The Public Health Dimensions of California Wildfire and Wildfire Prevention, Mitigation and Suppression

Executive Summary

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PSE Bringing science to energy policy

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In recent years, California experienced the largest, most destructive and deadliest wildfires in its history.[1] Wildfires can cause fatalities and injuries, impair air quality for nearby and distant populations, and devastate the immediate area, leaving communities with often burned and hazardous landscapes and infrastructure. Over the last half-century, California has experienced a five-fold increase in annual burned acreage from wildfires.[2] Atmospheric aridity and fuel-drying, extended drought, and pathogen-impacted forests . all of which are driven and compounded by anthropogenic climate change — increase risks posed by wildfires.[3] Additionally, increased development at the wildland-urban interface (WUI) puts more individuals at risk of harm from these disasters.

Increased wildfire risks are driving California to re-evaluate its strategies to both prevent and suppress wildfires and to mitigate wildfire impacts. These strategies include, but are not limited to, prescribed burning, the use of chemical fire suppression and, more recently, the implementation of public safety power shutoffs (PSPS). However, various approaches to prevent and suppress wildfire and mitigate wildfire-related impacts in California also hold near- and long-term implications for public health, and may shift health burdens to different populations, geographies and timescales. To date, the public health implications of various wildfire prevention and mitigation strategies have not been thoroughly characterized and synthesized.

In this report we summarize and integrate scientific information on the public health dimensions of both wildfire and approaches to wildfire prevention, mitigation and suppression into a synthetic framework. Our approach consists primarily of 1) a review of the peer-reviewed literature, government reports, grey literature and news media and 2) interviews with local and State agency staff. The aim of this project is to better equip California agencies, researchers and risk managers to effectively manage wildfire-related risks in ways that incorporate data-driven public health information into decision-making.

Key findings, conclusions and recommendations

Below, we provide the key findings, conclusions and recommendations (FCRs) from our review of the literature, organized under overarching principles. The aim of these FCRs is to inform efforts to integrate public health into decision-making regarding wildfire emergency response and recovery and wildfire prevention, mitigation and suppression efforts in California. Additional detailed report findings, including specific examples and policy models aimed to mitigate potential health risks and identified research gaps and limitations, are summarized below in Table ES-1.

[1] CAL FIRE, 2020. *Stats & Events*. https://www.fire.ca.gov/stats-events/.

[2] Williams et al., 2019. Observed Impacts of Anthropogenic Climate Change on Wildfire in California. *Earth's Future*, *7*(8), 892–910. https://doi.org/10.1029/2019EF001210.

[3] IPCC, 2019. Summary for Policymakers: In: Climate Change and Land: An IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. https://www.ipcc.ch/site/assets/uploads/sites/4/2020/02/SPM_Updated-Jan20.pdf.

Principle #1. Integrated, dense, resilient, and rapidly deployable air quality surveillance is beneficial to assess smoke exposure during wildfires and prescribed burns.

Increase resolution of air quality monitoring

Finding 1.1. Existing stationary air monitoring networks are distributed across California with low spatial density, in particular in high wildfire risk areas. As such, real-time air quality data during wildfire and prescribed burn events are often not readily available.

Conclusion 1.1. While current stationary air monitoring networks support assessments of regional air quality, these networks may not reflect local air quality, introducing uncertainty to the information necessary to estimate wildland smoke exposure and engage in enhanced risk communication and management efforts. Rapid deployment of air quality monitors may be necessary to capture air quality data during wildland fire smoke events in areas that lack air quality monitors. Efforts underway pursuant to Assembly Bill 617 (AB 617) are forming a model of how spatial intensity of this coverage could expand.

Recommendation 1.1. Agencies with jurisdiction should integrate or support the integration of air quality data from disparate air quality networks throughout the State of California and support additional air quality surveillance in high wildfire risk areas and in areas of high population density. These efforts could build upon the AB 617 community air quality monitoring program as a model to expand geo-spatial intensity of air quality data. Researchers, as well as local and state air quality agencies should be prepared to capture air quality data in real-time as wildfires occur and build these data into publicly accessible and real time reporting tools. Emerging efforts by the California Air Resources Board may help to address some of these air quality monitoring needs.

Ensure zero-emission backup energy sources for air quality monitors

Finding 1.2. Air quality monitoring networks largely rely on power provided by utility-scale electricity transmission infrastructure to collect and transmit air quality data and this infrastructure is vulnerable to failure and de-energization during wildfires and public safety power shutoffs (PSPS), respectively.

Conclusion 1.2. In the event of PSPS and other unexpected power outages, air quality monitoring networks may fail to collect air quality data to inform decision-making, risk communication and risk management.

Recommendation: 1.2. Air monitoring networks should be supported by zero-emission back-up energy sources (e.g., solar arrays, battery power, or other distributed energy resources) to provide power in the event of unexpected or utility-initiated loss of access to electricity.

Characterize the chemical composition of wildfire and prescribed fire smoke

Finding 1.3. The chemical composition of wildfire smoke is highly variable and is dependent on multiple factors, including but not limited to the materials that burn and the temperature of combustion. Wildfires directly and indirectly, through atmospheric transformation, emit criteria air pollutants and various toxic air contaminants. Existing characterizations of wildfire smoke composition and associated exposures often focus on criteria air pollutants, primarily particulate matter and ozone. Air pollutant emissions from prescribed burns may differ from air pollutant emissions from wildfires, particularly wildfires that result in the combustion of structural materials (e.g., homes, cars, businesses, etc.). Relatedly, few studies evaluate the differences in smoke composition between prescribed burns and wildfires.

