IN PURSUIT OF CLEAN AIR: LAYING THE GROUNDWORK FOR PUBLIC SCHOOL RESILIENCE TO WILDFIRE SMOKE

A Report by the Smoke: Wildfire Science and Policy Practicum | October 2023

Stanford | Climate & Energy Policy Program
Woods Institute for the Environment
Acknowledgements

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Lead Authors

Greg Zegas, MBA/MS Environment & Resources ’23, Stanford Doerr School of Sustainability
Isobel Anwyn Nairn, MS Earth Systems ’24, Stanford Doerr School of Sustainability

Lead Advisor

Jessica Yu, Postdoctoral Fellow, Stanford Woods Institute for the Environment

Practicum Instructors

Michael Wara, Director, Climate and Energy Policy Program and Senior Research Scholar, Stanford Woods Institute for the Environment
Deborah Sivas, Luke W. Cole Professor of Environmental Law and Director of the Environmental and Natural Resources Law & Policy Program, Stanford Law School; Senior Fellow, Stanford Woods Institute for the Environment
Michael Mastrandrea, Senior Research Scholar and Research Director, Climate and Energy Policy Program, Stanford Woods Institute for the Environment
Cassandra Jurenci, Wildfire Legal Fellow, Environmental and Natural Resources Law & Policy Program, Stanford Law School
Eric Macomber, Wildfire Legal Fellow, Environmental and Natural Resources Law & Policy Program, Stanford Law School

Additional Contributors

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1 Stanford’s Smoke: Wildfire Science and Policy Practicum engages students in learning about and helping to craft policy solutions to some of the significant challenges wildfires pose. The Practicum is directed by Michael Wara and Deborah Sivas. Report authored by Greg Zegas and Isobel Anwyn Nairn under the direction of the teaching team.
EXECUTIVE SUMMARY

Wildfires of increasing frequency and severity have become the new norm. The last decade has borne witness to 13 of the 20 largest wildfire events in California’s recorded history. Both in California and throughout the country, communities are being exposed more than ever to problematic levels of particulate matter (PM) pollution from wildfire smoke. These trends are likely to be exacerbated with drought conditions throughout the West expected to intensify as global climate change unfolds in the coming decades.

There is a clear macro-level need for interventions to enable communities to better protect themselves from wildfire smoke. Yet, granular data to guide policy and informed decision making is lacking. This is especially problematic for schools. Without information on indoor air quality and temperature, they are unable to determine the best course of action to protect students when facing smoke from a catastrophic wildfire event. While this is true of other problematic forms of air pollution with widespread health impacts—such as pesticide use in rural areas of California—the core focus of this paper is specific to wildfire smoke.

The objectives of the paper that follows are twofold. First, we distill learnings from relevant precedent projects and offer a starting point for best practices and guidelines that schools can adopt to reduce exposure to wildfire smoke. Second, we lay the groundwork for a coordinated research project across school districts where air quality monitors and potentially standalone air purifiers are installed across K-12 schools.

After reviewing guidelines, policies, and project precedent, we recommend addressing the hyper-local nature of air quality, including variations in indoor air quality, through continued research and updates to school policies. We suggest standardizing and refining official air quality guidelines, installing and maintaining indoor air quality monitors in schools and communities, allowing school-level decision making, and investigating alternatives available to schools during smoke events. Partnerships between existing community organizations and researchers can improve coordination between schools and communities and help identify and implement best practices. These recommendations are relevant to monitoring air quality in the context of other sources of air pollution, though they are not the core focus of this paper.

The objective of a wider research project would be to obtain a clearer picture of the air quality inside schools and classrooms during wildfire smoke events. To fund the administrative and equipment expenses of such a project, schools should first determine whether they are in a priority AB617 community to inform whether the community is a priority for Community Air Protection (CAP). Schools not located in AB617 communities should explore applying for

5 Note: AB617 communities are identified by the California Environmental Protection Agency pursuant to Section 39711 of the Health and Safety Code or an area that is a low-income area that is disproportionately affected by environmental pollution and other hazards that can lead to negative health effects, exposure, or environmental degradation. AB617 communities can be viewed at https://ww2.arb.ca.gov/capp-communities.
a Community Air Grant (CAG) directly from the California Air Resources Board (CARB), as well any other programs being implemented by their regional air quality management district or accessible through unprecedented levels of federal funding made available through the Environmental Protection Agency (EPA) and Department of Energy (DOE). Appendix 2 of this paper provides an editable spreadsheet tool to illustratively inform schools of the cost of installing air quality monitors or purifiers.

On the technical side of such a project, we recommend the following primary guidelines when selecting air quality monitors (see the full paper for more comprehensive recommendations):

- prioritizing temperature, humidity, and PM2.5 and PM10 data collection;
- prioritizing data access, e.g., through real-time monitoring, if easily implementable, or on-board storage to reduce the potential need for capacity building or paid support to access APIs to extract raw data from the sensors being stored on the cloud; and
- procuring air quality monitors from a brand that makes both an indoor version and an outdoor version of their monitor to ensure consistency between indoor and outdoor readings and ease of use.

Far more detail on technical recommendations and operational considerations are included in this paper, as well as an overview of recommendations regarding standalone air purifiers.

Schools throughout California face wildfire smoke events of increasing frequency and severity. Unfortunately, poor data availability on indoor air quality limits the ability of schools to provide and implement guidance around student activity and school closure when faced with a wildfire smoke event. A comprehensive research effort involving placement of air quality monitors is necessary to fill this data gap and better inform school guidelines. This paper provides a starting point for establishing school policies for wildfire smoke and introduces key issues for consideration when standing up a school air quality research effort. We note many areas of inquiry worthy of further investigation that could build from this starting point.
### ACRONYMS

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Full Form</th>
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<tbody>
<tr>
<td>AHAM</td>
<td>Association of Home Appliance Manufacturers</td>
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<td>APEN</td>
<td>Asian Pacific Environmental Network</td>
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<tr>
<td>AQI</td>
<td>Air Quality Index</td>
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<td>AQMD</td>
<td>Air Quality Management District</td>
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<td>ARP</td>
<td>American Rescue Plan of 2021</td>
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<tr>
<td>ASHRAE</td>
<td>American Society of Heating, Refrigerating and Air-Conditioning Engineers</td>
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<td>CADR</td>
<td>Clean Air Delivery Rate</td>
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<tr>
<td>CAG</td>
<td>Community Air Grants</td>
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<td>CalEPA</td>
<td>California Environmental Protection Agency</td>
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<tr>
<td>CAP</td>
<td>Community Air Protection</td>
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<td>CAPCOA</td>
<td>California Air Pollution Control Officers Association</td>
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<td>CARB</td>
<td>California Air Resources Board</td>
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<tr>
<td>CARES Act</td>
<td>Coronavirus Aid, Relief, and Economic Security Act</td>
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<tr>
<td>CBA</td>
<td>Cost-benefit Analysis</td>
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<tr>
<td>CBO</td>
<td>Community-based Organization</td>
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<tr>
<td>CO</td>
<td>Carbon Monoxide</td>
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<tr>
<td>CO₂</td>
<td>Carbon Dioxide</td>
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<tr>
<td>CRRSA</td>
<td>Coronavirus Response and Relief Supplemental Appropriations</td>
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<td>DIY</td>
<td>Do-it-yourself</td>
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<td>DOE</td>
<td>Department of Energy</td>
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<td>EANS</td>
<td>Emergency Assistance to Non-Public Schools</td>
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<td>EPA</td>
<td>Environmental Protection Agency</td>
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<tr>
<td>ESSER</td>
<td>Elementary and Secondary School Emergency Relief</td>
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<td>GEER</td>
<td>Governor’s Emergency Education Relief</td>
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<td>GGRF</td>
<td>Greenhouse Gas Reduction Fund</td>
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<tr>
<td>HEPA</td>
<td>High-efficiency particulate air</td>
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<tr>
<td>HVAC</td>
<td>Heating, Ventilation, and Air Conditioning</td>
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<tr>
<td>IAQ</td>
<td>Indoor Air Quality</td>
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<tr>
<td>IRA</td>
<td>Inflation Reduction Act</td>
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<tr>
<td>LAUSD</td>
<td>Los Angeles Unified School District</td>
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<tr>
<td>MERV</td>
<td>Minimum efficiency reporting value</td>
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<tr>
<td>NFOCA</td>
<td>North Fair Oaks Community Alliance</td>
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<td>OCOB</td>
<td>Our Communities, Our Bay</td>
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<td>PAUSD</td>
<td>Palo Alto Unified School District</td>
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<tr>
<td>PM</td>
<td>Particulate Matter</td>
</tr>
<tr>
<td>PM 2.5</td>
<td>Particulate Matter of diameter 2.5 microns or smaller, fine inhalable particles</td>
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<tr>
<td>VOCs</td>
<td>Volatile Organic Compounds</td>
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<td>WHO</td>
<td>World Health Organization</td>
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INTRODUCTION

Wildfires of increasing frequency and severity have become the new norm. The last decade has borne witness to 13 of the 20 largest wildfire events in California’s recorded history. Both in California and throughout the country, communities are being exposed more than ever to problematic levels of particulate matter (PM) pollution from wildfire smoke. These trends are likely to be exacerbated with drought conditions throughout the West expected to intensify as global climate change unfolds in the coming decades.

These trends pose far-reaching and enduring health risks to communities in California. The fundamental long-term health impacts of wildfire smoke have been well documented in the medical literature. PM inhalation triggers a cascade of negative physiological effects, ranging from systemic inflammation and vasoconstriction to higher heart rate and higher potential for arrhythmias. Unsurprisingly, a study has shown wildfires lead to an excess in cardiorespiratory-related deaths, to a degree far exceeding that of heat-related fatalities, during wildfire events. Volatile organic compounds (VOCs) and other heavy metal toxins emitted from wildfire smoke pose other known harms, including eye, nose, and throat irritation, nausea, and damage to the central nervous system. Ongoing research continues to explore more nuanced impacts, including at the cellular and immune system level and mental health, as well as the distinct pollutant compositions of smoke from wildfires burning through urban structures.

