

Living Under Smoky Skies—
**Understanding the Challenges
Posed by Wildfire Smoke in California**



Executive Summary

In this report, we (1) summarize trends in wildfires and associated smoke; (2) review research on the health and other effects of wildfire smoke, including on vulnerable groups; (3) discuss local, state, and federal roles and responsibilities related to smoke, as well as actions that the state currently is undertaking to address it; and (4) provide some guidance to the Legislature as it formulates its approach to addressing smoke in the coming years.

Wildfire Smoke Is a Significant and Growing Concern. Californians have been exposed to more large, high-severity wildfires in recent years. These wildfires have generated more smoke and greater emissions of various pollutants. Notably, the trend of growing wildfire smoke is anticipated to continue. Experts expect the state will experience more large and intense wildfires in coming years, fueled by a combination of climate change and decades of poor forest management. Additionally, some of the state's efforts to reduce the likelihood of these large and often destructive wildfires—such as through planned, controlled fires known as prescribed fires—while critical, will also generate smoke. Accordingly, Californians likely will have to adjust to living with higher levels of smoke than they have experienced in recent decades.

Wildfire Smoke Has a Wide Range of Negative Effects. The increase in wildfire smoke is of concern because it can have a wide range of negative health and other impacts. For example, wildfire smoke is associated with increases in emergency department visits for respiratory conditions such as asthma, as well as increases in mortality. Also, the adverse effects of wildfire smoke are not uniformly distributed across individuals, households, and communities. Instead, certain populations, such as those who are older or have underlying health conditions, tend to be more vulnerable to the negative effects of smoke.

Individuals and Governments Can Take Actions to Mitigate the Impacts of Smoke. Various activities, such as remaining indoors and running a portable air purifier, can help mitigate the effects of wildfire smoke. However, people face barriers that may not always make it possible for them to take such actions. In practice, individuals may not always know when smoke levels are elevated or what steps they should take. Additionally, even if they do have this information, it is not always feasible for everyone, particularly those with limited resources, to undertake actions to protect themselves. Notably, government agencies—at the state level, as well as at the local and federal levels—currently are undertaking a variety of activities to help address the effects of wildfire smoke and mitigate barriers. For example, state agencies are expanding their efforts to disseminate information about smoke events and piloting the use of clean air centers to serve as locations for people to avoid wildfire smoke.

Legislative Considerations for Building on Existing Efforts. Given the significant health and other impacts of wildfire smoke—particularly on those who are vulnerable due to their age, health status, or socioeconomic factors—the Legislature may want to consider what additional steps, if any, it would like to take to build on existing efforts. A few examples of the types of steps that the Legislature could consider taking include: supporting additional research and pilot projects to improve understanding of the best and most cost-effective approaches to address wildfire smoke; providing targeted funding for mitigations, such as purchasing portable air purifiers; or supporting efforts to improve information dissemination. Notably, another approach the state could take is to support expansions of prescribed burning. This is because, while prescribed

burns generate some smoke, they reduce the risk of large, severe wildfires, which typically produce the most dangerous and impactful smoke. Some key criteria for the Legislature to consider as it chooses among these and other available options include: (1) whether the state is the appropriate entity to undertake the activity, (2) whether there is a demonstrated need for the activity, (3) the strength of the evidence of the activity's cost-effectiveness, (4) the extent to which the activity targets vulnerable groups, and (5) the co-benefits that the activity provides beyond reducing the impacts of smoke.

INTRODUCTION

Smoke Is a Growing Concern of Statewide Importance. The state has made significant strides in recent decades toward improving its air quality by reducing emissions from both stationary and nonstationary sources (such as fossil-fuel power plants and vehicles). However, these improvements have been offset to some degree by a growing source of poor air quality: smoke from wildfires. In recent years, wildfire smoke emissions have trended upward and become a major contributor to air pollution in California.

Notably, the trend of growing wildfire smoke is anticipated to continue. Experts expect the state will experience more large and intense wildfires in coming years, fueled by a combination of climate change and decades of poor forest management. Additionally, some of the state's efforts to reduce the likelihood of these large and often destructive wildfires—such as through planned, controlled fires known as prescribed fires—while critical, will also generate smoke. Accordingly, Californians likely will have to adjust to living with higher levels of smoke than they have experienced in recent decades.

This Report Describes Challenges Posed by Smoke From Wildland Fires. This report is intended to help the Legislature and the public deepen their understanding of the challenges that smoke from wildland fires poses for the state. (Throughout this report, we use the term wildland

fires to refer to all fires that affect wildlands, including both wildfires and prescribed fires.) This report is intended to be a first step aimed at assisting the Legislature as it considers what additional state actions might be warranted to mitigate the impacts of this smoke, particularly on the Californians who are most vulnerable to its effects.

This report has four main sections. First, we summarize trends in wildfires and associated smoke, describing how Californians have been exposed to more smoke and associated pollutants in recent years and why this trend is anticipated to continue. Second, we review research on the health and other effects of wildfire smoke, including on vulnerable groups. Third, we discuss local, state, and federal roles and responsibilities related to smoke from wildland fires, as well as actions that the state currently is undertaking to address this smoke. Notably, some types of actions to address smoke lend themselves to a state role, while others are more appropriately taken by other entities. Finally, in the fourth section of this report, we provide some guidance to the Legislature as it formulates its approach to addressing wildland fire smoke in the coming years. The report also includes an Appendix, which lists the key studies referenced throughout the text.

WILDFIRE SMOKE TRENDS AND COMPONENTS

Below, we discuss how Californians have been exposed to more large, high-severity wildfires in recent years, which have generated more smoke and greater emissions of various pollutants. We also discuss how Californians may need to adapt to higher levels of smoke because climate change is likely to increase the threat of large and intense wildfires and because the state will need to step up its efforts to reintroduce controlled, typically low-severity fires into wildland areas, which will also generate some smoke.

Californians Have Been Exposed to More Smoke in Recent Years

State Has Experienced Growing Number of Large, High-Severity Wildfires. In recent years, California has experienced an increasing number of large wildfires. Notably, 12 of the 20 largest wildfires in the state's recorded history—as measured by the number of acres burned—have occurred within the last five years. As shown in

Figure 1, recent wildfires not only have affected large areas but also have burned significant acreage at high severity. (The severity of a fire is determined based on various factors, including the share of various types of vegetation—such as tree crowns—that are burned.) High-severity wildfires often denude landscapes, leaving large areas with mostly charred remnants. In contrast, lower-severity wildfires typically burn underbrush and smaller trees, but leave intact many larger, well-established trees and species that have adapted to withstand fire.