Conclusion 1.3. While studies have investigated the patterns and concentrations of particulate matter and tropospheric ozone associated with wildfire smoke, these studies are limited by the exclusion of a wider range of health-damaging air pollutants that may also be present (e.g., toxic air contaminants). Expanded information regarding the concentration and distribution of chemicals in wildfire smoke and prescribed fire smoke will help inform risk communication and management efforts aimed to protect populations from the impacts of both wildfire and prescribed burn activities.

Recommendation 1.3. Agencies with jurisdiction should support air quality and exposure surveillance that includes a broader array of health-damaging air pollutants beyond criteria pollutants including, but not limited to VOCs and ultrafine particles. This information should be integrated into risk communication and management efforts. Further, agencies with jurisdiction could support air quality monitoring and research that identifies and characterizes the drivers of wildfire smoke composition. Future exposure and risk assessments should consider multiple pollutant exposures associated with smoke from wildfire and further research is also needed to assess chronic (repeated) exposure to prescribed fire smoke and potential health risks.

Principle #2. Detailed and integrated health outcome surveillance during and following wildfire is necessary to support epidemiological investigations, identify disproportionate health risks and impacts, and implement effective public health interventions.

Evaluate additional health outcomes and chronic (repeated) exposures and outcomes

Finding 2.1. The existing peer-reviewed literature indicates a positive association between wildfire smoke exposure and various adverse health outcomes, including eye irritation, respiratory outcomes (asthma exacerbation, bronchitis, dyspnea and chronic obstructive pulmonary disease, and increased hospital admissions for respiratory illness); adverse birth outcomes; out-of-hospital cardiac arrests, and premature mortality. Commonly used public health metrics (deaths, hospitalizations, emergency department visits) do not comprehensively measure the total public health impact of wildfire smoke exposure, as these measures exclude subclinical or asymptomatic effects and impacts that take time to manifest.

Conclusion 2.1. The literature focused on associations between wildfire smoke exposure and various health outcomes is expansive for some health outcomes, and limited for others. For instance, health studies in populations repeatedly exposed to wildfire fire smoke have not been undertaken. A comprehensive health surveillance system would help to quantify the magnitude of health effects that result from wildfires and could result in more effective public health interventions.

Recommendation 2.1. Future research on health impacts associated with wildfire smoke exposure should assess understudied health outcomes including, metabolic disorders, pediatric cognitive development, cognitive decline among older adults, maternal health, as well as mental health outcomes and health outcomes with long latency (e.g., cancer). Long-term surveillance of populations repeatedly exposed to wildland fire smoke can help to evaluate the effects of repeated exposures. Additionally, stress should be examined for its role in the relationship between wildfire smoke exposure and various health outcomes.

Support mental health surveillance and mental health services

Finding 2.2. Events associated with wildfires (e.g., destruction of home and community, the process or threat of evacuation, and perception of risk) may contribute to mental health burdens or exacerbate existing mental health conditions in affected communities.

Conclusion 2.2. Mental health impacts can be mitigated by ensuring sufficient services are available to meet the needs of populations undergoing traumatic events. Mental health research may be informed by recent wildfire events and other natural disasters.

Recommendation 2.2. Additional studies are needed to evaluate wildfire smoke exposure and mental health outcomes, as wildfire smoke events may increase in frequency and intensity for certain populations due to climate change and other drivers. Mental health outcomes should be included in health surveillance during and after wildfire events, as well as an exploration of other factors tied to wildfires that influence mental health (e.g., the potential increase in experiences of homelessness in communities where properties have been damaged by fire). Studies can additionally evaluate more widespread mental health impacts associated with wildfires on broader populations via vicarious traumatization.

Principle #3. Strategic deployment of distributed clean energy resources can provide backup power to support critical services during wildfires, public safety power shutoffs (PSPS) and other natural disasters and grid outages.

Finding 3.1. PSPS – or the de-energization of electricity transmission infrastructure – is a critical tool to prevent wildfires. However, the continuity of electricity in communities is also fundamental to support critical public health services during wildfires and other natural disasters. During the 2019 wildfire season, public safety power shutoffs (PSPS) for wildfire prevention resulted in numerous documented impacts to public health and safety.

These health and safety implications of PSPS are noted at various settings, including residential (e.g., the inability to refrigerate medications and food, breast milk, pump water, filter indoor air, and regulate indoor temperature, power medical devices, and access emergency information via the internet); community (e.g., inability to pump and deliver water through distribution systems, traffic accidents due to traffic light outages; lack of cellular network for communication); and healthcare settings (e.g., rescheduling of medical procedures). Distributed clean energy resources (e.g., solar+storage systems) provide electricity and can serve as backup power options that, unlike diesel-powered generators, do not contribute to the cumulative burden of climate-forcing and health-damaging air pollutants.

Conclusion 3.1. PSPS should remain a tool available to reduce risk of wildfires. However, creating resilient and reliable electric power systems and preparing communities for power outages are critical to address decrease public health impacts of PSPS. PSPS also present health hazards, risks and impacts for populations both within and outside of wildfire risks areas. Distributed clean energy resources (e.g., solar and battery storage) can provide essential electricity to residences, critical facilities, and communities at large during wildfires, PSPS and other emergencies and natural disasters.

Recommendation 3.1. Agencies with jurisdiction should support advanced grid solutions to monitor for wildfire risk and implement targeted, rather than widespread, PSPS, when possible. Agencies with jurisdiction should support the development and siting of distributed clean energy resources to provide backup power and support critical services during wildfires, PSPS and other natural disasters and grid outages. Approaches to support the proliferation of these energy resources could be in the form of market-based incentives (e.g., rebates and financial incentives), power procurement requirements, or energy requirements during post-disaster community rebuilds.

Principle #4. Small-scale biomass-to-energy facilities should be evaluated further in the context of energy reliability, wildfire risk mitigation, and impacts to air quality compared to other vegetation management practices.