The known impacts of PM exposure are especially burdensome for vulnerable populations such as the elderly, pregnant women, and children. Meanwhile, research has begun to show how the health effects of air pollution follow racial and economic divides. This is especially troublesome in California, where studies have shown Latinx and other communities of color are exposed to far higher levels of air pollution than White communities throughout the state.

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12 “The Costs of Wildfire in California”, p. 97
14 “The Costs of Wildfire in California”, p. 57
15 “The Costs of Wildfire in California”, p. 57
There is a clear macro-level need for interventions to enable communities to better protect themselves from wildfire smoke. Yet, granular data to guide policy and informed decision making is lacking. This is especially problematic for schools. Without information on indoor air quality and temperature, schools are unable to determine the best course of action to protect students when facing smoke from a catastrophic wildfire event (e.g., whether to cancel classes, operate normally, or implement a hybrid schedule with certain activities restricted). Ultimately, schools need evidence-based guidelines to prepare for the new norm of increasingly frequent and intense wildfire smoke events. Though not the focus of this paper, these guidelines can guide school decision making in response to air pollution from other sources.

The objectives of the paper that follows are twofold. First, we distill learnings from relevant precedent projects and offer a starting point for best practices and guidelines that schools can adopt to reduce exposure to wildfire smoke in their learning environments. Second, we lay the groundwork for a coordinated research project across school districts where air quality monitors and standalone air purifiers are to be installed across K-12 schools and potentially public spaces (e.g., libraries, public pools, centers of faith, etc.) to create and monitor safe air spaces. This project has been undertaken through the Stanford Climate & Energy Policy Program under the Woods Institute for Environment.16

For more information, please contact the Stanford Climate and Energy Policy Program via https://woods.stanford.edu/climate-and-energy-policy-program/overview
1 ESTABLISHING SCHOOL DISTRICT BEST PRACTICES

a. Baseline Context

During wildfire smoke events, outdoor and indoor concentrations of air pollutants such as particulate matter can far exceed the healthy levels. However, it is not always easy to access air quality information at a specific location, particularly indoor air quality information. The state of California has numerous official monitors across the state, but the sensors are placed many miles apart and do not provide the granularity necessary to make decisions at the level of a single school due to the potentially hyper-local impacts of wildfire smoke. Meanwhile, crowd-sourced data from a network of PurpleAir monitors can give some insight into air quality levels in the vicinity of some schools. However nearby readings cannot always provide a good indication of what indoor air quality could be at a school, given a variety of building characteristics that could exacerbate or mitigate from wildfire smoke. Meanwhile, coverage is widely lacking both within and surrounding schools.

Efforts are underway to improve both indoor and outdoor air quality monitoring operations, particularly in under-resourced communities. S2476, introduced into the senate in July of 2021, sought to establish a pilot program for hyper-local air quality monitoring in environmental justice communities. Grants would be awarded by the Environmental Protection Agency (EPA) to state, local, or tribal air agencies to enhance air quality monitoring in communities disproportionately exposed to or harmed by localized poor air quality. AB1749, passed in September of 2022, requires the development of emissions reductions plans at the community level in areas “affected by a high cumulative exposure burden.” The plans rely on existing air quality data sources and are not associated with additional funding, but would target attention towards more rigorous analysis of existing air quality information. Nonprofit organizations and community institutions, including some schools, have also sought to individually monitor local outdoor and indoor air quality. When funding is not available, or if installing new air quality monitors is not feasible, school districts can use the US-wide EPA correction equation to convert publicly available data, including from the PurpleAir network, to inform school closure decisions on the local level.

18 The location and data of California’s government-installed air quality monitors can be viewed through the AirNow network via the following URL: http://gispub.epa.gov/airnow/?monitors=pm25&min=-13774793.067856526&max=-13342159.487759762&ymin=4423434.502957157&ymax=4573556.826598171&contours=none
19 See the following URL for a map of PurpleAir monitors in the Bay Area. See Section 1b of this paper for more details https://map.purpleair.com/1/imaQ0/a10j604800t/C0#8.91/37.5544/-122.07.
School districts have begun to acknowledge the importance of understanding indoor as well as outdoor air quality. Boston Public Schools, as part of an agreement with the Boston Teachers Union, have installed indoor air quality sensors in all classrooms, main offices, and nurse’s offices, with a rooftop sensor collecting outdoor air quality to serve as a baseline. The sensors report real time air quality data which is available publicly on the district’s indoor air quality (IAQ) sensor dashboard. Los Angeles Unified School District (LAUSD) unveiled its Know Your Air Network in 2022, installing sensors at 200 locations across the district so that no school is more than 1.6 miles from a sensor. Despite significant air quality concerns in the western United States due to wildfire frequency, there are very few district wide indoor air quality monitoring programs in the country that offer a publicly accessible database. Other major school districts that do monitor indoor air quality generally do not make public the indoor air quality data that is collected, despite its ability to help others understand existing data and decision making criteria and to improve transparency in processes. Even in school districts where indoor air quality data is collected in some or all classrooms, school closure action levels typically continue to be based on official air quality index (AQI) measures from outdoor sensors.

In the event of poor outdoor air quality, school districts are largely reliant on official AQI data published by local government agencies. This data is divided into tiers indicating the severity of health impacts at each AQI level. Some overarching standards exist on how to interpret these values, such as the recommendations by the Bay Area Air Quality Management District (AQMD) or the California EPA. Generally, school- or district-level guidelines on whether to close are not available, although at least one major school district in the Bay Area has created agreements with teachers’ unions on air quality data sources and the outdoor AQI above which schools must close. Decisions may primarily focus on student participation in outdoor physical activity. In these cases, using outdoor air quality as a metric can be useful for consideration of whether students should be able to participate in outdoor physical activities. Even schools with recently updated filtration systems may not regularly complete the inspections and maintenance required to keep systems operating at peak capacity.

Schools that have installed high quality filtration systems can keep students in school spaces with relative surety that indoor air quality will remain within safe levels. Many schools have installed new MERV-13 air quality filters in classrooms as of the COVID pandemic, and may choose to keep students in schools up to the point when the AQI

26 “BUSD Air Quality Index (AQI) Response Plan”
29 “Memorandum of Understanding between Palo Alto Unified School District & Palo Alto Educators Association”
reaches 200. Estimates on the cost of upgrading ventilation throughout a school district range from $60,000 for the most basic upgrades in a small district to millions of dollars for gold-standard protection in large ones. Meanwhile, estimates suggest that the total cost of installing or upgrading HVAC systems in all of California’s K-12 public schools would require $40 billion. Unfortunately, despite both statewide requirements that all new buildings install MERV-13 air filtration systems and the School Reopening Ventilation and Energy Efficiency Verification and Repair Program which provides grant funding for schools in underserved communities to upgrade their indoor air quality systems, many older buildings in California, particularly in low-income, rural, or minority communities have poor sealing and inadequate, or no, ventilation and air filtration systems.

Consideration of the alternative options available to students is essential. The majority of students are likely to remain indoors at home when schools are closed, although some parents and guardians may not follow guidelines that children should not participate in outdoor activities during poor air quality events. As part of school closure protocols, instructional guides and online resources should be provided to parents on how to protect students from wildfire smoke at home. Indoor air quality in students’ homes can be vulnerable to the same problems that exist in older school buildings, such as a lack of air conditioning systems and poor building sealing. California’s Strategic Growth Council has recognized that communities may not have access to healthy indoor spaces during poor air quality events, and in response has begun to develop Community Resilience Centers in partnership with community-based organizations including the Asian Pacific Environmental Network (APEN). These community-based air quality refuge centers provide air-conditioned spaces with filtration systems, as well as Wi-Fi and electricity. Given their ability to serve as community or civic spaces more generally (e.g., as polling places), schools can serve this function as well. However, knowledge about and utilization of these spaces is likely to be relatively low within communities, especially as they have only recently begun to be developed. Moreover, school districts may or may not be able to gather information about whether students have safe alternative indoor spaces to access when schools are closed. Therefore, even schools without the highest quality air filtration may choose to remain open when air quality is poor because it ensures that students will be kept indoors and prevents disruption to education.

Yet another factor in school closure decision making is the intersection of air quality and other weather events or emergency events, including extreme heat days, some of which are considered in existing school emergency planning processes. There is significant overlap between schools that have upgraded filtration systems and those that are able to provide sufficient air conditioning. Conversely, schools that are most vulnerable in extreme heat are also most likely to be vulnerable to poor indoor air quality and will need to consider both factors during extreme heat events. In California, extreme heat guidelines for schools often follow a similar structure to air quality guidelines. Schools that

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31 “Guidance for Schools During Wildfire Smoke Events”
34 Environmental Law Institute Database of State Indoor Air Quality Laws
can provide adequately air-conditioned spaces focus on reducing time outdoors, while schools without air conditioning may close schools or offer “minimum days” in which instruction is provided during cooler periods of the day. These minimum days allow schools to defer decisions on school closures and monitor temperatures and air quality throughout the day, with the option to send students home if conditions worsen.

Typically, students would be sent home at midday when temperatures are highest if it becomes infeasible to keep windows closed, reducing lost instructional time. Consideration of alternative spaces remains critical, and schools must weigh their ability to protect students both from extreme heat and poor air quality against the potential risks of sending students home. The coincidence of public safety power shutoffs with both air quality events and extreme heat events may reduce schools’ ability to maintain safe indoor spaces, as both air conditioning and filtration systems require electric power.37 Even schools with up-to-date air conditioning and filtration may need to reconsider guidelines based on outdoor conditions in the case of public power safety shutoffs.

