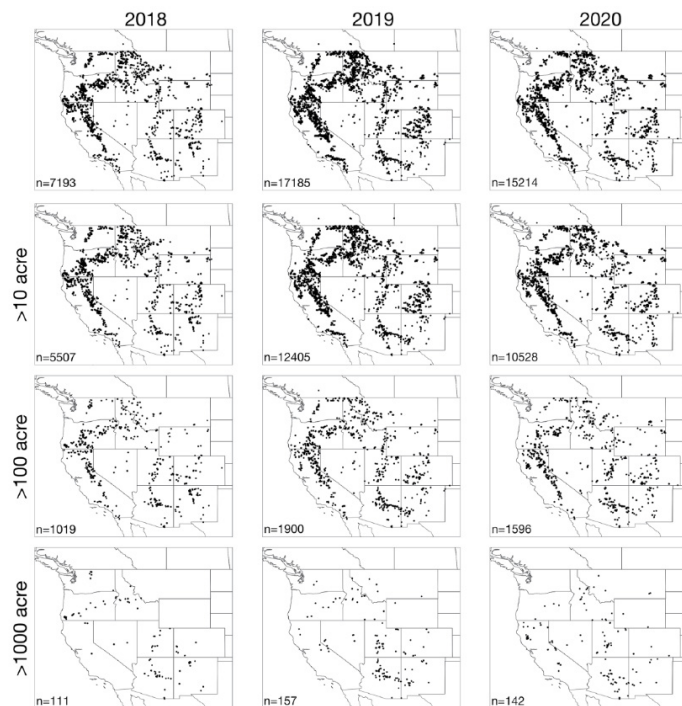


FIGURE 14: Prescribed Burns in the West 2018-2020 reported to National Fire Plan Operations and Reporting System. Credit: Kelp et al., Prescribed Burns as a Tool to Mitigate Future Wildfire Smoke Exposure, 2023.

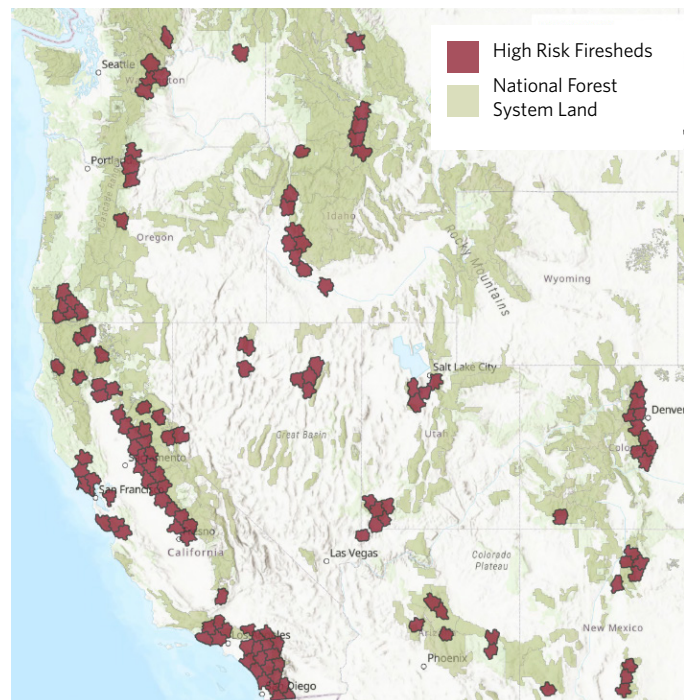
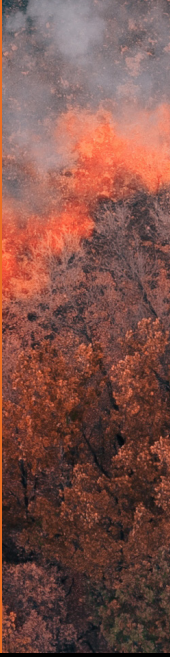


FIGURE 15: USFS Designated High-Risk Firesheds, 2022. Community exposure is a central factor in the strategy to confront the wildfire crisis. Other factors include Tribal and State plans, watersheds, equity, climate forecasts, and partner priorities Credit: USFS, Confronting the Wildfire Crisis, January 2022.

Under Fire: The Challenges of Growing the Use of Prescribed Burns



Despite the ecological, climate, wildfire mitigation, and cost advantages of prescribed burns and the recognized urgency to expand their use, several key challenges exist which prevent the widespread adoption of prescribed burns.