Finding 4.1. Vegetation management is an important pillar of wildfire risk management. Wood biomass in wildfire prone areas of the state may either be burned by wildfire, combusted via prescribed or pile burns or burned to generate electricity, all of which contribute to degraded air quality. Traditional direct combustion biomass facilities in California are among the highest sources of particulate matter (PM) and nitrogen oxides (NO_x) on the California electric grid. Small-scale gasification technologies (e.g., biochar) result in lower NO_x emissions, but in the United States these technologies are less mature and more expensive, and therefore less common. The health implications of wood biomass utilization for electricity generation are largely dependent on the quantity of fuels used, technology used to generate electricity or heat, the location of these facilities, the timing of use with respect to air quality and atmospheric conditions and the proximity, density and demographic characteristics of nearby populations.

Conclusion 4.1. Approaches to vegetation management should take air quality and public health factors into consideration. Strategic siting of future small-scale, distributed biomass facilities and ongoing operation of existing facilities should consider potential air quality and health impacts and key tree mortality and vegetation management zones.

Recommendation 4.1. Additional research should be undertaken to evaluate human health, energy reliability, air quality, ecological, and other implications associated with approaches to vegetation management. Research should evaluate the differential impacts to air quality between vegetation management techniques including but not limited to wildfire, prescribed and pile burns, and the siting of small (e.g., 5 MW), distributed biomass-to-energy facilities in key vegetation management zones to provide simultaneous benefits of fuel reduction and more resilient access to power in places that may also be likely to experience wildfire and PSPS. Detailed tracking of biomass from fuel reduction efforts can be used to verify that biomass is combusted in settings that prioritize reducing air quality impacts (e.g., biomass-to-energy facilities vs. open pile burns). Additional research and investment into cost reduction for emerging, distributed and lower-emission biomass gasification systems could also be explored.

Principle #5. While chemical fire suppressants are critical to protect human life and infrastructure from wildfire, numerous uncertainties remain regarding potential health risks associated with the use of these compounds.

Finding 5.1. While some ingredients in chemical fire suppressants are well-characterized, complete chemical formulations of fire retardants and foams are considered trade secrets and are not publicly disclosed.

Conclusion 5.1. Public disclosure of chemical formulations in chemical fire suppressants is essential to assess potential risks to human health and the environment.

Recommendation 5.1. Chemical formulations of fire suppressants should be publicly disclosed. Compounds in chemical fire suppressants that pose risks to human health or the environment or have unknown toxicological profiles should be replaced by substances with known toxicological profiles that pose little to no toxicity to human health and the environment. Alternatives assessments should require that alternatives have well-characterized chemical compositions, are evaluated for ecotoxicity and toxic potential in humans, and are tested to ensure performance standards are met.

Principle #6. Wildfire response and wildfire-related public health interventions need to be re-evaluated and adapted amid the COVID-19 global pandemic.

Finding 6.1. COVID-19, an infectious disease caused by an emergent coronavirus (SARS-CoV-2), is now a global pandemic affecting the global human population with no known treatment or vaccine. Key wildfire mitigation strategies including evacuations (e.g., transport and indoor sheltering of displaced populations) and clean air spaces (e.g., indoor public spaces that provide filtered air to reduce wildfire smoke exposure) present physical conditions that are clear risk factors for transmission of COVID-19, particularly if additional precautionary measures are not undertaken.

Conclusion 6.1. Strategies to mitigate health and safety risks associated with wildfire through existing wildfire emergency response efforts (e.g., evacuations and indoor shelters) and proposed public health interventions (e.g., clean air spaces) may increase risk of COVID-19 transmission among wildfire-impacted populations.

Recommendation 6.1. Multiple agencies have already begun efforts to re-evaluate typical wildfire emergency response activities in the context of COVID-19, and these efforts should continue to adapt to evolving circumstances. Agencies with jurisdiction should follow current and future CDC, WHO, and state and local health department guidance to reduce the spread of COVID-19 during wildfire emergency response activities and wildfire smoke exposure interventions, such as wearing face coverings, in particular when adequate physical distancing may not be possible.

In Table ES-1 below, we provide a summary of our report findings, including the health hazards risks and impacts associated with wildfire and approaches to wildfire prevention, mitigation and suppression; strategies and policy models to mitigate potential public health risks; and identified research gaps and limitations. It is important to note that this summary table aims to provide different policy models and examples aimed to mitigate potential human health risks associated with wildfire and approaches to wildfire prevention, mitigation and suppression, but it is not meant to be comprehensive.

Table ES-1. Summarized report findings, including health hazards risks and impacts associated with wildfires and approaches to wildfire prevention, mitigation and suppression; strategies and policy models to mitigate potential public health risks; and identified research gaps and limitations. (Note: This summary table aims to provide different policy models and examples aimed to mitigate potential human health risks associated with wildfire and approaches to wildfire prevention, mitigation and suppression, but it is not meant to be comprehensive).