A final concern with current school closure policies is the use of the same AQI action levels for poor air quality from wildfire smoke and other PM 2.5. Recent research suggests that PM 2.5 from wildfire smoke may be more harmful to health than PM 2.5 from other sources.38 Moreover, children under the age of 18 as a group are especially susceptible to the risks of air pollution as a “vulnerable” population. The activity recommendations appropriate for adults may not be sufficient for such vulnerable groups.39 Schools may therefore consider making action levels more conservative for school closures and outdoor activities when poor air quality is known to be related to wildfires. More research is necessary to determine whether this differentiation in policy is unnecessary.

The Washington State Department of Health provides useful step-by-step guidelines for school decision making during periods of poor air quality, including schools where indoor air quality may be unknown.40 In cases where air monitoring is not available in school buildings, the guidelines recommend considering variation in air quality within school buildings to understand where students will be best protected from poor air quality. Although portable sensors may not be as accurate as stationary sensors, they can be used to conduct a walkthrough of the school during air quality events to understand where air quality is best and worst. This guidance is not only helpful for schools attempting to keep students safe within their campus, but also provides an indication for how air quality monitors should be dispersed throughout school buildings when they are available.

37 “BUSD Air Quality Index (AQI) Response Plan”
### b. Project Precedents

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<thead>
<tr>
<th>Project Title</th>
<th>Location</th>
<th>Project Description</th>
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<tbody>
<tr>
<td><em>Climate and Energy Policy Program</em></td>
<td>Stanford, California</td>
<td>Research on indoor air quality in schools using PurpleAir sensors. Publicly available data suggests indoor air quality in schools with PurpleAir sensors reaches unhealthy levels.</td>
</tr>
<tr>
<td><em>North Fair Oaks Community Alliance</em></td>
<td>North Fair Oaks, San Mateo County, California</td>
<td>Community organization focused on equity, socio-economic, and environmental justice with a basis in community participation. Work relating to indoor air quality includes community disaster response and preparedness teams which have produced educational workshops on air quality and distributed air purifiers to community members.</td>
</tr>
<tr>
<td><em>South Coast AQMD</em></td>
<td>South Coast, California</td>
<td>Local government efforts to improve air filtration in schools. The South Coast AQMD implements environmental justice-focused projects to reduce student exposures to poor air quality, with a focus on limiting exposure to baseline emissions as opposed to wildfire smoke.</td>
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<tr>
<td><em>Climate Ready Schools Coalition</em></td>
<td>California</td>
<td>A coalition of education, climate, health, youth, and labor leaders collaborating and proposing policy priorities on the resilience and sustainability of California’s public schools.</td>
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<tr>
<td><em>APEN Resilience Hubs/In Home Climate Resiliency</em></td>
<td>Oakland and Richmond, California</td>
<td>APEN is working to create community centers that provide air filtration and air conditioning in addition to other climate-related public services. APEN's in-home resiliency program seeks to provide similar services for residents who are unable to leave their homes.</td>
</tr>
<tr>
<td><em>RYSE Youth Center</em></td>
<td>Richmond, California</td>
<td>Youth-led community center that is working to become a resilience hub with a focus on community-driven resilience.</td>
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<tr>
<td><em>Our Communities, Our Bay</em></td>
<td>East Palo Alto, North Fair Oaks, Belle Haven, Redwood City, Ravenswood, California</td>
<td>Research study assessing wildfire exposure interventions and impacts. Indoor PurpleAir sensors are installed in all participants’ homes.</td>
</tr>
<tr>
<td><em>Los Angeles Unified School District (LAUSD)</em></td>
<td>Los Angeles, California</td>
<td>LAUSD’s ‘Know Your Air Network’ installed sensors at 200 schools across Los Angeles to monitor smog, exhaust, industrial emissions, smoke, and dust.</td>
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<tr>
<td><em>Berkeley School District (BUSD)</em></td>
<td>Berkeley, California</td>
<td>All classrooms are equipped with air quality monitoring systems to monitor temperature, humidity, CO₂ levels, particulate matter, and Volatile Organic Compounds (VOCs).</td>
</tr>
<tr>
<td><em>Smokewise Ashland</em></td>
<td>Ashland, Oregon</td>
<td>Smokewise Ashland provides information and resources on how residents can protect themselves from poor air quality. Smokewise Ashland is currently working to retrofit five children-serving locations with indoor and outdoor air quality monitoring and indoor air purification.</td>
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Air quality monitoring has widespread community interest and a growing number of research and non-profit organizations are beginning to pursue projects measuring indoor air quality in schools and other community gathering areas. The publicly available map of PurpleAir sensors indicate that very few school districts have begun to independently monitor their own indoor air quality, or have chosen not to make this information publicly available. Of over a hundred schools identified in the map, less than 10% have an air quality monitor reporting data, only one of which focuses on indoor air quality.\textsuperscript{41} However, the COVID-19 pandemic and increasing frequency and severity of wildfires have hastened the focus on understanding air quality and ensuring that communities have access to clean air. This section will provide a brief overview of projects working within this space.

Smokewise Ashland, in Oregon, was created in response to the need to plan for smoke and address community health needs while accomplishing critical controlled burns in Ashland’s forests. The organization developed into an agency that provides information and resources on air quality, including indoor air quality, at a time when little information was available on how individuals could protect themselves from particulate pollution. Recently, Smokewise Ashland has begun partnering with indoor spaces serving children to monitor air quality and to design filtration systems for these spaces. These projects, and the challenges they have encountered, provide a helpful roadmap for working with communities and school districts to implement air monitoring programs.

The five locations include ScienceWorks’s Children Museum, Oregon Child Development Coalition, Ashland Children Library, Children’s World Montessori and a location in the Ashland School District. Smokewise Ashland installed multiple indoor and outdoor air monitors in different locations for each building and are collecting air quality data to better understand the ventilation and filtration needs in each building. adding portable air cleaners and air scrubbers, repairing broken windows, and ensuring the building envelopes are sealed, as well as monitoring whether indoor air quality in older buildings, with and without improvements, is satisfactory for young children.

Challenges specific to working with school districts include liability concerns and buy-in from parents and community members. The program’s Community Engagement Coordinator discussed concerns that publicly available information on indoor air quality in schools could expose inadequate indoor air quality and encourage lawsuits, especially if projects supply only monitors and not air filters or other solutions. Studies that seek to understand air quality in its present condition may need to perform community outreach or partner with school districts and trusted community partners to help parents understand the value of air quality monitoring. In Ashland, this outreach may include compiling information on absenteeism and test scores to present the case that indoor air quality was negatively impacting students. Other programs may weigh tradeoffs between making data publicly available in real time with building in a delay to ensure data quality. Concerns that parents or teachers may see temporary and potentially inaccurate spikes in real-time monitoring data and feel that schools should automatically close were a consistent concern by stakeholders with experience working in school districts.\textsuperscript{42}

\textsuperscript{41} Spreadsheet of all schools in Palo Alto Unified, Stockton Unified, and Napa Unified School Districts with available PurpleAir sensor data: https://docs.google.com/spreadsheets/d/1X4RzdD5s3bnEO6WXkkg2GECChOkU-v122ks8FFdM/edit?usp=sharing

Furthermore, the design of new monitoring and ventilation programs at the Oregon Child Development Coalition can be a model for both researchers and those looking to upgrade ventilation systems in schools. While physical setup is important, considerations should be given to who is implementing and maintaining equipment, and providing clear communication and training to ensure that technology is being used correctly. Even when monitors or purifiers are running, human error can reduce efficacy, and even automated systems may not respond correctly to novel situations. For example, HVAC systems that depend on circulating fresh air from outside may need to be manually overridden during smoke events to ensure adequate indoor air quality, despite appearing fully functional. Smokewise Ashland also recommends overseeing the placement of air quality monitors and ensuring that they are being installed in areas that are used frequently by children. The translation of policy into practice is likely to include some bumps, but learning from the challenges of past projects can help to avoid unnecessary blunders.

Many community-based organizations choose to implement community-based educational or capacity building initiatives in tandem with air quality monitoring network establishment or air purifier installation efforts, either using state funds or philanthropic funds. An example of the latter is the educational effort being facilitated by the North Fair Oaks Community Alliance (NFOCA) in the unincorporated neighborhood of North Fair Oaks near Redwood City. The effort centers around an air pollution-focused educational workshop series for North Fair Oaks residents, laying the groundwork for NFOCA’s future community disaster response and preparedness teams (“Block Action Teams” or “BATs”) with air pollution education. The project has facilitated two educational workshops on air pollution and air purifiers for ~35 members of the general public of North Fair Oaks, including provision of materials for a do-it-yourself (DIY) air purifier to each resident and instructions for assembling the unit. The DIY-style air purifiers are made from parts available at local hardware stores, and are more affordable (at approximately $40 per purifier) than commercially manufactured air purifiers. With proper usage, these purifiers can perform similarly to those costing hundreds or even thousands of dollars.

Air filtration improvement projects within schools may also be supported by local government funding. The South Coast AQMD is a model that has worked to implement air filtration projects within schools as Supplemental Environment Projects and through penalty settlement funds. New project plans as of 2022 continue to provide support for these projects, expand eligibility criteria for projects, and reduce cost sharing requirements to 0% for AB617 priority schools located near identified emission sources. AB617 established the Community Air Protection Program through CARB to address the disproportionate impact of air pollution on disadvantaged communities, defined as areas that are low-income area and disproportionately affected by environmental pollution and other hazards that can lead to negative health effects, exposure, or environmental degradation. These projects have an environmental justice focus and are primarily concerned with baseline emissions and point-source pollution as opposed to wildfire, although improved filtration within schools will almost always improve air quality during smoke events as well. Indoor and outdoor monitoring units “to collect usage data” are covered as eligible costs, although the language of the project plan and the Community Air Protection Incentives 2019 Guidelines do not emphasize air quality monitoring.

44 “Supplemental Environmental Project (SEP) Program”, South Coast AQMD District Prosecutor’s Office, http://www.aqmd.gov/nav/about/policies/supplemental-environmental-project-(sep)-program-aqmd-district-prosecutor’s-office
specifically, and instead focus on monitoring programs that evaluate the effective operation of filtration equipment. These programs are driven by the need to improve health outcomes for students in schools most vulnerable to consistent poor air quality and may benefit from independent air quality monitoring to measure project effectiveness.