Growth in Severe Wildfires Driven by Two Main Factors. Two key reasons explain the increase in large, high-severity wildfires in California in recent years. First, many of the state’s forestlands have become unhealthy, in part due to the focus on suppressing naturally occurring fires over the past century. As shown in **Figure 2**, these forestlands are densely filled with relatively small trees and brush, which serve as “ladder fuels” to carry wildfires into tree canopies, thereby increasing their spread and intensity. (The figure also shows how these more severe wildfires generate additional smoke and often leave landscapes denuded, as

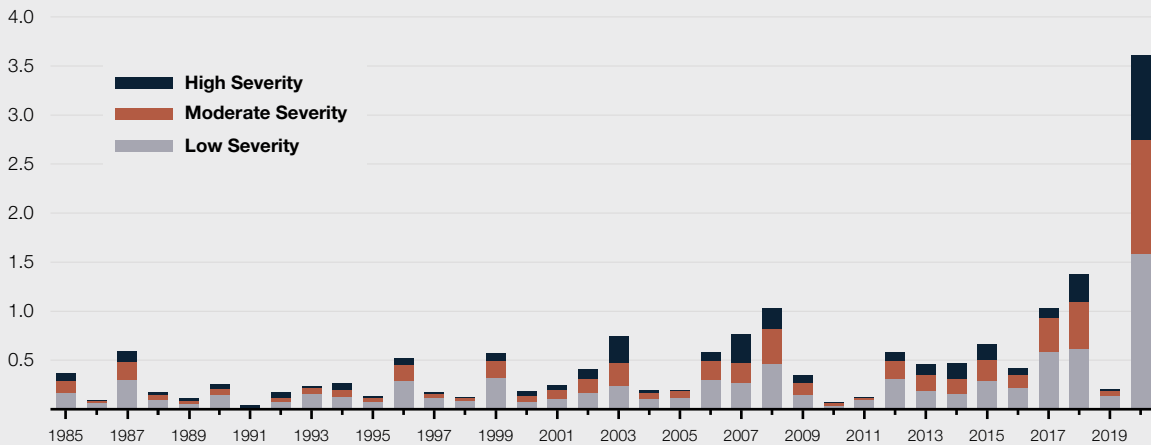
discussed elsewhere in this report.) Second, climate change has contributed to hotter weather and longer dry seasons in California than was previously typical. These conditions have increasingly dried out vegetation and lengthened the wildfire season, which has increased fire risks. Additionally, climate change has negatively affected forest health by increasing the frequency and severity of droughts, which put stress on trees and make them more susceptible to pest infestations. This, in turn, has led to more diseased, dead, and dying trees, which also have exacerbated the severity of wildfires by providing more combustible fuels.

Wildfires Generating Growing Amounts of Smoke. In part due to their size and severity, recent wildfires have generated large amounts of smoke that have affected significant portions of the state, sometimes for extended periods. As shown in **Figure 3** on page 6, major cities across the state experienced significantly more days of smoky air—days on which smoke was observed via satellite imagery—between 2016 and 2020 compared to between 2009 and 2013. (Smoke days may not always be obvious to residents, but can be observed by satellite and still have potential health

Figure 1

California Wildfires Growing Increasingly Severe

Acres Burned by Severity^a (In Millions)



^a The severity of a fire is determined based on various factors, including the share of various types of vegetation—such as tree crowns—that are burned. Definitions of low-, moderate-, and high-severity wildfires can be found at <https://burnseverity.cr.usgs.gov/glossary>.

Data Source: Monitoring Trends in Burn Severity data provided by U.S. Forest Service.



impacts, as discussed later in this report.) Notably, as we discuss further in the box on the next page, while smoke levels over the past few years have been higher than in the recent past, smoke from wildland fires likely was much more prevalent before European settlement and the advent of modern fire suppression. In particular, starting in the early 1900s, government policy emphasized suppressing all fires (often referred to as “fire exclusion”). This reduced the acreage burned and associated emissions, but also has contributed to the poor forest health that exists across the state today.

Smoke Pollutants Have Contributed to Worsening Air Quality

Wildfire Smoke Contains Various Pollutants. The increase in smoke from wildfires raises concerns due to the various pollutants such smoke can contain, such as particulate matter, ozone, volatile organic compounds, carbon monoxide, nitrogen oxide, and trace metals. Importantly, the composition of smoke can vary across wildfires. This is because the types and quantities of air pollutants depend on a variety of factors, such as the intensity of the wildfire, the type of fuels that burn, and the dryness of the fuels. For example, smoke from wildfires that burn structures can contain higher levels of certain contaminants, such as lead, than would be typical when fires only burn vegetation. Notably, smoke from a single wildfire can also change over time depending on the type and condition of the vegetation and other materials that burn, as well as how the resulting smoke is dispersed geographically by weather and atmospheric conditions.

Pollutant of Greatest Concern Is Fine Particulate Matter. Of the various air pollutants in wildfire smoke, the one that is generally considered to be of greatest concern is fine particulate matter of 2.5 microns in diameter or less, known as $PM_{2.5}$. The small size of $PM_{2.5}$ —roughly 1/30 or less of the width of a human hair—contributes to its ability to negatively affect people in a few notable ways. First, $PM_{2.5}$ can remain suspended in the air for extended periods. This, in turn, enables $PM_{2.5}$ to travel further

Figure 2

Forest Health Affects Severity of Wildfires and Smoke

Unhealthy Forest



Dense trees and brush, comparatively more small and young trees.



Larger, more intense wildfires generate more smoke.



Little vegetation remains after wildfire.

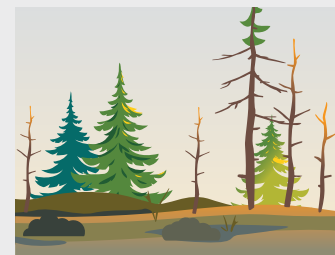
Healthy Forest



Sporadic trees and brush, comparatively more large and old trees.



Smaller, less intense wildfires generate less smoke.



Some vegetation remains, including larger trees and fire-adapted species.

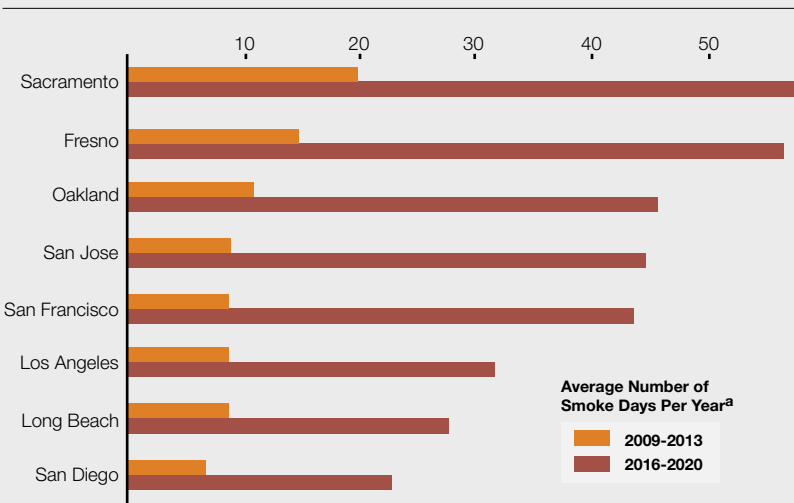
from wildfire activity than coarser matter would, sometimes leading it to affect communities hundreds of miles away from an active wildfire. Second, PM_{2.5}'s small size allows it to infiltrate indoor spaces relatively easily, particularly those spaces that are not well-sealed (such as older, drafty houses). Third, PM_{2.5}'s size also facilitates its travel deep into the respiratory tract, as well as into the bloodstream, where it can trigger negative health impacts. (We discuss these health effects, as well as other impacts of PM_{2.5}, in further detail later in this report.)