	Summary of health hazards, risks and impacts	Strategies to mitigate potential health risks	Policy model(s) / example(s)	Research gaps and limitations
The Public Health Dimensions of Wildfire *(Section 2.0)*				
Air quality *(Section 2.1)*	• Wildfires emit numerous health-damaging air pollutants, including criteria air pollutants, toxic air pollutants, ultrafine particulate matter, and ozone precursors. • The composition of wildfire smoke is dependent on the size and intensity of the fire, the chemical composition of materials combusted and oxygen availability. As such the composition of wildfire smoke plumes can vary greatly across geographies and even within a single fire event. • Exposure to wildfire smoke is associated with: eye irritation; respiratory illnesses (asthma exacerbation, bronchitis, dyspnea and chronic obstructive pulmonary disease); adverse birth outcomes; cardiovascular disease, and premature mortality. • Certain population subsets may be disproportionately impacted by wildfire smoke exposure. These populations include: children, pregnant women, older adults, outdoor workers, people with underlying respiratory or cardiovascular conditions; socioeconomically disadvantaged populations, • Children, pregnant women, older adults, outdoor workers, people with preexisting respiratory and cardiovascular conditions, people experiencing homelessness, and socioeconomically disadvantaged populations are disproportionately impacted by exposure to wildfire smoke. • Wildfire smoke can be transported vast distances, in many cases increasing the number of people exposed. High $PM_{2.5}$ concentrations during California wildfire events often extend beyond California air basins, traveling from the basin where the active burn occurs and into neighboring regions.	**Offering public access to forecasted local air quality and real-time air quality data shared in a public health context.** Ideal air monitoring networks would include data with high spatial and temporal resolution, equipped with resilient back-up power (e.g., solar+storage) in the case of power outages.	• **Air Quality Index (AQI)** – index placing air quality in a health context. • **AirNow** - Real- time and daily forecasts. • **PurpleAir**- Global network of low-cost sensors. • **California Air District websites** (e.g., BAAQMD). • **AB 617** Community Air Monitoring Networks (CARB AQview).	**Further characterization of wildfire smoke exposure is needed. Future investigations should consider:** • pollutants beyond $PM_{2.5}$, such as VOCs, PAHs, ultrafine PM, speciated PM. • evaluating pollutants relevant to structural fires. • multiple pollutant exposures. • additional air monitoring in high wildfire-risk communities. **Studies evaluating the relationship between wildfire smoke exposure and health outcomes:** • commonly use public health metrics (deaths, hospitalizations, ED visits) that do not represent the total public health impact of wildfire smoke exposure as they exclude, subclinical or asymptomatic effects. • should evaluate metabolic disorders, childhood development, cognitive decline, maternal health, as well as mental health outcomes and health outcomes with long latency. • should investigate repeated exposed to wildfire smoke and the influence of stress in relationship between wildfire smoke exposure and various health outcomes. **Evaluations should address effectiveness of public health interventions in reducing wildfire smoke exposure in different settings. For example:** • N95 respirator use among outdoor worker, vulnerable populations, and the general population. • AQI interpretation and use among general populations, especially sensitive receptors • reach and effectiveness of smoke response emergency response and planning and translated materials for hard to reach populations (e.g., non-English speaking populations). • optimal conditions for clean air community spaces (e.g., duration of availability).
		Incentives for indoor air purification technologies and provision of clean air community spaces. Incentives (e.g., cost reduction, rebates) can bolster the use of air purification technologies in residential and community settings. Public access to community spaces (e.g., libraries, youth centers, shopping malls) with air filtration during wildfire smoke events can reduce wildfire smoke exposure.	• During the 2018 Camp Fire, San Francisco Department of Emergency Management maintained and provided access to a list of clean air spaces on an online map. • **AB 836**: Wildfire Smoke Clean Air Centers for Vulnerable Populations Incentive Pilot Program.	
		Respiratory protective equipment: Recommended when outdoor and low-intensity activity cannot be avoided. Proper use of N95 masks can significantly reduce exposure to particulate matter in wildfire smoke.	• **CDPH Wildfire Smoke: Guide for California Public Health Professionals (CDPH)** provides detailed respirator guidance.	
		State-issued regulations to protect worker health during wildfires: Requires employers to communicate wildfire smoke hazards, train employees about the health effects of wildfire smoke and how to find the current AQI for $PM_{2.5}$, provide respirators and implement engineering controls or change workers' schedules to reduce exposures.	• **Cal/OSHA §5141.1**: Protection from Wildfire Smoke.	
		Inclusive educational materials, emergency planning and response for wildfire smoke events: Public access to air quality emergency notification alerts and accessible, translated materials regarding wildfire smoke exposure, respirators and in-home air filtration options. Local health departments can also coordinate with community-based organizations to identify vulnerable individuals that may benefit from additional outreach and/or wellness checks during poor air quality events.	• Bay Area Regional Air Quality Messaging Toolkit. • Alerts from local agencies (e.g., via Nixle). • **AB 661**: Wildfire Smoke Air Pollution Emergency Plan: Sacramento Metropolitan Air Quality Management District. • **SB 160**: Emergency services: cultural competence.	
		Coordinated health surveillance during wildfire smoke events: Comprehensive surveillance system of the health effects from wildfires and wildfire smoke events, including public and private healthcare providers.	• San Mateo County Health, Council of State and Territorial Epidemiologists (CSTE) Climatic Exposures and Respiratory Health Outcomes Pilot (CERHOP).	