Fear of an escape:

In April 2022, a prescribed burn by the US Forest Service in New Mexico that was meant to cover 2,500 acres escaped and caused the largest wildfire in the state's history, consuming over 300,000 acres.⁵¹ In response, Forest Service Chief Randy Moore announced a 90-day moratorium on prescribed burn operations across all National Forest System Lands, despite acknowledging that 99.84% of prescribed burns go according to plan.⁵²

Government agencies and private landowners alike are concerned about the liability risks associated with prescribed burns, leading to stringent risk mitigation protocols and hesitancy among landowners

to perform prescribed burns on their property. To combat this, several states have adopted legislation that protects burners from civil liability unless it can be proven that they acted with gross negligence. As mentioned above, Florida has had this policy in place since the 1990s, and California recently passed a similar law in 2022.⁵³ California also is trying to encourage more burning by establishing in 2023 the state's first-of-its-kind \$20 million Prescribed Fire Liability Claims Fund to cover losses in case a burn causes damage. The fund insulates private landowners against a lack of liability insurance by providing up to \$2 million for burns led by qualified burn bosses or cultural practitioners.⁵⁴ While this is a step in the right direction, a \$20 million dollar fund with \$2 million in coverage is only a fraction of the potential liability of a large fire. This small pilot is meant to be a proof of concept that could make the case for a much larger facility. For context, following the escaped New Mexico fire, Congress set aside nearly \$4 billion to pay

claims that are estimated to take over half a decade to fulfill.⁵⁵

In addition to liability risk, federal and state agencies are also fearful of the public backlash that results from escaped burns or any associated damages. Residents and state officials in New Mexico were livid once it was determined the wildfire was caused by a prescribed burn. A year later, New Mexico's Governor signed legislation to prohibit prescribed burns during periods of increased fire risk.⁵⁶ In October 2022, an Oregon-based US Forest Service employee was arrested by the local County Sheriff for reckless burning while conducting a prescribed burn, drawing national media attention and a public protest of the arrest from the Forest Service chief, Randy Moore.⁵⁷ Prescribed burns have also drawn scrutiny and backlash from certain environmental advocacy and non-profit groups. In Calaveras Big Trees State Park, home to over 1,000 giant sequoias, a prescribed burn in Fall 2022 scorched a pair of sequoias known as the "Orphans" over 100 feet up their trunks, burning so intensely that one of them is likely to have died.⁵⁸ As a result, the local community founded a new environmental nonprofit Save Calaveras Big Trees, with the goal of getting park officials to bring in more firefighting infrastructure to support the use of prescribed burns. These incidents are not only devastating for the communities and landscapes affected, but also make it even more difficult for federal and state agencies to garner public

support for the aggressive ramping up of prescribed burn activity. Even without escapes, agencies still experience backlash from community members, particularly in more urban areas where burns are less common, as people are anxious about the fire spreading and the temporary smoke pollution.

Few burn days worsened by regulatory hurdles

Windows when it is permitted to conduct prescribed burns, especially in the West, are few and far between, and these windows are shrinking amid a warming climate, contributing to the backlog of burns. In high-risk areas, only a few weeks in the fall and spring qualify when it is neither too wet nor too dry with the right wind conditions to safely perform a prescribed burn. Air quality regulations also act as a constraint, with burns near urban areas often getting canceled if air pollution levels are too high that day. The permitting process to get approval for a prescribed burn in some states can be cumbersome, particularly for infrequent burners or newcomers. For instance, in California multiple permits are needed, including: a burn permit from Cal Fire during the fire season, an air quality permit from the local Air Quality District, and approval under the National Environmental Policy Act (NEPA). While risk mitigation is important, overly complex permitting processes can introduce costs, bureaucracy, and delays, preventing prescribed burns

from happening during the limited burn windows and discouraging landowners from carrying out burns. On the other end of the spectrum, around twenty states recognize a “right to burn,” with no formal permitting process for low-risk burns to encourage landowners to use prescribed burns (see Figure 16).

Limited trained workforce

Another significant challenge for expanding prescribed burns is the limited availability of trained personnel to carry out the burns. Each prescribed burn is led by a qualified burn boss who is responsible for writing the burn plan, obtaining permits from air quality regulators or other agencies, notifying officials and nearby communities, coordinating with weather forecasts, and obtaining all qualified personnel and equipment.⁵⁹ In addition to the burn boss, other professionals often required include

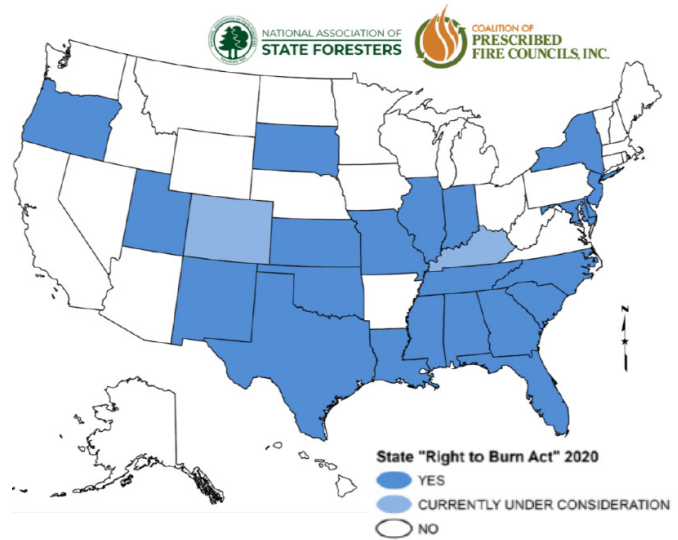


FIGURE 16: States which have or are considering a "Right to Burn Act" as of 2021, which grants landowners the legal right to burn on their land. Credit: 2021 National Prescribed Fire Use Survey Report.