This paper builds off previous research undertaken by the Climate and Energy Policy Program overseen by policy practicum students, Ben Maines, Allison Ong, and Lonnie Shumsky.\textsuperscript{45} Despite the overall lack of air quality monitors within school buildings, using data from PurpleAir sensors that are publicly available, Maines et al. concluded that indoor PM 2.5 levels in California public schools that had installed PurpleAir sensors reached hazardous levels during the 2020 wildfire season. They found that schools provided the least protection from poor air quality compared with all other building types (Figure 1), suggesting that students may be exposed to worse indoor air quality in schools than at home. Furthermore, the mean indoor PM2.5 levels inside private schools (8.6 µg/m³) was statistically different than in public schools (11.3 µg/m³), while the average percent reduction in PM2.5 levels indoors versus outdoors was also significantly higher in private schools (65%) than public schools (38.6%). Meanwhile, public schools had an average of 19.3% higher number of school days during which indoor PM2.5 concentrations reached the CDC-defined Level 1 level during the 2020 wildfire season (see Table 1). This indicated that public school buildings were less well-equipped to mitigate outdoor wildfire air pollution levels. However, these results may be skewed based on the circumstances under which people choose to install PurpleAir sensors; individuals who buy PurpleAir sensors for home use are likely to be the most conscientious users and are more likely to have invested in other air quality protection measures, while schools may have different motivations.\textsuperscript{46} Regardless, this preliminary research suggests a dire need to continue installing localized air quality monitors, especially within schools, to understand where people will be most protected during smoke events.

\textit{Figure 1: US school buildings exhibit the highest infiltration-rates of any building type}

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|}
\hline
Building Type & Infiltration Estimate & \textbf{n} \\
\hline
Single-Family Residence & 0.1 & 1,518 \\
Apartment/Townhouse & 0.2 & 422 \\
Unknown & 0.3 & 165 \\
Government Building & 0.4 & 15 \\
AQMD Building & 0.5 & 76 \\
Office Building & 0.6 & 28 \\
Other & 0.7 & 99 \\
School & 0.6 & 93 \\
\hline
\end{tabular}
\end{table}

\textsuperscript{45} Maines, et. al, 2022, “Smoke, Indoor Air Quality, and Schools”

\textsuperscript{46} Maines, et. al, 2022, “Smoke, Indoor Air Quality, and Schools”
Table 1: Average number of school days during which indoor PM2.5 concentrations reached each CDC-defined risk level in California schools during the 2020 wildfire season (Aug-Dec)

<table>
<thead>
<tr>
<th>School Type</th>
<th>Level 1 0-50µg/m³</th>
<th>Level 2 50-100µg/m³</th>
<th>Level 3 100-150µg/m³</th>
<th>Level 4 150-200µg/m³</th>
<th>Level 5 200+ µg/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Public</td>
<td>136.8</td>
<td>6.1</td>
<td>1.4</td>
<td>0.6</td>
<td>0.3</td>
</tr>
<tr>
<td>Private</td>
<td>114.6</td>
<td>7.3</td>
<td>1.3</td>
<td>0.5</td>
<td>0.4</td>
</tr>
<tr>
<td>All</td>
<td>126.5</td>
<td>6.7</td>
<td>1.3</td>
<td>0.6</td>
<td>0.2</td>
</tr>
</tbody>
</table>

An alternative route to tackling air quality impacts is to provide community-based air quality refuge locations in areas where individuals may not have access to safe air quality in homes and workplaces. While not directly connected with school air quality, these locations provide an alternative to staying at school during wildfire smoke events and may play a larger role in decision making as more centers are built throughout California. Multiple organizations are working to provide these types of centers within communities, ranging from informal decisions to make public libraries or town hall offices accessible during times of need to projects that build from the ground up safe locations designed to provide a variety of necessities to residents during crises. APEN is at the forefront of advocating for the creation of these centers in California, with projects both on designing Resilience Hubs and ensuring In-Home Resilience especially for community members unable to easily leave their homes.\(^\text{47}\) The goal of these centers is not only to provide access to clean air, but also to provide locations of climate resiliency, with a focus on the model of the RYSE Youth Center in Richmond, located in a community that has experienced disproportionate climate impacts.\(^\text{48}\) As an existing trusted space that provides a variety of youth programming, RYSE was identified as an ideal location for further improvements in resiliency, including a community solar and storage system, access to emergency supplies, public awareness campaigns, providing a connection to public sector services, and more.\(^\text{49}\) Projects taken on by other agencies typically focus less on the community resiliency model, but still work to provide similar services in locations accessible to all community members.

**Our Communities, Our Bay (OCOB)** has been identified as a collaborator doing critical research in the indoor air quality monitoring space. Working within disadvantaged communities (low income, mostly Spanish speaking households), OCOB enrolled 30 households as study participants in a pilot, and 300 households are enrolled for the full study.\(^\text{50}\) Enrolled households are outfitted with an indoor PurpleAir sensor, as well as a variety of other sensors designed to track exposures and long term associated health outcomes for wildfire smoke exposure. Participating households complete an initial survey on health and demographic characteristics and use a smartphone app to take

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\(^\text{48}\) Based on data from CalEnviroScreen: https://oehha.ca.gov/calenviroscreen

\(^\text{49}\) “RYSE Youth Center Origin Story”, RYSE Center, https://static1.squarespace.com/static/58ece61644024383be911a95/t/595670b215d5dbb7daa844fd1/1498840522317/RYSE+Origin+Story+PDF.pdf

\(^\text{50}\) Source: Herbert N. et. al., “Improving adaptation to wildfire smoke and extreme heat in frontline communities: Evidence from a community-engaged pilot study in the San Francisco Bay Area” *Environmental Research Letters* (2023)
additional surveys; through the smartphone app, participants can access information about wildfire smoke exposure and potential preventative measures.51 The project is primarily concerned with the measures households take during wildfires to decrease exposure as well as the impacts of potential interventions such as installing HEPA filtration systems in homes. In addition, OCOB seeks to gain an overall understanding of the hyper-local exposures that households may experience and is currently testing wearable monitors to understand exposures during transit or in the workplace. This project offers an excellent opportunity to better understand the potential exposures that children might experience in alternative locations during school closures due to poor air quality.

c. Recommendations

Based on existing infrastructure and available data, we make recommendations within the three following areas with the overarching goal of better understanding the status of school indoor air quality and protecting students from poor air quality whenever possible.

1. School closure decisions

School districts currently have a variety of basic guidelines, often conflicting, upon which to base their decisions on student activity and school closures. We recommend that whenever possible, agencies including the EPA, Air Quality Management Districts, and the World Health Organization (WHO), should standardize guidelines based on official AQI levels to provide clarity and consistency for school districts, or provide rationale for differences in guidelines across agencies. Agencies should also consider updating exposure guidelines to reflect emerging evidence on the disparate health impacts of PM 2.5 from smoke events compared with PM 2.5 from other sources. Agencies should also standardize measurements used in guidelines or provide conversions between AQI and micrograms per cubic meter. Challenges in decision making at the district level can be mitigated through clear guidance from experts.

At the district level, superintendents should consider allowing school-level as opposed to district-wide decision making on school closures. This reflects the hyper-local nature of poor air quality and the differences in school ventilation capabilities across districts, and allows for the consideration of indoor air quality. As one example, Palo Alto Unified School District (PAUSD) has installed updated MERV 13 filters district wide, except for one campus that is still being upgraded. Schools with known deficiencies in ventilation capacity may be encouraged to close before the rest of the district; schools that have tested their ventilation capacity in poor air quality conditions may be allowed to remain open longer. Schools may be able to take advantage of ventilation improvements pursued during the COVID-19 pandemic to revisit air quality closure guidelines. However, we recognize that this policy has both environmental justice implications and may be difficult to defend from a community perspective. School districts should weigh these factors, and when decisions must be made district-wide, should be made based on schools with the least ventilation capacity. Given that these also may also be schools where closures hit families hardest (e.g., ones where the costs of needing last-minute childcare are felt most deeply), absent other supports a district may consider school closure only an option of last resort or a requirement only when buildings are being retrofitted with better insulation and indoor air filtration.

51 “What is “Our Communities, Our Bay”?”, Our Communities Our Bay, https://www.ourcommunitiesourbay.org/project
Schools should consider the intersection of air quality with other student health concerns, including but not limited to COVID-19 and extreme heat days. Schools should attempt to reconcile policies designed to mitigate heat or health concerns (for example, keeping doors and windows open) with the need to seal buildings during periods of poor air quality, with the understanding that acute risks to student health must take priority. Whenever possible, schools should invest in air conditioning upgrades in tandem with ventilation improvements, with the justification that co-occurrence of poor air quality and extreme heat is likely to increase in the coming years. Recommendations from industry professionals are discussed in Section 2.

2. Use and development of community-based refuge centers

We recommend that schools provide outreach to students and parents about resources available in their communities and identify and publicize community spaces where vulnerable students can access ventilated indoor spaces during smoke events. If appropriate locations cannot be identified, or if capacity is limited, schools may consider remaining open for those students in need of a safe place to go during smoke events even if indoor air quality is not ideal.

Those who are working to develop community-based refuge centers should remain aware of the need to monitor air quality and ensure that sites are chosen with building seal and ventilation capacity in mind, as well as that accessible transportation options are available for community members to reach the refuge. In addition, these centers may benefit by coordinating with schools and researchers to collect data and make informed decisions on how to target and prioritize resources and mitigation responses. Finally, while beyond the scope of this research, we advocate for the continued development and funding of additional community-based refuge centers with a focus on environmental justice communities.