Wildfire Smoke Having Growing Impacts on State's Air Quality.

Recently, estimated emissions of PM_{2.5} from California wildfires have generally trended upward as the state has experienced more smoke from large wildfires.

Figure 3

Wildfire Smoke Exposure in California Cities Has Increased in Recent Years



^a Days in which smoke was observed on satellite imagery.

Source: Romero, Farida Jhabvala, et al. (2021).



Wildland Fire Smoke Prevalent Before European Settlement

Wildland Fires Burned Large Areas Before Modern Fire Exclusion Policies. Wildland fires are a natural part of California's ecosystems. Historically, significant parts of the state would burn annually, especially during the warm, dry months of the year. In the 1700s, for example, an estimated 4.5 million acres burned each year, on average. This is more than four times the average annual amount of acreage that has burned in recent decades, due in large part to the state's focus on suppressing wildfires. Some of the fires during the period before European settlement were intentionally set by Native American tribes for ecological, ceremonial, and other cultural purposes, while other fires were ignited without human intervention (such as by lightning strikes).

These Wildland Fires Generated Large Amounts of Smoke. These large fires that were left to burn hundreds of years ago generated significant amounts of smoke. A 2007 study points out that before European settlement and the introduction of modern fire suppression, smoke likely filled the skies in California during much of the summer and fall. Significant uncertainty exists regarding the level of emissions generated by these fires. For example, this study suggests that wildfires in California generated between 474 and 1,281 gigagrams (Gg) of PM_{2.5} annually prior to 1800. (PM_{2.5} refers to fine particulate matter of 2.5 microns in diameter or less.) As a point of comparison, the California Air Resources Board estimates that wildfires in the recent severe fire years of 2018 and 2020 emitted roughly 380 and 1,070 Gg of PM_{2.5}, respectively. Excepting those two severe years, wildfires between 2011 and 2020 emitted an average of roughly 136 Gg of PM_{2.5} annually. Thus, recent decades of relatively little smoke—driven by policies of fire exclusion—are likely well below the historical norm.

As shown in **Figure 4**, the average estimated annual $PM_{2.5}$ from wildfire smoke was significantly higher across much of the state in the seven years ending in 2020 than it was during the prior seven years (2007 through 2013). Over this period, emissions of $PM_{2.5}$ from other sources generally have declined, largely due to various regulatory policies. Accordingly, wildfire smoke has contributed a growing share of $PM_{2.5}$ in

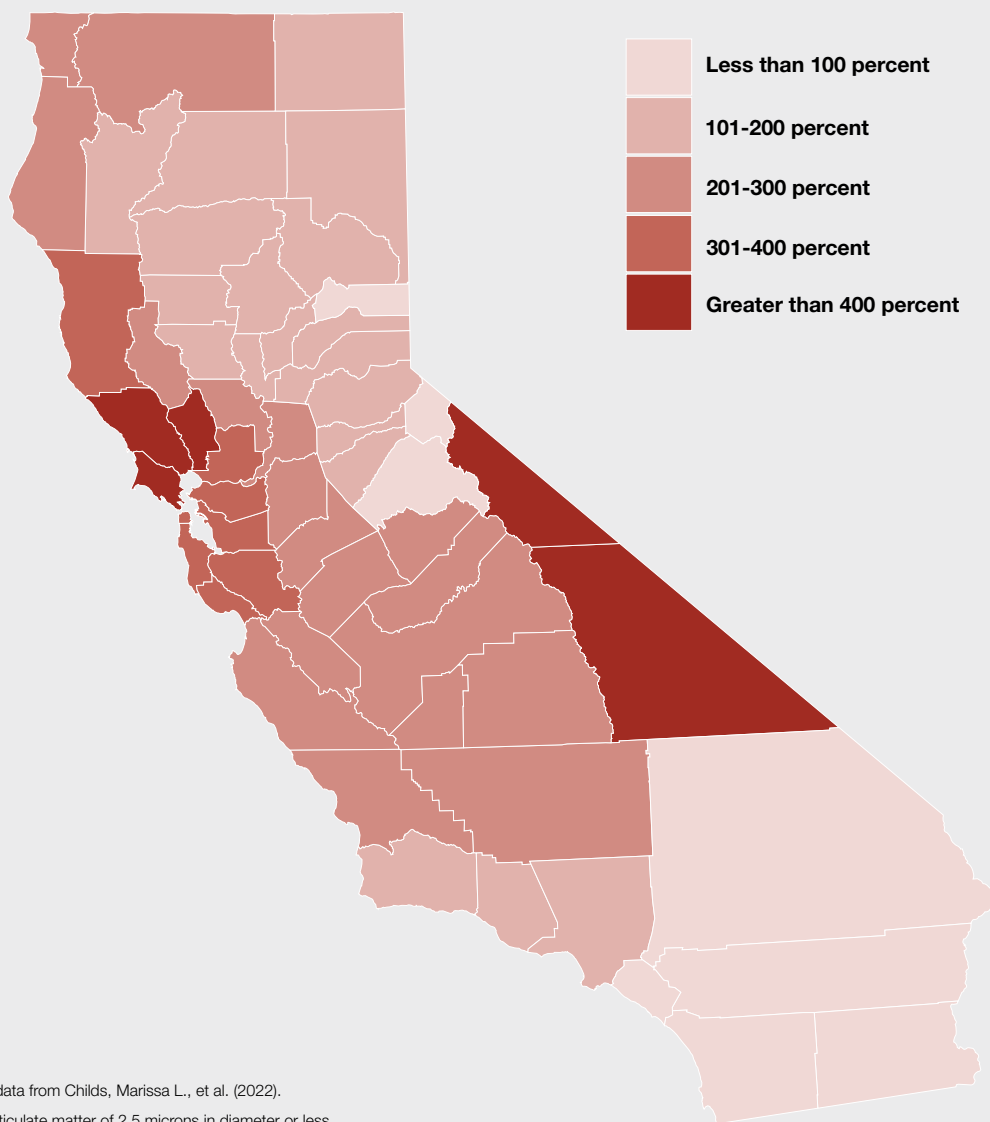
recent years in California. This trend has also been documented in the larger western region. For example, one **2021 estimate** found that wildfires account for up to half of small particulate matter in parts of the Western United States, compared to less than 20 percent a decade ago.