	Summary of health hazards, risks and impacts	Strategies to mitigate potential health risks	Policy model(s) / example(s)	Research gaps and limitations
The Public Health Dimensions of Wildfire *(Section 2.0)*				
Water quality *(Section 2.2)*	• California forested lands contain numerous key watersheds. 60% of the California water supply originates in the Sierra Nevada alone. • Wildfire events often increase erosion and subsequent sediment loads in surface waters, which can lead to impaired infrastructure, increased treatment demands, and increased formation of disinfection byproducts, some of which have been found to be toxic. • Water quality impacts can occur during wildfire events and for months and years after. • Recent California wildfires have resulted in volatile organic compound (VOC) contamination in water distribution systems. • Small, single source water systems in high wildfire risk areas may be at greatest risk of devastating wildfire-related impacts.	**Watershed quality assurance post-wildfire:** Erosion controls and silt collection devices are used on fire damaged properties. Potential sources of water contamination, including animal carcasses, hazardous waste and other debris are removed from landscapes and disposed of.	• California **Debris Management Task Force** led by CalEPA. • **Debris Management Teams** aim to limit impacts to water resources (e.g., response following the 2018 Woolsey Fire, Consolidation Debris Removal Program). *(For additional information on debris and hazardous waste removal, see Section 2.3, Soil and Crops.)*	• Toxicological profiles of unregulated disinfection byproducts, which have been detected in treated water post-wildfire, are not fully elucidated. • The mechanism(s) driving recent VOC contamination of water distribution systems post-wildfire are currently being explored. • Best practices need to be developed for: 1) mitigating VOC contamination in water distribution systems post-wildfire (e.g., consider materials used in distribution components and ways to isolate contamination); 2) testing throughout wildfire-impacted distribution systems; and 3) handling and disposing of VOC contaminated materials (e.g., contaminated water, contaminated water distribution infrastructure).
		Potable and drinking water management: Water providers take steps to re-pressurize systems, repair source intakes and leaks, conduct water quality testing throughout water treatment and distribution systems, and replace portions of systems, if warranted. Water advisories may be issued including Boil Water orders or Do-Not-Drink and Do-Not-Boil orders, depending on contaminants of concern.	• **Paradise Irrigation District** response following the 2018 Camp Fire (e.g., Water System Recovery Plan). • **City of Santa Rosa Water** response following the Tubbs Fire (e.g., Post-Fire Water Quality Updates).	
Soil and Crops *(Section 2.3)*	• Soil and vegetation burn can release nutrients and contaminants (e.g., PAHs, mercury) and inhibit the ability of water to infiltrate into soils. • Wildfire also can cause soil destabilization, particularly along steep slopes, increasing the risk of debris flows that may damage or destroy nearby buildings and infrastructure and result in loss of life. • Agricultural soils and crops may also be impacted by wildfires and wildfire-associated debris and ash.	**Debris and hazardous waste removal:** Includes coordinated handling, removal and disposal of burned and otherwise damaged materials in wildfire-affected areas, including burned structural materials (e.g., homes, vehicles, household items. other infrastructure).	• **Los Angeles County Department of Public Works** response following the 2018 Woolsey Fire (e.g., Consolidation Debris Removal Program). • **CA DTSC** Emergency Guidance on Wildfires #1: Handling Ash, Debris, and other Hazardous Materials from Burned Structures. • **CA DTSC** Emergency Guidance on Wildfires #2: Management Options for Expedited Collection of Hazardous Wastes from Burned Areas.	• More detailed characterizations of soils in developed wildfire-affected areas could further inform future remediation efforts. • Additional research is needed to assess uptake of wildfire-associated contaminants into a variety of crops.
		Post-fire debris-flow hazard assessments: Characterizes risk of soil destabilization and debris flow in wildfire-affected areas given local conditions (e.g., slope gradient, extent of reduced infiltration capacity of soils).	• **USGS** Emergency Assessment of Post-Fire Debris-Flow Hazards.	
		Soil testing in agricultural soils: Soils used for agricultural — from backyard gardens to large-scale farms — may need to be tested in areas directly impacted by wildfire or wildfire ash.	• **University of California Cooperative Extension Sonoma County**: Produce Safety after Urban Wildfire.	

	Summary of health hazards, risks and impacts	Strategies to mitigate potential health risks	Policy model(s) / example(s)	Research gaps and limitations
The Public Health Dimensions of Wildfire *(Section 2.0)*				
Mental health *(Section 2.4)*	• Events associated with wildfires including destruction of homes and forced evacuation of communities may contribute to mental health burdens or exacerbate existing mental health conditions. • While more research is required to understand the potential mental health impacts on populations exposed to wildfire smoke, studies evaluating associations between mental health outcomes and $PM_{2.5}$ exposure broadly indicate increased depressive and anxiety symptoms, increased emergency department visits for psychiatric concerns, and higher perceived stress. • Limited studies evaluating the direct and indirect experiences associated with wildfires also show evidence of related mental health impacts, including grief, acute stress, exacerbation of underlying disorders, symptoms of depression and symptoms of vicarious traumatization or secondary trauma. • Additionally, wildfires and other natural disasters can interrupt provision of mental health services for those that require additional services and for the general population during and after a fire.	**Mental health surveillance:** Data on mental health outcomes included in broader health surveillance during and after wildfire can inform allocation of resources to support mental health services and can inform efforts to anticipate needs of future wildfire events. **Provision of support services during and after wildfire:** An adequate supply of mental health professionals is necessary to respond to wildfires and other emergencies and natural disasters. Resources and staff are particularly needed to address the mental health needs of children and adolescents following disasters.	• **Healthcare Foundation Northern Sonoma County** Wildfire Mental Health Collaborative. • PsySTART Rapid Mental Health Triage and Incident Management System.	• Additional studies are needed to evaluate wildfire smoke exposure and mental health outcomes, as wildfire smoke events may increase in frequency and intensity for certain populations due to climate change and other drivers. Future studies evaluating wildfire smoke exposure should also assess impacts on mood and cognition, especially among vulnerable populations such as children and the elderly. • Mental health outcomes should be included in health surveillance during and after wildfire events, as well as an exploration of other factors tied to wildfires that influence mental health (e.g., the potential increase in experiences of homelessness in communities where properties have been damaged by fire). • Studies can additionally evaluate more widespread mental health impacts of wildfires on the broader populations that may experience secondary trauma, including those living in close proximity to wildfire-affected areas and those living in communities that absorb displaced populations after wildfire. • Future evaluations are needed to anticipate delivery of mental health services to guide preparation and response efforts for future wildfire events.