3. Adoption of air quality monitoring

Based on conversations with community stakeholders, monitoring programs should prioritize community engagement. Research teams should work with schools to make decisions on whether air quality data should be public or private, and consider performing outreach to parents and community members to provide information on the impacts of air quality on health and educational metrics to produce community support for monitoring initiatives. If school air quality data is public, researchers should consider housing this information within Air Quality Management Districts as opposed to through school websites or crowdsourced maps like PurpleAir to avoid alarming community members if sensors show inadequate air quality temporarily, due to errors, or because of a particular point-source that does not affect students school-wide.

To better understand the alternatives to schools during poor air quality events, we suggest providing monitors to community members, particularly in environmental justice communities. OCOB has been identified as a potential partner and more work can be done to reach out to other community organizations and research groups that are interested in installing indoor air quality sensors in homes and public spaces such as libraries, which sometimes
function as public health intervention sites with other programming. Monitoring indoor air quality in schools is an essential baseline; monitoring of overall potential exposures within communities, especially potential exposures for those most at risk, should be considered a best practice for school and district decision making during poor air quality events.

While we are currently in the process of information gathering, we advise caution when using continuous indoor air quality monitors alone to make school closure decisions. Until adoption is widespread, more research can be done, and guidelines can be produced, schools should use indoor air quality monitors to supplement, not replace, their current policies. Unanswered questions regarding how long a continuous indoor air quality monitor must display poor air quality as well as how to standardize and compare sensors to each other make it impractical to use them as a tool for decision making as of this writing. More research linking information on indoor air quality exposure in schools to data on health outcomes is advised.

Finally, we strongly recommend the installation of more air quality monitors in a variety of school spaces to understand schools’ capacity to protect students from poor outdoor air quality and to provide a solid baseline against which interventions can be measured for efficacy. These sensors should be placed in as many school spaces as possible, and in as many different schools as possible, in locations where children are likely to be present. This may be done independently or in tandem with improvements to ventilation in school buildings. Lack of resources to improve ventilation should not be a barrier to installing monitors. In fact, we suggest prioritizing the installation of monitors in schools that have not yet upgraded ventilation infrastructure, as these schools allow research to be done on changes to air quality after interventions are undertaken. Ultimately, we do not have enough real time information on indoor air quality in schools to determine the best course of action to protect students when facing smoke from wildfire events.

Figure 2 offers a model for school decision making that considers indoor air quality. This guide should supplement, not replace, current school guidelines until further research can be done on the use of indoor air quality monitors in schools. It is intended to be used to indicate the potential benefits of indoor air quality monitoring for hyper-local decision making in schools.

Figure 2: Indoor Air Quality Decision Tree

This tree is a guide for incorporating indoor air quality into decision making. All districts should consider their unique needs and capabilities in formulating appropriate responses to smoke events.

* See section 2d for definitions of “sufficient”.
* * See section 1b for examples of alternative community spaces.
*** Guidelines based on outdoor air quality are discussed in the first paragraph of section 1c.
In Pursuit of Clean Air: Laying the Groundwork for Public School Resilience to Wildfire Smoke

Stanford Climate and Energy Policy Program
2 FUTURE RESEARCH

The Climate and Energy Policy Program seeks to lay the groundwork for a coordinated research project across school districts where air quality monitors (at minimum) and air purification technologies (if circumstances allow) are to be installed across K-12 schools and potentially public spaces (e.g., libraries, public pools, centers of faith, etc.) to create and monitor safe air quality refuge centers. Throughout Autumn 2022, the project team communicated with potential project partners in school districts across the Bay Area. Further conversations with schools are necessary to collect information about the presence of air quality monitors and air purification measures, policies in place for wildfire smoke events, and funding availability for air quality monitoring or air purifier installation.

While further discussions with schools will determine the exact nature of a coordinated research effort, we present here considerations to shape those discussions. Section 2d includes specific recommendations for execution of the research effort.

a. Technical Program Design

This paper does not discuss building-wide HVAC or retrofits to mitigate the risk of heat and smoke events. California law requires that new buildings have ventilations systems with air filtration meeting certain standards.53 For older buildings, however, the complexity and cost of HVAC retrofits merit deeper consideration in a separate, equally important analysis.54 This paper offers recommendations for installation of air quality monitors and air purification devices. The quantity of monitors or purifiers installed in schools depends on funding and coverage preferences. We discuss key technical considerations in this section, covering target pollutants, performance verification, cost, and others, as recommended in the Environmental Protection Agency (EPA)’s Enhanced Air Sensor Guidebook.55

In this context, the monitor should, at minimum, collect temperature, particulate matter (PM) 2.5, humidity, and carbon dioxide (CO2) data at regular intervals. Other features to consider are connectivity to data networks, durability, weatherproofing, raw data storage capacity and modes, price, and ability to track pollutants such as volatile organic compounds (VOCs), carbon monoxide (CO), or nitrogen dioxide. We provide specific recommendations in Section 2d.56

If funding allows, standalone air purifiers can also be placed in all (or a subset of) rooms equipped with air quality monitors, which can verify the effectiveness of air purifiers or other HVAC upgrades. We summarize key technical considerations including filter technology, rating, noise, and efficiency.

Standalone purifiers can remove PM from air contaminated with wildfire smoke. Several ratings and standard systems evaluate that ability. In the US, the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Minimum Efficiency Reporting Value (MERV) and High-Efficiency Particulate Air [filter] (HEPA) classifications are typical. The non-proprietary MERV and HEPA filter medium entails a dense mat of fibers, arranged typically in a pleated rectangle. The rating, indicated by a number written after “MERV” or “HEPA”, ranges from 1 to 20 and signifies the percentage of particulates of a certain size removed.57 The US Department of Energy (DOE) standard and ISO 29463 define the HEPA rating as equivalence with MERV 16 or above, or elimination of 99.7% or above of particles above or below 0.3-microns.58 Other purification technologies include ionizers, UV lights, ozone generators, and proprietary methods. These entail potentially higher costs and may not be as effective at filtering PM—although some can be effective for other contaminants—and some, such as ozone generators, are even considered unsafe by CARB.59 A coarse particle pre-filter can be layered before the HEPA or MERV to extend the primary filter’s life. In some contexts, a carbon-activated filter can be used to eliminate odors or VOCs.

Other considerations include noise levels and Clean Air Delivery Rate (CADR). Purifiers may generate noise at a distracting level and, as noted in Section 2c, some California-based funding sources have a decibel limitation. CADR is a measure of the ability of an air purifier to output clean air, measured cubic feet per minute (cfm) or cubic meters per hour, enabling comparison of performance between purifiers with different technologies. To sufficiently protect against wildfire smoke, the Association of Home Appliance Manufacturers (AHAM) recommends having a purifier with a CADR rating equal to the square footage of the room, assuming an 8 ft. ceiling.60 CARB maintains a list of standalone air purifiers that comply with various standards in California, while AHAM maintains another list of CADR ratings for many models on the market.61 CARB provides a guide to calculating the CADR of an air purifier needed.62

CADR is limited in its ability to evaluate large air purifiers for large spaces. According to AHAM, the “maximum room size that the standard can confidently predict performance would be a room of 698 ft²”, leading to a maximum CADR for dust of 450 under the AHAM standard.63 This is due to the AHAM standard-compliant CADR test using a standard test chamber of 1,008 cubic feet. If a purifier that is designed to clean larger spaces is tested in the small standard chamber, it will rapidly clean the air, rendering the CADR calculation a poor representation of the purifier’s overall

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57 “What is a MERV rating?”, US Environmental Protection Agency, [https://www.epa.gov/indoor-air-quality-iaq/what-merv-rating](https://www.epa.gov/indoor-air-quality-iaq/what-merv-rating)
60 “Air Filtration Standards”, AHAM Verifide, [https://ahamverifide.org/ahams-air-filtration-standards/](https://ahamverifide.org/ahams-air-filtration-standards/). Calculators exist to adjust CADR ratings for rooms with ceilings higher than 8 feet, such as: [https://reviewsofairpurifiers.com/cadr-calculator/](https://reviewsofairpurifiers.com/cadr-calculator/)
strength.64 Another limitation of CADR is the disconnect from the particle size-focused rating of a filter, e.g., the MERV 15 or H13 rating, because CADR focuses on the volume of output of air that has passed through the purifier. In a higher-rated filter, the air coming out of the purifier may be “cleaner” in terms of the percentage of particulates removed in a single pass through the filter, but the volume of the clean air coming out, reflected in its CADR rating, can be lower, all else equal, due to restricted air flow.65

These dynamics make it extremely difficult for a layperson such as a school administrator to make nuanced decisions about filter type and CADR rating. All in all, filters with a HEPA rating will eliminate a higher percentage of particulate matter than filters with a MERV rating and therefore will be slightly more expensive. Specific recommendations on the filter rating, CADR, and other considerations are provided in Section 2d.

b. Budget

Studies have shown that installing HEPA purifiers and air quality sensors in classrooms can be a cost-effective approach to improving air quality in schools.66 For this context, a hypothetical, illustrative budget for a typical school is included below in Table 2, assuming a 19-classroom school and a program with both air quality monitors and purifiers.67 The bulk of this cost is driven by standalone air purifiers, including the cost of replacement filters for multiple years of operation in the initial outlay. Appendix 2 provides more information on the assumptions and a link to a spreadsheet tool to adjust the project cost estimate according to desired program features and input parameters. One key assumption of note is that purifiers are used for only six months of the year (reducing the operating cost). The illustrative budget does not include costs related to education, community outreach, capacity building, or administrative costs for personnel designing and overseeing the programs. Appendix 1 includes a table of potential air quality monitors and their relevant product specifications.