ignition crews who apply fire to the ground, holding crew who keep the fire within the control lines, and fire effects monitors who track the weather conditions and fire behavior.⁶⁰ One of the most labor-intensive and costly steps of conducting prescribed



FIGURE 17: Prescribed Burn in Plumas County, CA, February 2023. Credit: Andrea Dunlap.



FIGURE 18: Prescribed burn in Sonoma County, CA, June 2023. Credit: Andrea Dunlap.

burns is during preparation—in particular, building the critical control lines which maintain the edge of the burn. If natural control lines such as a road or water body are absent, the vegetation must be manually dug up. In dense forest landscapes, it is also important to perform tree thinning beforehand to remove lower tree branches or overgrowth below trees to reduce the chance of fire moving up “fuel ladders” and igniting the tree canopy.

In 2021, Cal Fire issued a curriculum for certifying private burn bosses.⁶¹ As of July 2023, only 21 State-Certified Prescribed Fire Burn Bosses possess an active certification in California that allows them to plan

and manage prescribed burns on private lands.⁶² To help train prescribed burn crews, initiatives including the nationwide Prescribed Fire Training Exchanges (“TRES”), established in 2008, are beginning to build local prescribed fire capacity. In 2019, TRES programs trained over 500 people across the US.⁶³ Shortages at the federal level persist, with the Forest Service flagging in its wildfire strategy that the Forest Service needs to “build workforce capacity to accomplish fuels and forest health treatments [in the West] at the necessary pace and scale.”⁶⁴ Longer fire seasons compound the problem, as fewer firefighters are available to help with prescribed burns.

Bringing Wildfire Technology Into the 21st Century

Given the urgency of the wildfire crisis, we need to use all available tools to help overcome barriers and expand the use of prescribed burns. We need a combination of innovative policymaking, technologies, and funding models. This section will highlight how new technologies can help.

One example is **Rain***, which is working to adapt autonomous aircraft with wildfire intelligence to rapidly perceive, understand, and suppress wildfire ignitions in a rapid way. Rain's wildfire intelligence system for autonomous aircraft unlocks the ability to preposition many aircraft in high wildfire risk areas to significantly reduce response time to suppress fires when they are first detected, before they grow out of control. Designed to integrate with existing firefighting aircraft to enable remote human command and supervision of fast and effective autonomous wildfire containment missions, wildfire response times can be reduced to under 10 minutes from the moment of ignition, significantly increasing the successful containment of nascent wildfires. Rain also offers

fire intelligence and AI to support rapid, enhanced, and iterative decision-making during active wildfires. Rain's helicopters are equipped with cameras, sensors, software, and onboard communications hardware that can transmit back real-time fire imagery and analytics every second to an incident commander located miles, or even cities away. In October, Rain announced a collaboration with Sikorsky, a Lockheed Martin company. The partnership will leverage autonomous flight technology



"Prepositioned, autonomous helicopters can provide a suppression capacity should a prescribed fire grow out of control"

– Max Brodie, CEO and Co-Founder of Rain

FIGURE 19: Rain's Black Hawk Automated Helicopter. Credit: Rain.

* A DBL portfolio company

developed by Sikorsky over the last dozen years and Rain’s unique Wildfire Mission Autonomy kit to demonstrate the use of an uncrewed Black Hawk helicopter to drop water on wildfires within minutes of detection.

In addition to helping contain and suppress wildfires before they get out of control, Rain’s helicopters and capabilities could be utilized for year-round wildfire mitigation efforts and hazard support in prescribed burn settings. For example, Rain’s CEO and Co-Founder Max Brodie explains how the company’s “prepositioned, autonomous helicopters can provide a suppression capacity should a prescribed fire grow out of control, which can help to relax other weather and environmental constraints.” Moreover, Rain’s technology could bring significant peace of mind to agencies and landowners knowing that Rain-equipped helicopters could be instantly deployed to suppress any spot fires outside a prescribed burn’s control lines, protecting nearby communities and assets while reducing their liability risks. Similarly, if community

members learn that prescribed burns in their region are backed by Rain’s advanced technology on adapted military helicopters, they would likely be less concerned about the historical risk profile of prescribed burn projects. With less public resistance toward burns, federal and state agencies may be able to increase their use of prescribed burns with less friction.