	Summary of health hazards, risks and impacts	Strategies to mitigate potential health risks	Policy model(s) / example(s)	Research gaps and limitations
The Public Health Dimensions of Wildfire Prevention, Mitigation and Suppression *(Section 3.0)*				
Public safety power shutoffs *(Section 3.1)*	**Within the home, lack of electricity limits one's ability to:** • Safely store and refrigerate food, medication and breastmilk; • Run pumps for water wells or septic systems; • Power or charge electric or battery-operated medical devices; • Charge electric bikes or cars; • Filter indoor air and regulate indoor temperatures; and • Access emergency information via the internet. **In a community setting, lack of electricity can cause:** • Inability to pump water throughout water distribution systems; • Increases in traffic accidents on roads due to traffic light outages; • Closures of schools, offices, businesses, and community spaces which may result in lost wages; and • Limited or lack of cellular network for communication; and • Limited or lack of air quality monitoring data. **In medical settings, lack of electricity can result in:** • Rescheduling of medical procedures; • Transporting patients to other facilities; • Placing burden on those individuals and facilities with various electricity-dependent requirements (e.g. comorbidities, elderly care facilities).	*Strategies to reduce fire risk from power lines*		• Development of a formalized process for documenting potential health and safety impacts associated with public safety power shutoffs. • Comprehensive identification of medical baseline customers and other at-risk and vulnerable populations is needed. • Investigations into disproportionate impacts of PSPS events is warranted. • Identification of resilient sites for strategic deployment of distributed energy resources statewide, with an emphasis on communities that may be disproportionately impacted by wildfire, natural disasters, PSPS and other grid outages. • Effectiveness of utility and State agency efforts to mitigate public safety power shutoffs risks and impacts need to be evaluated, with particular focus on vulnerable and hard to reach populations.
		Grid inspections and vegetation management: Transmission and distribution power infrastructure require ongoing inspection and maintenance to remove tree branches and other vegetation growing too close to electric lines.	• Monitoring technology for inspections, including drones and video cameras, as well as physical inspections (e.g., SoCal Edison recently installed weather stations, high-resolution cameras, etc.) • **SB 167**: Electrical corporations: wildfire mitigation plans.	
		Burying wires: Undergrounding electric wires significantly reduces risk of ignition, but can be prohibitively expensive and time-consuming. **Grid hardening:** Hardening grid infrastructure includes covering exposed wires and replacing poles and transformers with more fire-resistant alternatives.	• As Paradise (CA) rebuilds following the 2018 Camp Fire, PG&E commits to put all electric distribution power lines underground. • **SB 70**: Electricity: undergrounding of electrical infrastructure.	
		Strategies to create a resilient electric power system		
		Residential solar+storage: Household-level solar+ storage systems can provide resilience during PSPS events and other emergencies while supporting the transition to a clean, low-carbon electric grid. **Islandable solar:** Solar photovoltaic systems are typically set up such that they do not provide electricity when the grid at large goes down. However, the inclusion of a separate disconnect on solar systems can allow them to island from the grid and provide electricity while the sun is shining. This would provide less resilience than a solar+storage system, but at a significantly lower cost. **Solar+storage for critical facilities and resources:** Solar+storage can provide back-up for critical facilities, including hospitals, clinics, police and fire stations, water treatment facilities, emergency responders and food distribution centers. In addition, solar+storage can help ensure that traffic lights, street lights, communications infrastructure and water distribution systems continue to function during grid outages. **Resilient community centers:** Resilient community centers are sites that can be equipped with solar+storage to provide a safe place for community members to receive critical support during grid outages. Potential resilient community sites include cooling centers, gyms, libraries, schools and other public buildings. **Microgrids:** Solar, storage, and other generation resources can be integrated across larger regions to island from the electric grid to provide resilience during blackouts.	• **Comparative tool for emergency backup power options** (CARB Emergency Backup Power Options - Residential). • AB 1144: Self-generation incentive program: community energy storage system, high fire threat districts. • **City of Fremont Fire Station Microgrids.** • Proposed clean-energy microgrid community for select facilities (e.g., public buildings, schools, community centers) in downtown Berkeley (Berkeley Energy Assurance Transformation, BEAT). • The **Blue Lake Rancheria tribe microgrid** equipped to provide power to an estimated 8% of the county's population during the PSPS events in October 2019. • **Montecito Community Microgrid Initiative.**	

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<tr><td colspan="5">The Public Health Dimensions of Wildfire Prevention, Mitigation and Suppression (Section 3.0)</td></tr>
<tr><td rowspan="7">Public safety power shutoffs
(Section 3.1)</td><td rowspan="7">Within the home, lack of electricity limits one's ability to:
• Safely store and refrigerate food, medication and breastmilk;
• Run pumps for water wells or septic systems;
• Power or charge electric or battery-operated medical devices;
• Charge electric bikes or cars;
• Filter indoor air and regulate indoor temperatures; and
• Access emergency information via the internet.

In a community setting, lack of electricity can cause:
• Inability to pump water throughout water distribution systems;
• Increases in traffic accidents on roads due to traffic light outages;
• Closures of schools, offices, businesses, and community spaces which may result in lost wages; and
• Limited or lack of cellular network for communication; and
• Limited or lack of air quality monitoring data.