64 “Why Can’t CADR Values over 800m3/hr or 450cfm Be Measured Reliably?”, Smart Air, https://smartairfilters.com/learn/smart-air-knowledge-base/purifier-cadr-800m3-450cfm-measure-reliable/. Note: Companies with larger purifiers may circumvent this limitation by enlarging the test chamber, usually (but not always) noting their CADR specification is based on in-house testing.
66 “Clean Air For Schools Project”, University of Colorado Boulder, https://www.colorado.edu/faculty/hernandez/clean-air-schools-project.
67 Note: For an illustrative school, an assumption of 19 classrooms per school can be used, based on California’s 2022-2023 public school enrollment across 10,010 public schools. Enrollment data is available at https://www.cde.ca.gov/ds/ad/ceffingertipfacts.asp. An assumption of 30 pupils per classroom can be used (an approximation of the California Department of Education’s pupil-per-classroom guidelines available at https://www.cde.ca.gov/fg/aa/pa/cefcsp.asp).
Table 2: Illustrative School Air Quality Monitoring & Purification Program Cost

<table>
<thead>
<tr>
<th>Cost Category</th>
<th>Illustrative Cost Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equipment costs (e.g., air quality monitors, air purifiers)</td>
<td>$60,000</td>
</tr>
<tr>
<td>Maintenance &amp; labor</td>
<td>$15,000</td>
</tr>
<tr>
<td>Additional electricity costs over program life</td>
<td>$15,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$90,000</strong></td>
</tr>
</tbody>
</table>

As a framing exercise, we extrapolate this per-school cost to a wider population. California Senate Bill (SB) 535 gives the California Environmental Protection Agency (CalEPA) authority to identify disadvantaged communities to target for investments, based on certain criteria. CalEPA data on total population in these communities (28.7% of state population) can be used to approximate the number of public schools in disadvantaged communities. This simplified approach implies approximately 3,000 public schools in disadvantaged communities in California. Extrapolating the per-school values of Table 2, **we can estimate the budget required to install air quality monitors and air purifiers with 100% classroom coverage across those 3,000 schools would be in the ballpark of $270 million.** It is worth noting this encompasses a range of costs including the equipment cost of the purifier, the cost of replacement filters, and the cost of electricity to run the purifiers for six months per year over a period of 10 years. **An air quality monitor-only program would require a budget in the range of $37 million across those 3,000 schools.** In both cases, accessing favorable bulk pricing through a large project could lower procurement costs significantly. While a more detailed cost-benefit analysis (CBA) is necessary, these costs appear reasonable given that the near- and long-term costs of wildfire smoke health impacts are approximated at $100 billion per year nationally and considering a large portion of nationwide wildfire activity occurs in California. These approximations are intended to be illustrative only and, as noted, more details on assumptions are included in Appendix 2.

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68 See Appendix 2 for detailed assumptions.
70 Note: this high-level calculation does not reflect nuances such as differences in the number of private or public schools present in disadvantaged communities compared to all statewide communities.
71 “The Costs of Wildfire in California”
c. Funding

As a result of the increasingly destructive presence of wildfires across the state as well as the state-wide emphasis on environmental justice, numerous funding mechanisms have been established to target air quality in California. This section attempts to unravel the ecosystem of funding mechanisms to illustrate potential channels for California schools to access funding for air quality monitoring and air purification.

i. CARB Community Air Protection Program: Established under California Assembly Bill 617 (AB617), CARB's Community Air Protection Program provides funding for a range of air pollution-related activities. Some of these funds are disbursed through California's Air Districts, while others can be accessed from CARB directly by communities.

Air district-based funding

The California Legislature established the "California Climate Investments funding for Community Air Protection (CAP)" incentives to support implementation of AB617's air quality-focused programs. A series of funding appropriations by the State allocates funds to be administered by the air districts in partnership with communities across multiple program types, one of which includes community-identified projects developed by air districts in consultation with communities.72

The SB856 and AB134 funds were ultimately appropriated from California’s Greenhouse Gas Reduction Fund (GGRF) using proceeds from the state's cap-and-trade mechanism. The California Climate Investments program has requirements that dictate how the GGRF funds can ultimately be used, e.g., the proportion of the funds going to disadvantaged communities, as determined by AB1550. AB617 also designated ten priority communities (and three additional communities were added in 2021) where the CAP incentive funds should be prioritized.73

In 2019, CARB also approved the “Community Air Protection Incentives 2019 Guidelines” (“Guidelines”) to facilitate use of previously appropriated funds.74 The Guidelines added “Reducing Air Pollution in Schools” as one of the two new eligible project types for CAP incentive spending, in addition to the areas previously defined. Chapter 5 of the Guidelines is specifically focused on school air pollution-related projects. There are several forms of school air pollution, but one of the four eligible project areas defined in the Guidelines is “Air Filtration” to reduce particulate contaminants such as PM2.5.

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72 Note: funding was first appropriated in AB134, which focused on the Carl Moyer Memorial Air Quality Standards Attainment Program (Moyer Program) and the Proposition 1B Goods Movement Emission Reduction Program (Proposition 1B Program), and later through SB856, which introduced four additional program types: mobile-source projects (focusing on zero-emission equipment), zero-emission charging infrastructure projects, stationary source projects (focused on stationary sources of air pollution not regulated under California's cap and trade mechanism), and community air projects. More information is available at [https://ww2.arb.ca.gov/sites/default/files/2020-10/cap_incentives_2019_guidelines_final_rev_10_14_2020_0.pdf](https://ww2.arb.ca.gov/sites/default/files/2020-10/cap_incentives_2019_guidelines_final_rev_10_14_2020_0.pdf).


While the Guidelines initially emphasize “air filtration” in the context of HVAC filtration systems, with a stipulation that such systems meet requirements set by the California Energy Commission (e.g., requiring at least MERV 13-rated filters in the HVAC systems of newly constructed buildings), standalone air purifiers are also an eligible funding item. The Guidelines define an eligible standalone air purifier as follows: “[a] standalone air ventilation unit with a MERV of 14 or greater and with a noise threshold at or below 45 decibels […] [with] a clean air delivery rate (CADR) for tobacco smoke […] or CADR equivalent manufacturer’s rating for filtration that is appropriate for the classroom size.” Up to 90% of the cost of standalone units can be covered through the CAP incentives. Installation costs are included as an eligible cost, and the maximum project life is 5 years.

Two additional key elements of the Guidelines are community outreach and cost-sharing. Air districts are required to include outreach details in disbursement requests and CAP incentive reporting, demonstrating an important avenue by which school districts and public schools can influence an air district’s CAP fund allocation across the “community-identified” and “air pollution in schools” project categories. Applicants for CAP-based funds granted through the relevant air district must generally share at least 15% of the project’s CAP incentives-eligible cost. Under certain circumstances, the cost share requirement can be waived, subject to CARB’s case-by-case review of a waiver request submitted by the air district.

**CARB-based funding**

In addition to being able to access funding through the regional air district, schools and communities can access funding directly from CARB. This mechanism is referred to as the “Community Air Grants” (CAG) program. CAG recipients can be not-for-profit community-based organizations (with a 501(c)(3) tax exempt status), a non-government, for-profit organization in partnership with a tax exempt not-for-profit as a sub-grantee, or a Native American Tribe. The CAG fund is replenished annually, with $10 million set aside in the 2022 funding period.

Eligible project types include community engagement and outreach, support for community operated air monitoring, and support for data collection and analysis (which can include participatory research projects). A project implementing air quality monitor installation in schools or other public settings would fall in the “technical” category with a $300,000 award limit. This funding is generally spent on community education, capacity building, planning, and partnership creation with a special emphasis on the design and implementation of community air monitoring programs. Review of all Community Air Grants awarded in 2021 indicate standalone air purifiers are not typically proposed or funded in the project scope of work, the exception being one case of DIY purifiers being provided to community members participating in training and capacity building.

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75 “Community Air Protection Incentives 2019 Guidelines”
76 “Community Air Grants”, California Air Resources Board, [https://ww2.arb.ca.gov/capp-cag](https://ww2.arb.ca.gov/capp-cag)
77 The eligible project types and relevant grant application caps are available in more detail here through “AB 617 Community Air Grant Program DRAFT Request for Applications”, California Air Resources Board, October 2022, [https://ww2.arb.ca.gov/sites/default/files/2022-10/Draft%20CAG%20RFA%202022%20-%20Final_0.pdf](https://ww2.arb.ca.gov/sites/default/files/2022-10/Draft%20CAG%20RFA%202022%20-%20Final_0.pdf)
ii. Additional Funding Mechanisms

An overview of potential non-CARB funding avenues is summarized below. Some of these funding mechanisms are already exhausted, but are included nonetheless to provide broader context on the ecosystem of funding opportunities that has historically existed.

• **AB247:** Section 9 and Section 13 allow for allocation grants and modernization upgrades, respectively, to maximize indoor air quality, among other eligible uses. The bill places the “Kindergarten Through Community College Public Education Facilities Bond Act of 2024” proposition on the 2024 ballot, which, if passed, would increase school district bonding capacity from $5 million to $15 million to support these purposes.

• **The Inflation Reduction Act (IRA) and Bipartisan Infrastructure Law (BIL):** Among many other unprecedented provisions, IRA and BIL allocate hundreds of millions of dollars to improve schools and other public buildings. Some programs are specifically targeted toward air pollution in public schools. These funds are administered through different federal agencies, as elaborated below.

  – **Environmental Protection Agency (EPA):** The IRA allocated $117.5 million to EPA in the Air Pollution Monitoring program to improve air quality monitoring in communities across the US, including in Tribal areas.  

  An initial $30 million was used to supplement the American Rescue Plan of 2021 (ARP)’s Enhanced Air Quality Monitoring for Communities program. It is unclear whether IRA funds will continue to supplement the program or be administered through a different program in future years.  

  The IRA also allocated $50 million to the EPA School Air Pollution program for grants and technical assistance to monitor and reduce air pollution at public schools in low-income and disadvantaged communities (LIDCs). While this program’s guidelines on eligible recipients do not include independent school districts, schools can be served by nonprofits or other State, local, or Tribal agencies that are eligible to be recipients. The IRA also allocated $3 million to support air quality sensor purchases in LIDCs, to be channeled through State, local, or Tribal agencies or other public or private nonprofit institutions or organizations. EPA’s “Wildfire Smoke Preparedness in Community Buildings” funding opportunity could have future funding cycles to support smoke readiness planning and other wildfire smoke-related actions in public pre-schools and local education agencies, among other eligible recipients.  