Impact of Wildfire Smoke on Air Quality Is Episodic. While wildfire smoke has become a more significant contributor to overall air quality

Figure 4

Most of State Has Experienced Large Increases in Wildfire-Driven Air Pollution

Percentage Increase in Estimated Average Annual $PM_{2.5}$ From Wildfires Between 2007-2013 and 2014-2020



Prepared using data from Childs, Marissa L., et al. (2022).
 $PM_{2.5}$ = fine particulate matter of 2.5 microns in diameter or less.

than it was a decade ago, annualized data do not fully capture how such smoke affects air quality. This is because emissions from wildfires, unlike many other sources of pollutants, are not spread out evenly throughout the year. Instead, since wildfires are episodic, they produce smoke and associated emissions intermittently. Accordingly, during some periods of a given year, wildfires contribute very little to emissions, while at other times they might be very large factors. Importantly, when the air quality in the state is very poor, wildfires are often an important contributor. For example, a [2016 study](#) estimated that wildfires contributed an average of over 70 percent of total daily PM_{2.5} in the Western United States on days that exceeded federal regulatory standards, compared to an average of 12 percent of total daily PM_{2.5} over the course of the entire study period from 2004 to 2009. This temporal characteristic of wildfire smoke is important because the health impacts of relatively short-term, very high levels of pollutants such as PM_{2.5} could potentially differ from the impacts of prolonged, lower levels of pollutants. This is the case even if average levels of exposure across a given period of time are the same.

Californians Likely Will be Exposed to More Smoke From Wildland Fires in Future

Trend of Increasing Large and Severe Wildfires Likely to Continue. As mentioned previously, climate change has already contributed to more frequent large, severe wildfires. This trend is generally anticipated to continue as the state experiences more of the impacts of climate change, such as increased average temperatures and more frequent and prolonged droughts. Importantly, the degree to which climate change will increase wildfire activity

and associated particulate matter emissions in the future is subject to uncertainty. However, one [2016 study](#) estimates that *average* emissions of PM_{2.5} in the Western United States from wildfires could increase by more than 60 percent by mid-century (compared to 2004 through 2009) and *maximum* PM_{2.5} emissions from wildfires could increase by close to 400 percent.

Greater Use of Prescribed and Other Beneficial Fire Also Will Generate Smoke. As discussed above, along with climate change, another contributor to the growth of large, severe wildfires has been the poor condition of many of the state's forests and wildlands. In the coming years, the state will need to accelerate its efforts to better steward these lands—such as by removing some of the excess vegetation that has accumulated—to improve their health and resilience to wildfires. A key component of the state's strategy to accomplish these improvements is to reintroduce a greater level of ongoing, controlled fire onto landscapes across the state. This includes expanding the use of prescribed fire by the state and its partners. The state also is seeking to facilitate more cultural burning by Native American tribes and greater use of managed wildfires by the federal government. These types of fire, which together are sometimes referred to as beneficial fire, help remove surface fuels, thin forests, and burn lower branches to lift tree canopies. Notably, in total, [California's Strategic Plan for Expanding the Use of Beneficial Fire](#) calls for the state and federal governments and their partners to increase the use of beneficial fire to 400,000 acres per year by 2025. (For context, based on information in the Strategic Plan, we estimate that between 2017 and 2020, these entities used beneficial fire on over 100,000 acres annually.) Beneficial fire is important for returning landscapes to more natural, healthy conditions, but will inevitably result in some smoke and associated emissions.

EFFECTS OF WILDFIRE SMOKE

In this section, we summarize the growing body of research on impacts to physical health and other effects of wildfire smoke. We also summarize how the adverse effects of wildfire smoke are not uniformly distributed across individuals, households, and

communities. Instead, certain populations of people, such as those who are older or have underlying health conditions, tend to be more vulnerable to the effects of this smoke.

Wildfire Smoke Associated With Numerous Negative Effects

Wildfire Smoke Associated With Various Negative Physical Health Impacts. A growing body of research links wildfire smoke to negative effects on human physical health and to increases in mortality. We highlight some key examples of this research in **Figure 5**. As shown in the figure, much of this research explores the association between exposure to wildfire smoke and associated emissions of particulate matter, and measures of use of medical care (such as hospital admissions or emergency department visits). The most well-documented, consistent relationship is between wildfire smoke and respiratory conditions, such as asthma. Evidence also exists—although generally is somewhat less consistent—connecting wildfire smoke to cardiovascular effects, such as heart attacks. Some research also finds associations between exposure to wildfire smoke and birth outcomes, such as the likelihood of preterm birth. (Preterm births are associated with higher risks of various long-term health problems.) Additionally, evidence not only links wildfire smoke to health conditions, but also to a greater risk of death.

Notably, the overall health effects of wildfire smoke still are being studied and some key gaps in research still exist. For example, most existing research focuses on linking specific, short-term wildfire events to health outcomes experienced thereafter. The effects of repeated or prolonged exposure to wildfire smoke still are not widely understood. (As we discuss in the box on the next page, relatively little research on the health effects of prescribed fire has been conducted, but existing research suggests it likely has substantially fewer negative impacts than wildfires.)

Wildfire Smoke Also Linked to Economic and Other Impacts. The most widely studied effects of wildfire smoke have been related to physical health conditions. However, emerging research links wildfire smoke to other negative outcomes. For example, one **2022 study** found a relationship between wildfire smoke levels and poorer cognitive performance on a brain-training game, and another **2022 study** found a link between smoke exposure and lower test scores. A third **2022 study** revealed links between estimated exposure to smoke from wildfires and various labor outcomes, including lower income, employment, and labor force participation. Specifically, the study estimated that wildfire smoke reduced nationwide earnings from jobs by an average of close to 2 percent per year (the equivalent of \$125 billion annually) between 2007 and 2019. These studies are not without their limitations. For example, participants in the

Figure 5

Findings From Recent Research on Physical Health Effects of Wildfire Smoke



Respiratory Effects

- Several studies have found associations between wildfire smoke and increases in emergency department visits for respiratory diseases, such as asthma (Malig, et al., 2021; Wettstein, et al., 2018; Alman, et al., 2016; and Rappold, et al., 2011).
- Recent research has also linked smoke to increased asthma diagnoses at emergency departments, office visits, and outpatient visits, as well as an increase in inhaler medication refills (Gan, et al., 2020).



Cardiovascular Effects

- Several studies have found links between wildfire smoke and increases in emergency department visits for cardiovascular reasons, such as heart attacks (Malig, et al., 2021; Wettstein, et al., 2018; and Rappold, et al., 2011).
- A recent study has linked wildfire smoke to an increase in out-of-hospital cardiac arrests (Jones, et al., 2020)
- Other studies have failed to find associations between smoke and cardiovascular-related emergency department visits (Alman, et al., 2016), physician visits, and hospital admissions (Henderson, et al., 2011).