Rain could also provide prescribed burn projects with real-time intelligence on the fire’s behavior and weather conditions, helping burn bosses make informed decisions and potentially lowering risk levels sufficiently such that burn windows can be expanded. An internal review of the causes of the escaped burn in New Mexico found that fire managers had not sufficiently understood how dry the conditions were as nearby automated weather stations were offline, leaving personnel to rely only on “local expertise” to assess the wind conditions.⁶⁵ Another set of tools, that pair with Rain-equipped helicopters, are AI-enabled early detection sensors. These include cameras with



FIGURE 20: Cal Fire helicopter using a heli-torch to ignite a prescribed burn in the Rogue River-Siskiyou National Forest. Credit: KTVL 10, 2019.

BEYOND THE BURN

algorithmic smoke detection capabilities, like **Pano.AI** and **Alchera**, as well as chemical-based smoke sensors like **N5 Sensors**. Several of these early detection tools are already integrated with Rain's onboard flight system to allow for immediate dispatch to a specific longitude and latitude of a suspected wildfire. These cameras and sensors, along with the onboard cameras in the Rain helicopter, could also be used in the prescribed burn scenarios to monitor the size and growth of the prescribed fire, as well as detect spot fires that occur outside of the control area.

Rain-equipped helicopters could also help with igniting burns more efficiently than the current practice of sending crews with drip torches on foot: this would expand the acreage of burns on the limited burn days available while reducing the human effort needed. Helicopters are already used by agencies today on prescribed

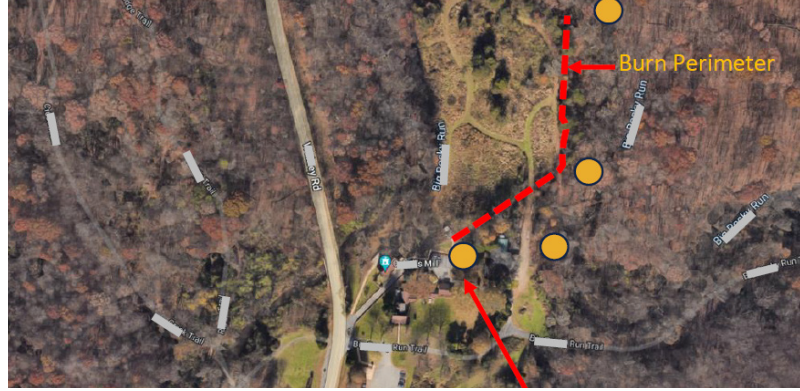


FIGURE 21: A burn plot with N5 sensors placed around the perimeter to monitor the fire and provide real-time fire data. Credit: N5 Sensors.

burns for igniting large areas or difficult-to-reach terrains, either by a “heli-torch” which is a large napalm-fueled torch, or by dropping incendiary balls that ignite shortly after being dropped. Rain can offer these same tools but eliminate the need for risking crews’ lives. This is important, as crews often must fly at dangerously low altitudes to perform ignitions. In 2019, a helicopter crashed into trees while igniting a prescribed burn in Texas, fatally injuring a Forest Service crew member.⁶⁶

Rain is not alone in bringing cutting-edge aerial technologies to fire management. **Drone Amplified** is a company that is pioneering the use of drones for aerial ignition, with its **IGNIS** technology equipping drones with ping pong ball-sized incendiary balls, offering similar benefits to manned helicopter aerial ignition but at a lower cost and without risking helicopter crews’ lives. Their drones also have infrared sensors and cameras that allow them to fly in smoky conditions or at night, expanding burn windows. **IGNIS** is already being used today by the Forest Service and Department of Interior on both active wildfires, where they set off backburns to help build defensive lines in rugged hard-to-reach terrains, as well as on prescribed burns for



FIGURE 22: A drone equipped with **IGNIS** incendiary balls. Credit: Drone Amplified.

ignition and monitoring. **Parallel Flight Technologies** is a company designing drone platforms that can be used in firefighting, from aerial ignition to spot fire suppression. Last year, the Forest Service created the Unmanned Aerial System Aerial Ignition Academy as it works to expand its use of drones in fire settings.⁶⁷

BurnBot is a company that makes prescribed burn machines that integrate ignition, containment, smoke management, and mop-up (i.e., extinguishing) into a controlled system that is then towed over landscapes to maximize fuel reduction safely while regenerating the land and recycling nutrients back into the soil. BurnBot's machines burn only the land directly below them, enabling them to burn areas close to houses or high-value assets with little to no risk of the fire escaping, alleviating concerns around liability and backlash. Similar to the peace of mind provided by Rain helicopters, BurnBot also offers the opportunity to expand burn windows by virtue of its enhanced containment measures. BurnBot's enclosed chamber also creates less smoke, reducing its impact on local air quality, which could potentially unlock more permitted burn days from local air quality regulators.