  Finally, the EPA is competitively disbursing $27 billion through the Greenhouse Gas Reduction Fund in several funding competitions announced in summer 2023. The funds are intended to help communities reduce emission greenhouse gases and other pollutants and are expected to be channeled through national, regional, or local institutions such as green banks or community development financial institutions (CDFIs) that subsequently support local stakeholders with technical assistance and capacity building, debt financing, and other financial mechanisms. GGRF funds could, for example, be used for building or HVAC upgrades that reduce greenhouse gas emissions with co-benefits such as improved ventilation, improved air sealing, and reduced exposure to air pollution.

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Department of Energy (DOE): The BIL allocates new funding to the State Energy Program ($500 million) and Energy Efficiency Revolving Loan Fund ($250 million) which both provides funds that can support school building retrofits. For former is being distributed through the Renew America’s School program, with the first awards anticipated in June 2023, and a subsequent round of funding expected in FY2024. The BIL also allocates $500 million to the Energy Efficiency and Renewable Energy Improvements at Public School Facilities program, for schools to deploy energy efficiency, renewable energy, and alternative fueled vehicles. DOE kicked off the process to disburse the first $80 million of this program in early 2023. Finally, in May, 2023, the DOE announced the Renew America’s Nonprofits program, through which eligible nonprofits be subrecipients receiving grants up to $200,000 to retrofit buildings with energy efficiency measures, including more efficient HVAC systems. Public K-12 schools designated as 501(c)(3) nonprofits are eligible subrecipients. Under this program, DOE is expected to select a number of nonprofit intermediaries across the country to receive awards in Autumn 2023; these intermediaries will in turn facilitate provision of the grants to eligible nonprofit buildings.

- Research-related government funding: There are one-off opportunities to gain access to funding for air quality monitoring equipment through participation in a research study applying for specific Funding Opportunity Announcements. An example is the “Collaborative Centers in Children’s Environmental Health Research and Translation” project funded through the National Institutes of Health and executed by the University of Southern California.

- COVID-19-related funding: Although these funding opportunities have closed, the information is provided nonetheless to clarify the terminology of relevant programs in the recent past. The Coronavirus Aid, Relief, and Economic Security Act (CARES Act) included the initial Elementary and Secondary School Emergency Relief (ESSER I) fund with billions of dollars for schools across the U.S. to improve indoor air quality through improvements to heating, ventilation, and air conditioning systems in K-12 schools. Later, the Coronavirus Response and Relief Supplemental Appropriations (CRRSA) Act introduced additional ESSER II and ESSER III funds for similar purposes. Alongside these was the Higher Education Emergency Relief Fund which had similar support for higher education facilities. Applications for ESSER I closed in July 2021 and ESSER II and ESSER III closed December 2021. Similarly, the Governor’s Emergency Education Relief (GEER) fund was introduced under the CARES Act, which included assistance to non-public schools through the Emergency Assistance to Non-Public Schools (EANS) Fund. The federal American Rescue Plan of 2021 (ARP) included $2.75 billion set aside for GEER funds at the state level. California, in turn, received an ARP EANS award of about $181 million, about 99% of which is allocated to eligible non-public schools. EANS funding applications closed in 2021.

84 “Southern California Center for Children’s Environmental Health Translational Research”, University of California, https://reporter.nih.gov/project-details/10307480#details
• **Air quality refuge centers**: AB 836 (2019) allocated a total of $5 million to Wildfire Smoke Clean Air Centers. Of that, $925,000 has gone to the California Air Pollution Control Officers Association (CAPCOA) Wildfire Smoke Clean Air Centers for Vulnerable Populations Incentive Pilot Program. The Bay Area Air Quality Management District (AQMD), San Joaquin Valley Air Pollution Control District, and South Coast AQMD have each elected to administer their own AB 836 grant funding within their districts.  

### d. Recommendations

#### 1. Funding

A high-level overview of the California-based funding sources is shown in Figure 3. Schools should first determine whether they are in a priority AB617 community (although this would likely already be known, considering the proliferation of CARB-driven activity in those communities). This would inform whether the community is a priority for CAP investments and could shape school discussions with CARB and the local air quality district. Schools and communities can influence the direction of local air quality management district spending through community consultations along the “community-identified” and “air pollution in schools” project areas, as noted in Figure 3. Schools not located in AB617 communities should still explore applying for a Community Air Grant directly from CARB, as well as any other programs being implemented by their regional air quality management district.

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86 “Clean Air Center Grant Program”, CAPCOA, [https://capcoa.org/clean-air-center-grant-program/](https://capcoa.org/clean-air-center-grant-program/)

87 A map of AB617 communities is available at [https://ww2.arb.ca.gov/capp-communities](https://ww2.arb.ca.gov/capp-communities).
Figure 3: Air quality monitoring funding channels. Starred areas are most relevant to the type of project discussed in this paper.

1. California-based Funding Channels

1a. Is the school in an AB617 Community?

- **YES**
  - Air district-based funding
    - AB617 Community Air Protection ("CAP") Incentives
      - Mobile-source projects (zero-emission equipment)
      - Stationary source projects
      - Zero-emission charging infrastructure
      - *Community-identified projects
      - Hexavalent chrome plating facilities
      - *Reducing air pollution in schools
    - Community Air Grants ("CAG")
      - Educational
      - *Technical
      - Targeted – Community Capacity Building
      - Targeted – Emissions Reduction Strategy Development
      - Targeted – Emissions Reduction Strategy Expansion
      - Targeted – Community Air Monitoring Plan Development

- **NO**
  - CARB-based funding

1b. Regardless of AB617 status

- *AB247 – Modernization upgrades
- *AB836 – Wildfire Smoke Clean Air Centers

2. Potential Federal Funding Channels

2a. EPA

- FenceLine Air Monitoring program ($117.5 million)
- School Air Pollution program ($50 million)*
- Air quality sensors in LIDCs ($3 million)*
- Wildfire Smoke Preparedness in Community Buildings ($10.6 million)*
- Greenhouse Gas Reduction Fund ($27 billion)*

2b. DOE

- State Energy Program ($500 million)
- Energy Efficiency Revolving Loan Fund ($250 million)*
- Energy Efficiency and Renewable Energy Improvements at Public School Facilities program ($500 million)*
- Renew America’s Nonprofits program ($45 million)*

2c. Research efforts through federal agencies & in partnership with higher education

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To access federal funding, schools should pay attention to any updates related to IRA and BIL-related funding opportunities.\textsuperscript{88} Absent state or federal funding, communities should explore philanthropic funding with local or regional nonprofit organizations or partnerships with community-based organizations (CBOs) or research institutions with relevant programming.

2. Air quality monitors

We recommend the following guidelines as selection criteria for air quality monitors:

- Prioritize temperature, CO\textsubscript{2}, and PM2.5 and PM10 data collection. If technology and budget allow, consider collection of other pollutants (e.g., CO, VOCs, CO\textsubscript{2}, or other pollutant types) to explore more empirical work, given their known health impacts.

- While many monitors offer some sort of Wi-Fi connectivity, we do not recommend fully relying on a Wi-Fi connection for data storage and access, due to potential complications that may arise when connecting to school Wi-Fi networks. For simplicity, we suggest connecting only the outdoor monitor and one internal monitor to the internet (through Wi-Fi or 4G cellular networks) for purposes of remote viewing through internet-based platforms. Other indoor monitors can remain unconnected to external networks. Prioritizing on-board storage reduces the potential need for capacity building or paid support to access APIs to extract raw data from the sensors being stored on the cloud.

- For the purposes of this project, we recommend procuring air quality monitors from a brand that makes both an indoor version and an outdoor version of their monitor to ensure consistency between indoor and outdoor readings and ease of use.

- We do not recommend a specific air quality sensing technology to be used (e.g., the specific type of laser or algorithm used for measurement). Our impression is that they are functionally equivalent in consumer-level sensors on the market, but further research could confirm this.

The report’s authors reviewed many brands of sensors noted in Appendix 1 and found that the PurpleAir or AirVisual brands generally meet the above-noted criteria that would serve school air quality needs. Specifically, using the PA-II-FLEX (in outdoor settings) and the PA-I-Indoor (in indoor settings), or the AirVisual Node Outdoor (in outdoor settings) and AirVisual Node (in indoor settings) would be sufficient for the purposes of this research. If pollutant types other than particulate matter is to be prioritized, the EPA’s Evaluation of Emerging Air Sensor Performance or the Air Quality Sensor Performance Evaluation Center (AQ-SPEC) can be a useful tool for selecting the sensor.\textsuperscript{89} These recommendations are not based on affiliation or paid review/advertisement with noted brands.

\textsuperscript{88} Note: A subset of open grant opportunities can be accessed at https://www.epa.gov/grants/air-grants-and-funding.

On placement and layout of monitors, if funding allows, we recommend installing a monitor in all regular classrooms, the school gymnasium, at least one administrative office, and at least one exterior monitor on the school grounds. We do not recommend placing a monitor inside cafeterias or other rooms where there is potential for behaviors (e.g., cooking) to influence particulate concentration readings. To mitigate concerns over parent or teacher’s union intervention during the research effort, monitor data should not be accessible on public-facing air quality websites during the research program.

Central to the question of how schools should design their wildfire smoke event guidelines is whether or not students will have access to clean air while at home. To explore this issue, we recommend purchasing additional air quality monitors – both indoor and outdoor – to place in the homes of a sample of school students. This effort can utilize any research protocols that already put or intend to put air quality monitors at residences in the school’s town. Alternatively, an unbiased, random selection of student households can be selected for installation of one additional outdoor monitor and one additional indoor monitor of the same model and with the same operational considerations discussed above for the school-based monitors. Some reimbursement should be provided to those participating households as a token of appreciation for enabling the project to extend outside of the classroom beyond covering incremental electricity costs associated with device operation.