Poor Pregnancy and Birth Outcomes

- A couple of recent papers have found associations between smoke and pre-term births (Heft-Neal, et al., 2022 and Abdo, et al., 2019).
- Recent studies have also found links between smoke and a greater risk of gestational diabetes in pregnant people (Abdo, et al., 2019), as well as slightly reduced birth weight among infants exposed to smoke in utero (Holstius, et al., 2012).



Increased Mortality

- Various studies have found a positive relationship between smoke and all-cause and respiratory-related mortality (Chen, et al., 2021 and Doubleday et al., 2020).
- Research is more mixed regarding the relationship between smoke and cardiovascular-related mortality, with some research finding positive associations (Chen, et al., 2021) and others not (Doubleday et al., 2020).

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Health Impacts From Prescribed Fires

Available Evidence Suggests Prescribed Fires Likely Have Fewer Impacts. The health effects of prescribed fires are not fully understood, since associated research is limited. However, available evidence suggests that smoke from prescribed fires likely has substantially fewer negative effects than from wildfires. For example, a [2019 study](#) comparing children in Fresno who were exposed to similar-sized fires found that those exposed to prescribed burns showed lower levels of pollutants in their blood (such as fine particulate matter of 2.5 microns in diameter or less, known as PM_{2.5}) compared to those exposed to wildfires. Additionally, in 2021, the [United States Environmental Protection Agency published a report](#) analyzing case studies of two wildfires, which concluded that scenarios in which prescribed fire was used would have resulted in significantly lower emissions of PM_{2.5}.

A main reason why prescribed fires are considered to be less impactful is that they are planned and managed to specifically avoid major negative effects. For example, prescribed fires are typically limited in size and intensity. Additionally, they generally are conducted when atmospheric and weather conditions are favorable, such as when winds are expected to move smoke away from population centers. Finally, because prescribed fires are planned, nearby communities can be notified in advance of prescribed fires, which makes it easier for their impacts to be mitigated. Nevertheless, continuing to research the effects of prescribed fires will be important to better understand how to most effectively mitigate their effects. As we discuss in the next section of this report, the California Air Resources Board has been supporting some such research.

brain-training game were not randomly selected and their exposure to smoke was not measured with precision. Nonetheless, when taken together, these studies suggest that exposure to smoke has important effects beyond those that are captured in readily observable health measures such as emergency room admissions.

Certain Groups are More Vulnerable to Negative Effects of Wildfire Smoke

Exposure, Sensitivity, and Adaptive Capacity Affect Vulnerability to Wildfire Smoke. Three key factors make some individuals and households more vulnerable to smoke than others. First, some populations are more likely to be exposed to smoke due to their occupation and other characteristics. Second, some individuals might be comparatively more susceptible to being harmed when they are exposed to a given amount of smoke (often referred to as sensitivity). Third, individuals and households can be more vulnerable if they do not have the capacity or resources to adapt to smoke exposure (often referred to as adaptive capacity). As we show in [Figure 6](#) and discuss below, characteristics associated with increased exposure, higher

sensitivity, and lower adaptive capacity can cause varying levels of vulnerability to wildfire smoke.

- **Health Status.** Some health conditions make people more sensitive to the effects of wildfire smoke. For example, conditions such as asthma or chronic obstructive pulmonary disease can be exacerbated by wildfires. Pregnancy can make people more sensitive to the effects of wildfire smoke by increasing breathing rates and blood volumes. Also, wildfire smoke can affect fetuses. For example, as mentioned above, some research links exposure to wildfire smoke with elevated risks of preterm birth.
- **Age.** Babies and children are considered to be more vulnerable to wildfire smoke. This is primarily because (1) their lungs and immune systems are still developing, which makes them more sensitive to smoke; (2) they inhale more air per pound than adults, so they get a greater dose of pollutants; and (3) children tend to spend more time outside, which increases their potential exposure. Older adults, generally those over 65, also are considered to be more

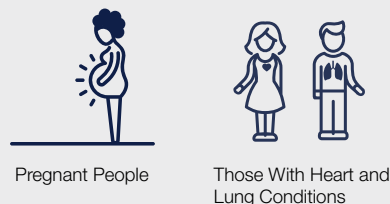
vulnerable, in part because they have higher rates of underlying health issues—such as conditions affecting the lungs and heart—and because people typically experience a gradual decline in physiological processes as they age.

- Occupation.** Certain occupations are associated with greater levels of smoke exposure. Most notably, compared to the general population, firefighters are typically exposed to wildfires at closer proximities and more frequently. Thus, while firefighters generally are a relatively healthy population, **some evidence** suggests that they may face some elevated effects from smoke exposure, such as declining lung function. Other outdoor workers, such as those in the agricultural and construction sectors, also experience greater exposure to wildfire smoke, raising their vulnerability.
- Socioeconomic Status.** Lower-income households also are more vulnerable to wildfire smoke for a few reasons. First, populations earning lower incomes are more likely to lack housing or live in structures that are not as protective against smoke, such as older housing that is draftier. This can result in more exposure to wildfire smoke. Second, in general, lower-income households also have fewer resources to adapt, such as by implementing the mitigation measures we discuss further below (like running an air conditioner with a high-efficiency filter). Additionally, populations earning lower incomes also are more likely to have some of the other characteristics described above, such as older age and outdoor jobs, which can contribute to greater vulnerability.
- Location.** Some individuals and households are more vulnerable to smoke as a result of the community in which they live or work. Some conditions that can increase exposure of certain locations to wildfire smoke are their proximity to fire-prone wildlands and their topography. For example, wildfire smoke can get trapped in valleys, sometimes exposing residents to pollutants for extended periods. Additionally, certain communities—such as those in the San Joaquin Valley air basin—are burdened by higher

Figure 6

People With Greater Vulnerability to the Effects of Wildfire Smoke

Health Status



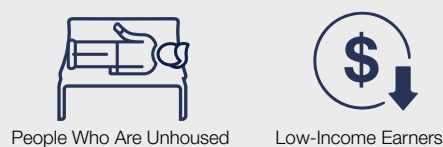
Age



Occupation



Socio-Economic Status



Location



levels of baseline pollution from other sources, such as agricultural production and other large industries. When wildfire smoke affects people in these communities, it adds an additional load of particulate matter on top of that significant existing level. Additionally, some communities are home to disproportionately large populations

of Californians earning lower incomes which therefore may have fewer resources to devote to mitigating smoke impacts at the community level. For example, certain communities may have less ability to support extended hours at libraries and community centers to serve as locations where residents can go to avoid smoke.