Several companies are innovating in tree thinning, which is an important and labor-intensive preparation step for prescribed burns in overgrown forests, as it reduces the risk of the fire growing too intense from too much fuel. For example, **Kodama Systems** is a company working to accelerate forest



FIGURE 23: BurnBot's prescribed burn machine. Credit: PG&E.

thinning treatments by using automated machinery to make the process faster and cheaper, and then burying the biomass byproduct, which if implemented correctly can ensure the carbon already captured in tree thinning is not returned to the atmosphere.⁶⁸ **AirForestry** is using drones to perform the thinning and then transport the wood to the nearest road.⁶⁹ **Earth Force** is automating forestry and vegetation management through remotely-operated machinery and in-field sensors.⁷⁰ While tree thinning is an important component of fuel management, following it with prescribed burns in fire-adapted landscapes can reap the ecological benefits and restore the landscape's overall health and resiliency. Reducing the labor intensity of this important preparation step could help lower costs and shift the human effort needed to conduct more burns.

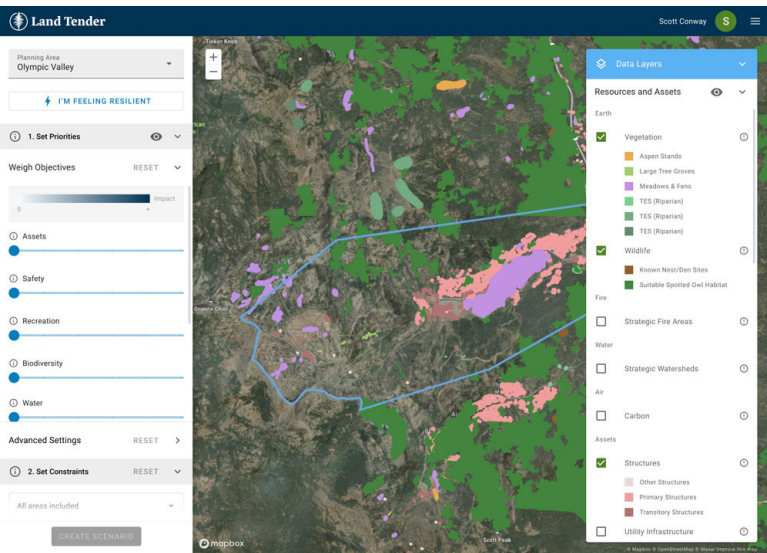


FIGURE 24: Vibrant Planet's Land Tender tool helps planners optimize their fuel treatment plan. Credit: Vibrant Planet.

Several companies are harnessing data to help optimize forest and vegetation management programs to reduce fuels and restore forest health. One example is **Vibrant Planet**, which utilizes data science and high-resolution satellite imagery to recommend the optimal mix of over 70 potential land treatments, including

prescribed burns, to help planners make the best decision given their constraints. According to Vibrant Planet, every plan recommended through its Land Tender product includes prescribed burns in order to restore ecosystem health.⁷¹ Similarly, **Wildfires.org** has built a software tool that helps the US Forestry Service more easily manage environmental permitting for fuel treatment programs. **Overstory** and **TreeSwift** are two other data-driven software companies that use artificial intelligence and satellite or drone imagery to help utilities develop vegetation management plans to mitigate the risk of wildfires.⁷² Agencies are currently seeking out data-driven solutions like these, with California's Strategic Plan for Expanding the Use of Beneficial Fire stating that new technologies that help improve fire behavior and smoke management modeling could help increase the number of allowable burn days based on greater certainty about smoke impacts.⁷³



FIGURE 25: A wildfire burn scar. Credit: Mast Reforestation.

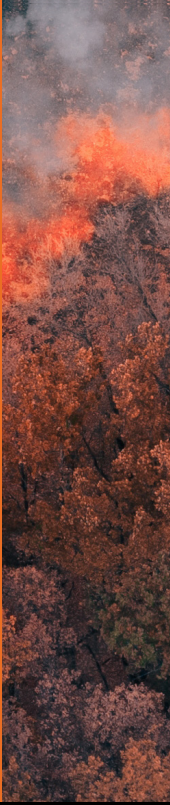
Technology can also be transformative for forest recovery when wildfires inevitably do occur. As climate change has contributed to hotter and more destructive fires, in many cases forests are no longer capable of naturally regenerating after a wildfire.⁷⁴ Instead, burn scars are increasingly converting brush or other sparse vegetation that results in reduced water quality, increased mudslide risk, and a dearth of habitat and ecosystem services compared to the forest that existed before a wildfire. While some environmental organizations have raised questions about whether replanting should be done in “wilderness areas,” the National Park Service and university scientists are observing that recent high-severity fires are behaving in such a way that forests cannot adapt, finding that in some cases the number of trees that would

naturally regenerate on the land post-fire is less than 10% of the historical number.⁷⁵ A company called **Mast Reforestation*** is working to restore forest health and resiliency in the aftermath of such damaging wildfires. Mast Reforestation provides end-to-end tech-led reforestation services, using satellite mapping to create tailored reforestation plans, cultivating site-specific seedlings, and monitoring for growth. Mast operates the West’s largest seed bank and tree nurseries in which it cultivates seedlings optimized for post-wildfire reforestation, and is able to offer its services to landowners at little to no cost by selling carbon removal credits. Reforesting burn scars strategically to be fire-resilient can help reset the forests, with regular prescribed burns thereafter ensuring the forests maintain their resiliency long into the future.