In medical settings, lack of electricity can result in:
• Rescheduling of medical procedures;
• Transporting patients to other facilities;
• Placing burden on those individuals and facilities with various electricity-dependent requirements (e.g. comorbidities, elderly care facilities).</td><td colspan="2">Strategies to create a resilient electric power system (continued)</td><td rowspan="7">• Development of a formalized process for documenting potential health and safety impacts associated with public safety power shutoffs.
• Comprehensive identification of medical baseline customers and other at-risk and vulnerable populations is needed.
• Investigations into disproportionate impacts of PSPS events is warranted.
• Identification of resilient sites for strategic deployment of distributed energy resources statewide, with an emphasis on communities that may be disproportionately impacted by wildfire, natural disasters, PSPS and other grid outages.
• Effectiveness of utility and State agency efforts to mitigate public safety power shutoffs risks and impacts need to be evaluated, with particular focus on vulnerable and hard to reach populations.</td></tr>
<tr><td>Diesel generators: Diesel generators can supply critical power during outages. However, diesel combustion releases criteria pollutants such as particulate matter as well as greenhouse gases.</td><td>During 2019 PSPS events:
• Caltrans used diesel generators to support the Caldecott Tunnel (Oakland).
• Portable generator was deployed at pump station to provide water for the City of Vallejo.</td></tr>
<tr><td>Advanced grid infrastructure: Modernization of grid infrastructure, including smart meters, synchrophasors, flexible electric loads, and other forms of grid flexibility and demand management, can allow the utility to identify outages and other problems and shut off and restart portions of the grid remotely.</td><td>SDG&E has integrated technologies to remotely turn off parts of the grid.</td></tr>
<tr><td colspan="2">Additional strategies to prepare and support communities</td></tr>
<tr><td>Support telecommunications and emergency notifications during PSPS events: Includes preparation for power outages in communities that may be isolated during PSPS and development of protocols for rapid response to outages that may impact communication.</td><td>• SB 670: Telecommunications: community isolation outage: notification.
• SB 560: Wildfire mitigation plans: deenergizing of electrical lines: notifications: mobile telephony service providers.</td></tr>
<tr><td>Preparation to mitigate health and safety impacts associated with PSPS for vulnerable populations: Develop protocols related to mitigating public safety impacts of power shutoffs on vulnerable populations, including those receiving medical baseline allowances.</td><td>• SB 167: Electrical corporations: wildfire mitigation plans.
• During 2019 PSPS, the City of Vallejo in partnership with Touro University and Solano County, performed wellness checks on those with medical needs.</td></tr>
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<tr><td colspan="5">Forest management strategies (Section 3.2)</td></tr>
<tr><td rowspan="4">Wildland-urban interface policies
(Section 3.2.1)</td><td rowspan="4">• An estimated 4.46 million homes are located and 11.2 million people live within the WUI in California, more than any other state.
• Increased development at the WUI represents the introduction of fuel and the alteration of local fire regimes, which may affect fuel loading and exacerbate wildfires and their associated impacts.
• WUI policies include wildfire risk identification, creation of defensible space, vegetation management, home hardening, disincentivizing development within the WUI and managed retreat.
• WUI policies overwhelmingly protect public health and safety.</td><td>Risk communication for all residing in the WUI: Clearly communicating risk to those living in the WUI, including permanent residents, as well as seasonal or temporary residents.</td><td>• AB 38: Fire safety: low-cost retrofits: regional capacity review: wildfire mitigation</td><td rowspan="4">• Detailed tracking of populations movement to and from WUI areas in California could inform current WUI policies and future projections of wildfire risk among populations in the WUI.
• Local and regional planning departments could evaluate managed retreat strategies from high risk WUI areas and the capacity to promote urban infill to reduce wildfire risk for populations in proximal WUI regions in California.</td></tr>
<tr><td>Utilize safe fire-resistant building materials: This includes the further development, evaluation, and implementation of safe fire-resistant building materials. These materials may include wood treated with flame retardants, or foams used in combination with concrete. Fire-resistant building materials should be well-characterized and evaluated to ensure that they pose little to no risk to human health and the environment under normal conditions and in the event of conflagration.</td><td>• Designated fire-resistant materials include ignition materials listed by the State Fire Marshal and materials that have been tested in accordance with SFM Standard 12-7A-5 (CAL FIRE).</td></tr>
<tr><td>Re-evaluate local zoning and land-use policies for new development in the WUI: Future zoning policies could limit construction of new homes in very high fire hazard severity zones. Current construction standards exist for fire-resistant homes, but there are regions of the state where development still occurs in high fire hazard regions. While new development is required to meet certain standards, modifications and retrofitting should also be considered for existing development.</td><td>• Policy examples and recommendations provided in the Office of Planning and Research Fire Hazard Planning: General Plan Technical Advice Series .</td></tr>
<tr><td>Promote development of dense urban infill: The cost and scarcity of housing in urban areas is driving the increased development in the WUI. A partial solution to reducing the number of residents living in the WUI is to construct more housing in urban areas. Urban infill policies can promote healthy, active lifestyles and provide access to healthy food, affordable housing, and quality jobs by directing development in underutilized urban areas.</td><td>• Examples of urban infill policies throughout California are outlined by Planning for Healthy Places, a program of Public Health Law & Policy (Healthy Planning Policies: A Compendium for California General Plans).</td></tr>
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<tr><td rowspan="2">Prescribed burns
(Section 3.2.2)</td><td rowspan="2">• Prescribed burning of the forested helps to reduce biomass fuels that may otherwise contribute to risk of incidence and intensity of wildfire. However, simultaneously, this type of vegetation management emits health-damaging pollutants.
• The composition of pollutants emitted to the atmosphere during prescribed burns is often similar to wildfire smoke (e.g. $PM_{2.5}$ and other Criteria and Hazardous air pollutants), and are well-known to be associated with various adverse health outcomes.
• Chronic exposure to these pollutants can occur for populations living downwind of landscapes with ongoing prescribed burn activities.
• Similar to populations vulnerable to wildfire smoke exposure, various population subsets, including people with underlying cardiovascular and respiratory conditions, children and older adults may also be susceptible to smoke from prescribed burns.</td><td>Air quality monitoring during prescribed burns: Current smoke management guidelines require districts to evaluate air quality when determining a permissive burn day. Air quality monitoring during prescribed burns could produce useful data to assess potential health impacts in nearby populations.</td><td>SB 1260: Fire prevention and protection: prescribed burns.</td><td rowspan="2">• Emissions from prescribed burns should be further quantified and characterized.
• Additional research on exposure to smoke from prescribed burns is needed, particularly focused on repeated smoke exposures.
• Future research should explore the differences between smoke from prescribed burns and smoke from wildfires, focusing on the implications for public health.</td></tr>
<tr><td>Prescribed burn reporting: Smoke Management Guidelines require reporting of prescribed burn activities.