RESPONDING TO THE IMPACTS OF WILDLAND FIRE SMOKE

While wildland fire smoke can have negative effects, particularly on certain populations, various approaches can help mitigate these effects. In this section, we summarize these approaches. We also discuss some activities government agencies currently are undertaking to address the issue of smoke from wildland fires in California.

Approaches to Reduce Effects of Wildland Fire Smoke

Generally, efforts to mitigate the effects of wildland fire smoke focus on actions to reduce the concentration of exposure to pollutants, the duration of exposure to pollutants, and the rate of inhalation of the pollutants in smoke. We summarize these approaches below, some of which are shown in **Figure 7**.

Decreasing Proximity to Smoke. One approach to reducing smoke exposure is to leave the affected area and travel to an area with lower concentrations of pollutants.

Creating Clean Air Spaces. Another way to reduce smoke exposure is to make indoor spaces—such as individual homes, workplaces, schools, or community centers—cleaner. This can be accomplished by taking a variety of actions aimed at reducing the amount of smoke that travels into buildings and filtering the indoor air. Such actions include:

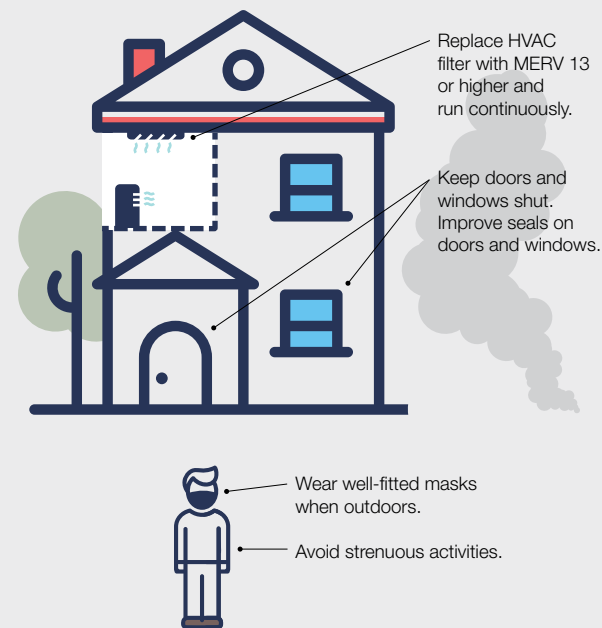
- **Closing Windows and Doors.** If windows are open, the level of particulate matter indoors is likely to be similar to outdoors. If windows are closed, pollutant levels can be maintained at lower levels, particularly if the indoor air is filtered. After a wildland fire event, it is important to open windows and doors again, so any pollutants that may have accumulated inside can be released.

- **Improving Window and Door Sealing.**

Improved sealing of buildings—such as by replacing old, leaky, single-paned windows with well-sealed double-paned versions—can reduce the infiltration of smoke and other outdoor pollution. Pairing improved sealing with filtering of indoor air is important, as

Figure 7

Examples of Approaches to Reducing Impacts of Wildfire Smoke



HVAC = heating, ventilation, and air conditioning and MERV = Minimum Efficiency Reporting Value.

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discussed below. Otherwise, indoor air quality can gradually decline, since some smoke from the outdoors still is likely to enter even well-sealed buildings over time. Also, absent filtration, a well-sealed building can be prone to accumulating higher concentrations of indoor pollutants (such as from gas stoves), which can also have some offsetting negative health effects.

- **Using High-Efficiency Filters.** One way to maintain cleaner indoor air is to place air filters with a Minimum Efficiency Reporting Value (MERV) rating of at least 13 in a building's heating, ventilation, and air conditioning (HVAC) system. (Air filters are assigned a MERV rating from 1-16. Typically, the higher the number, the higher the filter's efficiency at removing pollutants, such as PM_{2.5}.) Recent research has found that HVAC systems with high-efficiency filters can be effective at improving indoor air quality, but the level of effectiveness varies. For example, a [2020 study](#) found that MERV 14E filters were about 40 percent effective on average at reducing PM_{2.5}, with a range of between 15 percent and 90 percent depending on the characteristics of the homes and HVAC systems.
- **Operating Portable Air Purifiers.** Another effective way to filter indoor air is to use a portable, stand-alone air purifier. A [2021 literature review](#) by the United States Environmental Protection Agency concluded that portable air purifiers reduce indoor PM_{2.5} concentrations by 40 percent to 90 percent, depending on the characteristics of the buildings and the study design. Notably, a [2017 study](#) modeled various options for improving air filtration in homes during Southern California wildfire events and found that the long-term benefits of these air purifiers (as measured by the value of reduced mortality) generally outweigh the costs.

Reducing Outdoor Exposure and Activity Level. One approach to reducing wildfire smoke exposure is to go inside where air can be filtered. When remaining outside, exposure can be reduced by evading strenuous activities to avoid taking in higher volumes of air—and pollutants—

in each breath. Notably, over a longer period, reduced activity levels can lead to other negative effects, so this approach may have some trade-offs.

Using Respiratory Protective Equipment When Outdoors. Particularly when outside, wearing a respirator or a high-quality mask, such as an N95 mask or equivalent, can help reduce smoke effects. N95 masks are certified to filter out at least 95 percent of airborne particulates of at least 0.3 microns in size, and studies show that they can filter pollutants from smoke. However, the real-world effectiveness of these masks varies greatly depending on their quality and fit.

Barriers Exist for Implementing Smoke Mitigations. The approaches discussed above rely on people taking individual steps to protect themselves from smoke, but such actions may not always be possible. In practice, individuals may not always know when smoke levels are elevated or what steps they should take. Additionally, even if they do have this information, it is not always feasible for people, particularly those with limited resources, to undertake the approaches discussed above. For example, some people have job responsibilities that make leaving areas affected by smoke or remaining indoors impossible. Those who can remain indoors still may face barriers to keeping their indoor air clean. For example, people do not always have control over the quality of the air in the indoor spaces they occupy for large portions of the day, such as their workplaces or schools. Also, the cost of electricity and high-efficiency filters for HVAC systems can be cost-prohibitive for low-income households. Additionally, some homes lack HVAC systems, and low-income households may find purchasing and operating portable air purifiers unaffordable. Also, for those without HVAC systems, indoor temperatures can sometimes become intolerably warm if windows are shut. An additional complication is that wildfires can be accompanied by power shutoffs, which prevent the use of HVAC and portable air purifier systems. In concept, providing clean indoor spaces in community centers—which can be outfitted with high-quality air filters and powered by backup power sources—can help households that are not able to maintain good air quality in their homes. However, for these centers to be effective, making

them sufficiently accessible and comfortable for people to stay long enough to effectively reduce their smoke exposure is essential. As noted in a [2020 report](#) by the National Academies of Sciences, Engineering, and Medicine, evidence is still lacking on how effective these centers of Sciences, Engineering, and Medicine are at improving respiratory health in practice.