* A DBL portfolio company

Lighting a Flame: How to Fund More Prescribed Burns - Today and In the Future



Growing Federal and State Funding

Today, government funding or grants pay for nearly all prescribed burns. Recently, new sources of additional federal funding for fuel management to improve forest resiliency have emerged. The Bipartisan Infrastructure Law provided the Forest Service and the Department of Interior with nearly \$3 billion and \$878 million, respectively, to reduce hazardous fuels and restore forests and grasslands.^{76,77} Of this funding, \$500 million is specifically allocated for prescribed burns.⁷⁸ The Inflation Reduction Act provided the Forest Service an additional \$1.8 billion for hazardous fuel management on National Forest land within the wildland-urban interface.⁷⁹

The Bipartisan Infrastructure Law also allocated \$1 billion to help launch Community Wildfire Defense Grants designed to assist at-risk communities,

Tribal communities, non-profits, state forestry agencies, and Alaska Native corporations with planning for and mitigating wildfires.⁸⁰ In its first year of funding, the program awarded \$197 million to 99 project proposals across 22 states and seven Tribes.⁸¹ Existing prior to these programs, funding is also available through programs such as the US Forest Service and Natural Resources Conservation Service Joint Chiefs' Landscape Restoration Project, which has been funding projects on state, private, and Tribal lands since 2014, as well as the Forest Landscape Restoration Program, established in 2009.⁸²

States are also allocating funding toward fuel management and prescribed burns. California aims to expand prescribed burns from around 125,000 acres today to 400,000 acres annually by 2025 across federal, state, Tribal, and private lands, backed by the Governor's \$1.5 billion investment



FIGURE 26: Forest that has been treated with prescribed burn in Klamath National Forest 2021. Credit: U.S. Forest Service.

in forest health and wildfire resilience in 2021 and an additional \$1.2 billion for 2022 to 2024.⁸³ As mentioned above, California also announced a \$20 million Prescribed Fire Liability Claims Fund earlier this year, protecting burners from a lack of liability insurance. Private landowners seeking funding can apply to participate in Cal Fire’s Vegetation Management Program in which Cal Fire performs prescribed burns on their land and assumes liability for the burn.⁸⁴ Another example is Cal Fire’s Wildfire Prevention Grants, supported by the \$52 billion California Climate Commitment, for projects in or near high-risk communities that reduce hazardous fuels, or conduct wildfire prevention planning or education. In July 2023, Cal Fire awarded \$113 million in grants to support 96 projects across the state through this program, at least four of which included prescribed burns.⁸⁵

This new wave of funding is a much-needed start to help with improving forest management and expanding the use of prescribed burns. Given the scale and urgency of the problem, we must also welcome new funding models that can unlock even more capital to not only deploy existing solutions, but also to increase available funding for R&D and new technologies that could dramatically scale the ability to use prescribed burns in the future.

New Private Markets

First, looking to industry, timber companies including Sierra Pacific Industries, which is the largest landowner in California, and utilities including PG&E have a vested interest in protecting their assets from wildfires. Earlier this year, PG&E announced plans to invest \$18 billion in wildfire

prevention through 2025, which includes vegetation management in the highest-risk locations.⁸⁶ While PG&E is not conducting prescribed burns today, in June it conducted a pilot with BurnBot under high-voltage transmission powerlines as part of a California Public Utilities Commission regulated PG&E Electric Program Investment Charge (EPIC) project to demonstrate novel vegetation management technologies, with additional tests planned for 2023 to test fire as a means to create control lines and as a new means of tackling herbicide-resistant weeds and invasives.⁸⁷ Sierra Pacific Industries is also investing in vegetation management, removing dry brush and performing tree thinning in overgrown forests to mitigate wildfire spread,⁸⁸ and has partnered with Cal Fire to conduct prescribed burns.⁸⁹

Insurance companies are increasingly financially motivated to reduce catastrophic wildfire risk, as it becomes less sustainable for them to cover losses from wildfires. The 2018 wildfire season in California generated around \$13 billion in insurance claims,⁹⁰ and in 2023, State Farm, California's largest home insurer, announced that it would stop selling coverage to homeowners across the state to "improve the company's financial strength."⁹¹ Others are following suit. During California's September legislative session, The California Senate, The Insurance Commissioner, and The Governor were in negotiations to bring forward a bill that would have considered whether to allow companies to use forward-looking catastrophe models, potentially

setting the stage for more accurate pricing and incentivization of mitigation efforts. Ultimately, a bill was not brought forward, leaving the issue unresolved at this time.⁹²