Notification systems: Notify communities nearby prescribed burn areas, particularly nearby sensitive receptor facilities (hospitals, elderly care facilities, schools, day care centers).</td><td>• Smoke Management Plan (implemented by CARB and Air Districts).
• California Prescribed Fire Information Reporting System (PFIRS).</td></tr>
<tr><td>Biomass waste to energy production
(Section 3.2.3)</td><td>• Health implications of wood biomass utilization for electricity are largely dependent on the quantity of fuels used, technology used to generate electricity or heat, the location of these facilities, and the proximity, density and characteristics of nearby populations.
• Traditional direct combustion biomass facilities in California are among the highest sources of PM and NO_X on the California electric grid.
• However, biomass facilities tend to be located in less densely populated areas (median population living within 1 mile is 1,400).</td><td>Siting, developing and upgrading biomass facilities using best available technologies: Biomass facilities should be sited and designed to minimize both air pollutant emissions, the distance biomass fuel travels to reach the plant (e.g., considering locations of key tree mortality zones), and undergrounding electrical infrastructure to reduce wildfire risk.</td><td>Resources relevant to evaluating potential health implications of biomass facilities:
• California Power Map (PSE Healthy Energy)
• California Biomass Residue Emissions Characterization (C-BREC) tool models air pollutant emissions from biomass energy systems (under development).
• The best use of California's biomass to meet air quality and climate goals (CARB, pending publication)
• Assessment of the Emissions and Energy Impacts of Biomass and Biogas Use in California (Carreras-Sospedra et al., 2015; prepared for CARB)</td><td>• Additional research about biomass facility operations, associated emissions, and local dispersion patterns is critical to understanding the potential public health implications of biomass facilities.
• Future investigations should evaluate and compare individual biomass facility operations and emissions.
• Tracking pre-fire fuel treatments, such as forest thinning, could aid researchers and policy-makers in understanding the success of management strategies. These metrics could include data about biomass utilization, such as how much fuel is diverted as waste to energy facilities.
• Additional research and investment into cost reduction for emerging, distributed and lower-emission biomass gasification systems could also be explored.</td></tr>
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	Summary of health hazards, risks and impacts	Strategies to mitigate potential health risks	Policy model(s) / example(s)	Research gaps and limitations
The Public Health Dimensions of Wildfire Prevention, Mitigation and Suppression *(Section 3.0)*				
Chemical fire suppression *(Section 3.3)*	• While some ingredients in fire retardants and foams are well-known, complete chemical formulations of fire retardants and foams are considered trade secrets and are not publicly disclosed. • Chemicals historically used in firefighting foams, such as per- and poly-fluoroalkyl substances (PFAS), are persistent in the environment, bioaccumulate in the body, and have been found to be toxic at lower concentrations than current federal drinking water standards. • Fluorine-free fire suppressants are utilized in Europe and are being considered in certain industries in the United States (e.g., at airports).	**Safer chemical fire suppressants:** Transparency and public disclosure of chemical formulations in chemical fire suppressants. Compounds that pose risks to human health or the environment or have unknown toxicological profiles may be replaced by substances with known toxicological profiles that pose little to no toxicity to human health and the environment.	• **Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH),** fluorine-free foams. • Removing requirements for fluorinated fire suppressants from industry or federal standards (e.g., FAA Authorization Act of 2018, H.R. 302). • **SB 1044 (*Proposed*):** Firefighting equipment and foams: PFAS chemicals.	• Chemical formulations of fire suppressants used historically and currently in California are not well characterized. • Additionally, many unknowns remain regarding the toxicological profiles of past and present chemical fire suppressants. • Fluorine-free fire suppressant alternatives need verification, full characterization to determine if toxicological profiles pose little or no risk to human health or the environment. • In California, PFAS source investigations and drinking water well sampling in recent wildfire-affected urban areas are being conducted. Research is needed to determine the extent of population exposure to PFAS compounds associated with wildfire suppression activities. • Additional research is needed regarding the potential health impacts associated with PFAS exposure, specifically low dose and long-term exposure over time in human populations.
		Safe application of fire suppressants: Existing fire suppressants are noted for aquatic toxicity and persistence in the environment, and are generally prohibited from being applied 300 feet from surface water and in areas with threatened, endangered and sensitive species (unless public safety and human lives are threatened).	• US Forest Service designated avoidance areas.	
		Drinking water standards for known toxic chemicals in firefighting foams: Adoption of notification and response levels and drinking water standards for PFAS used currently and historically in firefighting foams.	• **SWRCB** notification and response levels for PFOS and PFOA • **OEHHA** public health goals and maximum contaminant level for PFOS and PFOA (in progress).	
		Environmental monitoring for toxic chemicals in firefighting foams and common household items: Ongoing environmental monitoring at health-relevant levels of detection, particularly in wildfire-affected areas where exposure pathways are likely.	• **SWRCB** PFAS Investigation.	

AB– Assembly bill; AQI– air quality index; Cal/OSHA– California Occupational Safety and Health Administration; CA DTSC – California Department of Toxic Substances Control; CalEPA – California Environmental Protection Agency; CARB – California Air Resources Board; ED– emergency department; NO_x – nitrogen oxides; PAH– polycyclic aromatic hydrocarbons; PFAS– per- and poly- fluoroalkyl substances; PFOA– perfluorooctanoic acid; PFOS– perfluorooctanesulfonic acid; PG&E – Pacific Gas and Electric; PM– particulate matter; SB– Senate bill; SDG&E – San Diego Gas and Electric; USGS – United States Geological Survey; VOC– volatile organic compound.