Existing Government Activities to Address Effects of Wildfire Smoke

Many Entities Have Roles and Responsibilities for Addressing Wildland Fire Smoke. As shown in [Figure 8](#), several agencies at various levels of government have responsibilities related to wildland fire smoke, including those related to providing people with information and overcoming other barriers to implementing the mitigation measures discussed above. For example, at the local level, air quality management districts (AQMDs) play a key role in collecting and tracking local air quality data and issuing air quality advisories to help inform the public regarding smoke events. AQMDs also run some programs to help people take individual actions to mitigate smoke impacts. For example, the Bay Area AQMD launched a home air filtration program in 2021. This program provides portable air purifiers to low-income individuals with poorly controlled asthma. Additionally, AQMDs perform regional air quality planning activities and have certain air quality permitting responsibilities, such as for prescribed burns.

At the state level, two of the key entities involved in addressing wildland fire smoke include the California Air Resources Board (CARB) and the California Department of Public Health (CDPH). These departments have a variety of smoke-related roles in addition to their many other responsibilities. For example, CARB is responsible for coordinating, encouraging, and reviewing the efforts of all levels of government as they affect air quality. CARB also plays an important role in monitoring air quality, including during smoke events, by operating a network of permanent and portable air quality monitors in collaboration with local and federal partners. Additionally, CARB provides the public with information on smoke events and funds smoke-related research, among other activities.

State Agencies Are Undertaking Steps to Address Wildland Fire Smoke. State agencies currently are undertaking a number of smoke-related actions, consistent with their respective roles and responsibilities. For example, based on information provided by CARB and CDPH, we estimate that these two departments are spending roughly \$20 million annually on these and other efforts to related to wildfire fire smoke. Some of the recent or expanded efforts that state agencies are undertaking include:

- **Disseminating Information.** Recently, state agencies have been taking additional steps to share information about wildfire smoke. For example, in 2021, CARB launched a mobile application known as [California Smoke Spotter](#), which allows the public to track prescribed fires and wildfires, access information on air quality from air quality monitors and smoke forecasts, and set up alerts. Also, CDPH, along with CARB, [updated a document in 2022](#) that is intended to serve as a guide for local public health officials. This document summarizes information on sources of air quality information, populations at elevated risks from the effects of smoke, and strategies to reduce exposure. It also identifies some considerations for planning public health responses to smoke events.
- **Supporting Research to Fill Knowledge Gaps.** State agencies are funding new research to fill some of the gaps in the existing understanding of wildland fire smoke. For example, CARB is funding studies to better understand topics such as (1) the impacts of short-term exposure to particulate matter on lost work days; (2) the components of the smoke released when structures burn; and (3) the impacts of short-term, repeated exposure to wildfire smoke. Results from these studies are expected over the next few years. Additionally, CARB funded some research on prescribed fires in 2019-20 and has identified additional research on this topic as a continuing priority in its [2021-24 research plan](#).

Figure 8

Key Local, State, and Federal Agencies With Roles Related to Wildland Fire Smoke

Agency	Key Roles and Responsibilities
Local	
Air quality management districts (AQMDs)	<ul style="list-style-type: none"> • Collect and track local air quality data. • Issue public air quality advisories. • Run programs to help mitigate smoke impacts. • Conduct regional air quality planning activities. • Issue prescribed burn permits.
Local cities and counties, including health departments	<ul style="list-style-type: none"> • Issue public health advisories, including those related to wildfire smoke. • Operate community centers and other facilities where people can avoid smoke.
School districts	<ul style="list-style-type: none"> • Decide whether to cancel events or close schools in response to smoke events.
State	
California Air Resources Board	<ul style="list-style-type: none"> • Coordinates, encourages, and reviews the efforts of all levels of government as they affect air quality. • Operates air quality monitors in collaboration with local and state partners. • Provides public information, such as through the Smoke Spotter mobile application. • Funds research on wildfire smoke. • Provides grants to local AQMDs for Wildfire Smoke Clean Air Center program. • Regulates portable air purifiers.
California Department of Public Health	<ul style="list-style-type: none"> • Assesses public health effects of wildfire smoke and recommends protective measures. • Prepares guidance materials and disseminates information to the public. • Funds research on wildfire smoke.
California Department of Industrial Relations' Division of Occupational Safety and Health	<ul style="list-style-type: none"> • Issues regulations related to protecting employees from wildfire smoke.
California Office of Health Hazard Assessment	<ul style="list-style-type: none"> • Provides technical assistance assessing health risks.
California Department of Forestry and Fire Protection	<ul style="list-style-type: none"> • Suppresses and prevents wildfires on over 31 million acres of mostly privately owned land known as the State Responsibility Area (SRA). • Administers programs, such as the Forest Health grant program, that fund prescribed fire and other forest health activities. • Issues prescribed burn permits in the SRA.
Federal	
U.S. Environmental Protection Agency (U.S. EPA)	<ul style="list-style-type: none"> • Conducts Clean Air Act regulatory processes.
Various agencies participating in the Interagency Wildland Fire Air Quality Response Program	<ul style="list-style-type: none"> • Monitors and forecasts wildfire smoke levels. • Maintains AirNow website showing smoke and air quality information, in collaboration with U.S. EPA and other partners.
U.S. Forest Service	<ul style="list-style-type: none"> • Owns and manages about 15.5 million acres of federally owned forestland in California.

- **Developing Guidelines.** CDPH is in the process of implementing Chapter 412 of 2021 (AB 619, Calderon), which requires the department to develop a plan with recommendations and guidelines for counties to use in case of a significant air quality event caused by wildfires or other causes.

- **Launching Clean Air Center Pilot Program.** As required by Chapter 393 of 2019 (AB 836, Wicks), CARB is undertaking a \$5 million pilot program to establish a network of wildfire smoke clean air centers focused on vulnerable communities, in partnership with three local AQMDs. As of the preparation of this report, the AQMDs were in the process of awarding

grants to specific projects. Notably, the state also provided a total of \$185 million to the Strategic Growth Council (SGC) in the 2021-22 and 2022-23 budgets to establish community resilience centers, with another \$85 million planned for 2023-24. These centers, though not specifically focused on smoke, may help

serve as centralized locations where people can go to avoid smoke events, as well as other types of events such as heat waves. Along with this funding, the Legislature required SGC to provide annual reports identifying measurable outcomes achieved by the centers.

FORMULATING THE STATE'S FUTURE RESPONSE TO SMOKE

Given the significant health and other impacts from smoke—particularly for those who are vulnerable due to their age, health status, or socioeconomic factors—the Legislature may want to consider what additional steps, if any, it would like to take beyond those it is already supporting. In this section, we provide some initial guidance to the Legislature as it formulates its approach to addressing smoke from wildland fires in the coming years. We begin by identifying some types of additional actions that the state and other governmental agencies could take to address smoke. Next, we identify some criteria the Legislature could consider as it prioritizes across options for addressing wildland fire smoke.