Insurance providers such as AIG and Chubb are both investing in wildfire mitigation to avoid damage and loss proactively on insured properties. For instance, AIG's Wildfire Protection Unit offers complimentary at-home consultations for its Private Client Group policyholders on how to reduce wildfire risk.⁹³ Chubb and other insurers partner with a Montana-based company Wildfire Defense Systems to offer policyholders wildfire mitigation services such as a personalized wildfire hazard assessment at no additional cost.⁹⁴ As of October 2022, insurance providers in California are now also required to provide consumers discounts if they reduce wildfire risk around their property, such as by reducing fuels.⁹⁵ As demonstrated by these programs, insurance companies are already budgeting in wildfire prevention costs, and incorporating prescribed burns as part of these efforts would be an effective tool to help them reduce the risk of catastrophic wildfires and avoid billions of dollars in claims. To mitigate future risk, these companies may increasingly turn to risk reduction at a larger scale, seeking a solution like Rain's automated helicopter as an effective way to both protect their assets and reduce wildfire risk by using Rain's system to contain wildfires during the fire season and conducting prescribed burns during burn windows.

Opportunities for partnerships also exist between companies and private landowners to pool resources together to increase prescribed burns. These new approaches could allow for splitting the costs of new technologies, such as Rain or BurnBot, that could reduce liability risk and make people less afraid of an escape while also making prescribed burns safer for practitioners using automation. Mendocino County Cooperative Aerial Fire Patrol has demonstrated for over 70 years that cost-sharing models like these can work. Today, around 750 landowners and a few timber companies pay annual contributions totaling around \$160,000 to support a spotter plane that flies six hours a day every day throughout the fire season to detect early wildfires; they are the first to report up to 15 fires per year.⁹⁶ Similar models could exist for prescribed burns. We are already seeing cost-sharing among ranchers and private landowners today through Range Improvement Associations and Prescribed Burn Associations (PBAs), in which members pool their knowledge, equipment, and other resources to conduct prescribed burns safely and effectively by themselves.⁹⁷ Currently, 100 PBAs are located across 18 states primarily in the Midwest and Southeast,⁹⁸ and nearly 20 have been formed in California since 2018 (see Figure 28).⁹⁹ Range Improvement Associations, PBAs, and companies with high-value assets are aligned in their goal to reduce wildfire risk, and partnerships like the Mendocino County Cooperative could unlock new sources of capital to bring on new technologies to expand prescribed burns.

Innovative Models for the Future

Prescribed burns could also be funded through novel investment vehicles like Blue Forest's Forest Resilience Bonds that source financing from private and philanthropic investors to fund forest restoration projects on private and public lands to reduce the risk of catastrophic wildfire.¹⁰⁰ The first Forest Resilience Bond provided \$4 million in capital from four investors to finance treatments across 15,000 acres of Tahoe National Forest lands in 2018. This financing made it possible for the Forest Service to shorten the timeline of its restoration projects from up to 12 years down to four years.¹⁰¹ Tools like Forest Resilience Bonds could help prescribed burn practitioners tap into the estimated \$26 billion of private capital invested in nature-based solutions each year to accelerate and scale the use of prescribed burns without the constraints of existing budgets.¹⁰²



FIGURE 27: Mendocino County Cooperative Aerial Fire Patrol. Credit: Ukiah Daily Journal.

Selling carbon credits is another avenue that could help fund prescribed burns when considering the avoided emissions of catastrophic wildfires. This is already happening in Australia, where, since 2015, landowners who conduct prescribed burns on savannas can earn carbon credits as the burns reduce the size, intensity, and frequency of savanna wildfires, thereby reducing emissions. Landowners can then sell the carbon credits to the Australian government, to companies, or to other private buyers for cash.¹⁰³ In the US, the American Forest Foundation and The Nature Conservancy’s Family Forest Carbon Program also financially reward family forest owners for implementing climate-smart forestry—including managing

vegetation and fuel load treatments—through the sale of carbon credits.^{104,105} The size of the global voluntary carbon offsets market is estimated to be \$2 billion today, and some frequently cited projections forecast substantial growth to \$100 billion by 2030 and \$250 billion by 2050, as companies and countries aim to meet ambitious climate targets.¹⁰⁶ Funding prescribed burns through the sale of carbon credits could help landowners fund burns while helping to satisfy the growing demand for carbon offsets.