Types of Actions State Could Consider Taking

State Has Various Options for Expanding Efforts. As shown in **Figure 9**, government entities, including the state, could consider taking several types of activities to build off of existing efforts to help address the issue of wildland fire smoke. For example, given that multiple agencies currently are involved, the state could undertake additional actions to facilitate greater coordination of California's response to wildland fire smoke. It could also undertake additional strategic planning activities, continue to work towards filling gaps in existing research, or provide more targeted assistance to vulnerable individuals to undertake mitigation measures (such as supporting a home air filtration program similar to that operated by the Bay Area AQMD).

Criteria the State Should Consider When Choosing Among Options

While the state could consider taking various actions to address the issue of smoke from wildland fires, not all of them may be feasible. In part, this is because the state does not have sole control over the issue. Rather, as mentioned previously, various non-state entities have important roles and responsibilities related to wildland fire smoke. Also, the state has limited funding and resources and faces a range of other important challenges to confront beyond just addressing smoke. Thus, targeting its funding and policy efforts will be critical for the state, so its limited resources can effectively achieve the greatest benefits. As it does so, we suggest that the Legislature focus on supporting the activities that meet certain criteria discussed below.

Activities That Lend Themselves to State Role. Some types of activities make sense for the state to undertake, rather than relying on individuals or local communities or local agencies. These include activities that are accomplished much more efficiently at a large scale (such as the development of educational materials and public information systems) and those that require statewide coordination (such as conducting statewide planning). Similarly, the state is well-positioned to support research and pilot projects that provide broad benefits by filling key gaps in knowledge. Finally, the state could take steps to mitigate the impacts of the smoke from prescribed fires it undertakes, such as by providing N95 masks. This is because, while prescribed

Figure 9

Potential Activities for Addressing Wildfire Smoke

Activity	Description
Coordination and planning	Undertaking planning activities and coordinating the efforts of the various entities with a range of roles and responsibilities.
Research and pilots	Supporting and conducting additional research and pilot projects to continue to improve understanding of the best and most cost-effective ways to address wildfire smoke. Facilitating the collection of additional information, such as by making it easier to identify smoke-related health effects in medical data.
Air quality monitoring	Maintaining and expanding networks of air quality monitoring equipment to improve the quality of information on smoke exposure.
Guidance	Providing greater guidance to local agencies and the public, such as what conditions should lead to cancellation of outdoor activities.
Regulatory requirements	Establishing additional regulatory requirements to help mitigate the impacts of smoke, such as activities employers should undertake to protect employees.
Education, information, and outreach	Providing more information to the public, such as regarding smoke levels and forecasted air quality.
Targeted individual and community assistance	Funding additional in-kind or financial assistance to offset the costs of undertaking mitigations, such as purchasing portable air purifiers.
Prescribed fire and other forest management activities	Supporting and conducting more prescribed fires to reduce the risk of high-severity wildfires, which tend to generate more harmful smoke.

fires likely are significantly less harmful than the large, severe wildfires that they help prevent, they still can create localized smoke impacts on nearby communities. If the state mitigates these impacts, it could make prescribed fires more acceptable to some communities, and thus help support the state's strategy to increase the use of beneficial fire on landscapes.

Activities That Fill Demonstrated Need.

The state and other governmental agencies already are undertaking some efforts to address wildland fire smoke, as discussed above. As such, ensuring that new or expanded activities focus on documented gaps in these activities will be important to avoid duplication and address unmet needs. (In some cases, gaps could occur because activities are not being funded currently, while in others current funding might be insufficient due to rising costs, such as from inflation.) For example, state, local, and federal agencies currently support various education and outreach activities related to wildland fire smoke. When deciding whether to expand these activities, the state will want to consider whether the current activities have significant deficiencies and, if so, how the proposed expansion would address them.

Cost-Effective Activities. To the extent possible, focusing on supporting areas where good evidence of cost-effectiveness exists is important. By funding activities that are the most cost-effective, particularly compared to other alternatives, the state can achieve the greatest benefits from a given level of expenditure. When considering cost-effectiveness, the state will want to ensure that analyses reflect measured efficacy in real-world settings (rather than, for example, a laboratory setting). This is because certain approaches, such as providing portable air purifiers and masks, rely heavily on individuals taking personal actions. Accordingly, given the various barriers that individuals may face to implementing them, the effectiveness of these approaches can depend heavily on whether and how they are used in practice. Notably, in some cases, while approaches may seem promising, evidence on cost-effectiveness may be lacking. In these cases, the state can play an important role in improving understanding by funding pilot projects that are designed to allow for robust program evaluation prior to implementing the project statewide.

Activities Targeting Vulnerable Populations. As it considers the potential merits of specific activities to reduce the impacts of smoke, the

Legislature also will want to target resources to individuals and communities who most need the assistance. As discussed above, some individuals are more vulnerable due to their health status, socioeconomic status, or other factors. In such cases, a strong argument exists for the state to provide in-kind or financial assistance to those who could not otherwise afford to undertake mitigation efforts. Additionally, given the disparities among communities, the Legislature could focus efforts on specific areas that are more vulnerable, such as those with higher baseline pollution levels, those located in greater proximity to fire-prone wildlands, or those that have fewer community resources to support local mitigation efforts.

CONCLUSION

Expecting that the state will eliminate all smoke from wildland fires is not realistic. In part, this is because fire is a natural part of California's landscape. As the state has learned, policies that attempt to exclude fire can contribute to poor forest health and ultimately lead to more severe wildfires than would otherwise be the case. Thus, smoke is likely to be an inevitable part of life for many Californians in the coming years, as wildland fires—both intentional prescribed fires and unintentional wildfires—cover more of the state's landscapes.

Given the significant health and other impacts from this smoke—particularly on those who are

Activities With Co-Benefits. The Legislature may seek to not only consider the direct benefits of interventions, but also the potential co-benefits. For instance, some of the activities that mitigate smoke impacts—such as improving access to portable air purifiers that improve indoor air quality—have been found to have other benefits, such as reducing exposure to and transmission of COVID-19 and other airborne viruses. Additionally, undertaking projects to improve forest health, such as through the introduction of prescribed fire, can have ecological and public safety benefits in addition to reducing the likelihood of large, intense wildfires that create the largest smoke impacts.

vulnerable due to their age, health status, or socioeconomic factors—the Legislature may want to consider what additional steps, if any, it would like to take to mitigate its negative effects. As we discuss, some key criteria for the Legislature to consider as it chooses among its options include: (1) whether the state is the appropriate entity to undertake the activity, (2) whether there is a demonstrated need for the activity, (3) the strength of the evidence of the activity's cost-effectiveness, (4) the extent to which activity targets vulnerable groups, and (5) the co-benefits the activity provides beyond reducing the impacts of smoke.

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