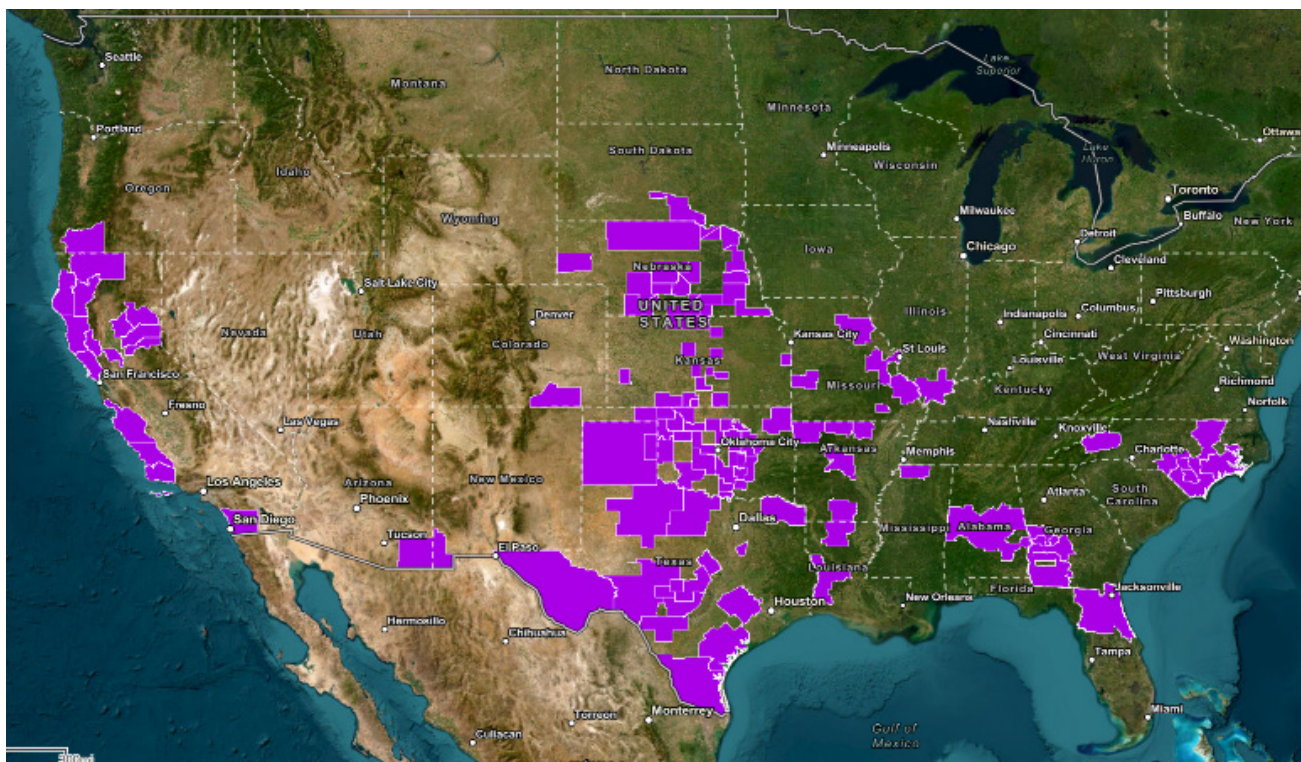


FIGURE 28: Map of Prescribed Burn Associations. Credit: Great Plains Fire Science Exchange and Kansas Forest Service.



Conclusion: Igniting a New Era of Landscape Resilience

Expanding the use of prescribed burns is a massively underrecognized opportunity to restore the resilience of fire-adapted landscapes, to save lives and communities, and to avoid millions of tons of greenhouse gas emissions from catastrophic wildfires. The wildfire crisis is ever-expanding, with record-breaking wildfires becoming the norm around the world, from across the US and Canada down to Australia and Brazil. We need to invest in and utilize every tool in the

toolkit, harnessing new cutting-edge technologies and innovative funding models to accelerate the scale and pace at which we can revive the ancient practice of prescribed burns. While the US government is already allocating billions of dollars toward managing the country's hazardous fuel levels across federal, state, private, and Tribal lands, unlocking innovative capital from the private sector can scale these efforts substantially, igniting a new era of restorative land management with benefits for humanity, wildlife, and the planet.



We need to be investing in and utilizing every tool in the toolkit, harnessing new cutting-edge technologies and innovative funding models

Appendix: List of Interviewees

- 6/30/23: Anukool Lakhina (BurnBot, CEO)
- 7/7/23: Allison Woolf (Vibrant Planet, CEO)
- 7/14/23: Nathan Truitt & Aimee Tomcho (American Forest Foundation, Senior VP and Senior Forestry Manager)
- 7/14/23: Jared Childress (Central Coast Prescribed Burn Association, Program Manager and Burn Boss)
- 7/20/23: Mark Bathrick (Dept. of Interior Office of Aviation Services, Former Director)
- 7/20/23: Mark Biaggi (TomKat Ranch, Pescadero, CA, Ranch Manager)
- 7/21/23: Max Brodie (Rain, CEO and Co-Founder)
- 7/31/23: Scott Kelly (Mendocino County Aerial Fire Patrol Cooperative, Former Chairman, Board)
- 8/1/23: Sarah Collamer (Cal Fire, Forester and Burn Boss; Burn Boss at TomKat Ranch, Pescadero, CA)

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