Operationally, behavioral training is essential to maximize potential benefits provided by monitors and air purifiers. We recommend assuming the monitors will be plugged in and running 24/7 to minimize the need to manually turn the monitors on or off, thereby minimizing the risk of data unavailability due to human error. We recommend against use of humidifiers in the same classroom as monitors, as studies have shown that high levels of humidity can erroneously inflate particulate matter concentration readings in some air quality monitoring devices. We suggest a weekly visual inspection of the monitors and backup of raw data from each monitor at least on a quarterly basis. Further attention should go toward others operational considerations such as quality checks, drift (i.e., loss of calibration), collocation with reference-grade sensors (i.e., air quality monitoring stations used for government purposes), and potentially establishment of data measurement systems (although from simplicity and cost perspectives, a manual collection approach is feasible). The EPA The Enhanced Air Sensor Guidebook can be a resource in those considerations and decision tools. We recommend closure of doors and windows while purifiers are turned on to maximize purifier effectiveness and, consequently, use of air conditioning on smoke days. This recommendation should be discussed further in the context of extreme heat event policy, potential building envelope improvements (e.g., window sealing), and consideration of whether air conditioning systems would bring dirty outside air into the classrooms.

90 More guidance on sensor placement is available at the EPA Air Sensor Toolbox (https://www.epa.gov/air-sensor-toolbox/guide-siting-and-installing-air-sensors) as well as page 29 of the EPA’s Emerging Approaches to Cleaner Indoor Air During Wildfires presentation, available at https://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=351926&Lab=CEMM&simplesearch=0&showcriteria=2&sortby=pubDate&searchall=holder&dimentype=&datebeginpublishedpresented=08/03/2019
92 For example, see the government monitors through airnow.gov
3. Standalone air purifiers

Inclusion of air purifiers significantly inflates the project budget due to the higher costs of the units as well as the need for replacement filters on an ongoing basis. Additionally, more effort should be spent compiling standalone air purifier information (similar to the air quality monitor information in Appendix 1) or creating an easy-to-use decision-making tool to help schools identify standalone purifiers that fit their specific needs. That said, the discussion hereafter makes general recommendations and assumes that enough budget is available to provide standalone purifiers to all or a subset of classrooms participating in the project.

In the context of wildfire smoke events, schools need purifiers to filter particulate matter. Given that, we recommend procurement of air purifiers with MERV 17 or above or HEPA filter ratings according to the U.S. ASHRAE standard, or H13 above in the EN 1822 standard. While not required, we recommend selection of purifiers including a coarse particle pre-filter to extend the life of the primary filter. The purifier’s noise level should be below 45 decibels to comply with the requirement of CARB-based funding (or any future iteration of that requirement). Given the limitations of CADR, we recommend following the AHAM rule of thumb on having a purifier with a CADR rating equal to the square footage of the room, but not restricting eligibility to CADR ratings stemming from the prescriptive AHAM testing protocol (i.e., allowing for in-house CADR calculations) to avoid putting more powerful purifiers designed for larger spaces at a disadvantage in procurement evaluation. Electricity usage for air purifiers, while not insignificant from a cost perspective, should not be a major decision criteria.94 From an electricity usage perspective, equipping all 3,000 schools noted in Section 2b. with standalone air purifiers in all classrooms would result in incremental electricity usage of approximately 12.5 gigawatt-hours (GWh) per year, a negligible amount (0.005%) of California’s 2021 electricity usage.95 Additional analysis could be done on incremental electricity usage associated with air conditioning or new HVAC systems.

Given air purification needs will be lower outside of the primary wildfire season, we recommend exploring the purchase of lower-strength filters (e.g., MERV-13 rating) to use in standalone air purifiers when there are no active wildfire or smoke events. This should be a lower priority than the higher-strength filters, however. We note this possibility after hearing a similar setup was used in a major California school district. However, we have not built this cost into the illustrative budget of Appendix 2 given the wildfire season duration is difficult to predict (and becoming longer) and because it is difficult to provide detailed recommendations without already having more data on classroom air quality levels under normal circumstances. The air quality data collected over the course of this research can lead to more informed recommendations on this front.

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94 Power consumption can vary widely between purifiers depending on the size of the room it is intended to filter (i.e., the size of the unit). Anecdotal review of several large air purifier models indicate power usage will be in a similar approximate range of wattage and therefore not become a significant differentiating or contributing factor to the lifetime costs of the unit. We recommend placing more importance on other criteria during procurement decisions. Estimations of electricity usage are available in the EPA’s technical summary on residential air purifiers (p. 39) available at https://www.epa.gov/sites/default/files/2018-07/documents/residential_air_cleaners_-_a_technical_summary_3rd_edition.pdf.

95 “2021 Total System Electric Generation”, California Energy Commission, https://www.energy.ca.gov/data-reports/energy-almanac/california-electricity-data/2021-total-system-electric-generation. Calculation note: assumes 150 watt capacity per purifier, usage of 10 hours per day for 20 days per month for 6 months of the year, leading to 180,000 watt-hours or 180 kilowatt hours (kWh) per purifier per year. Assumes 25 purifiers per school (see budget tool in Appendix 2) across 3,000 schools, leading to 13,500,000 kWh per year, or 13.5 gigawatt hours per year.
Operationally, we recommend planning to leave air purifiers on uninterrupted when the classroom is occupied and whenever PM2.5 concentration (indicated by the room’s air quality monitor) exceeds a threshold of 15 micrograms per cubic meter or μg/m³ (approximately 56 on the AQI scale), the EPA’s annual exposure standard (and this threshold should be adjusted to follow any future changes to EPA guidance to 9-10 μg/m³). We recommend building in budget to replace filters at a regular interval. Additional effort could go toward developing a simple usage tracking tool to help schools keep track of their purifier usage during the wildfire season. In the absence of such a tool, filters should be replaced according to the guidelines of the model (generally ranging from every 90 days of usage to once per year). In all cases, the project should directly train facility managers and custodian staff on the purifier’s maintenance needs and socialize proper operation among students and teachers.

If funding allows, we recommend that the research protocol explores provision of the same model of air purifiers placed in the school to other venues in the community (e.g., community air quality refuge centers such as libraries). This can be used to better understand air quality elsewhere in the community and assist with planning for future projects to establish community air quality refuge centers. Along that discussion, it is worth exploring the feasibility of a county- or school district-wide air purifier loan program, in which a central bank of air purifiers could be distributed to schools on a rotating basis depending on exposure to wildfire smoke events. Such a loan program could be modelled after the EPA’s Air Sensor Loan Programs. If logistically feasible, and if the county or school district is spatially large enough that not all schools would face a wildfire smoke event simultaneously, such a program could drive cost savings by avoiding the need for standalone purifier procurement for all schools.

4. Other recommendations

We recommend further research on CBA of air purifiers, and incorporating data on CBA elements in the project’s research design, if possible. This could entail collecting data on student absenteeism and medical expenditures during the study period for a subset of students attending the school.

Finally, the installation of monitors in schools presents an opportunity for education for students. We recommend that a project includes funding and plans for educational assemblies with content on types of air pollution, the ways air pollution affects human health, air quality indices and exposure guidelines, and standalone air purifiers, including DIY air purifiers. The families of students selected to directly participate in the project with at-home monitors can receive additional training specific to the air quality monitors they receive. The educational component of the project can leverage the expertise of community-based organizations with relevant programming.

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96 Note: 15 μg/m³ is equivalent to approximately equal to a rating of 50 on the Air Quality Index (AQI) scale. We recommend basing decisions off microgram measurements rather than AQI because of potential confusion that can arise due to some applications calculating AQI differently, particularly across different countries.

97 An example of one such effort can be read about in “Wildfire Smoke Clean Air Centers: Identifying Barriers and Opportunities for Improvement from California Practitioner and Community Perspectives” (2022).

98 Air Sensor Loan Programs”, US Environmental Protection Agency, https://www.epa.gov/air-sensor-toolbox/air-sensor-loan-programs
CONCLUSION

Schools throughout California face wildfire smoke events of increasing frequency and severity. Unfortunately, poor data availability on indoor air quality limits the ability of schools to provide and implement guidance around student activity and school closure when faced with a wildfire smoke event. A comprehensive research effort involving placement of air quality monitors is necessary to fill this data gap and better inform school guidelines. This paper provides a starting point, a manual of sorts, for establishing school policies for wildfire smoke and introduces key issues for consideration when standing up a school air quality research effort. We note many areas of inquiry worthy of further investigation that could build from this starting point.
In Pursuit of Clean Air: Laying the Groundwork for Public School Resilience to Wildfire Smoke
APPENDIX 1. AIR QUALITY MONITOR COMPARISON

Further research is necessary to understand the ease with which cloud storage-based raw sensor data can be accessed (usually through using the company’s API) and for what historical time intervals the raw data is available. The information included is based on publicly available information rather than personal testing and is not meant to be exhaustive, comprehensive, or devoid of errors.

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<th>CO2</th>
<th>PM1</th>
<th>PM2.5</th>
<th>PM10 Pressure</th>
<th>Connectivity</th>
<th>Local storage data capacity (years of data)</th>
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</table>
APPENDIX 2. ILLUSTRATIVE BUDGET TOOL FOR SCHOOL AIR QUALITY MONITORING

This budget tool is intended to provide an illustrative framework for estimating costs associated with an air quality monitor and/or air purifier installation intervention in a school. This budget does not feature purchase of additional air quality monitors to place in the homes of a sample of school students or in other public venues to assess air quality in areas other than the school itself (see Section 2d for relevant discussion). The numbers shown or design of this tool should in no way be construed as a recommendation for program design or cost. Basic assumptions are noted in the spreadsheet.

An editable version of this basic budget tool can be accessed at the following URL:
https://docs.google.com/spreadsheets/d/17ypWc1rL3y0xlZ5nVmsQwK3urElG15FL_Si6AJ92Ubw/edit?usp=share_link.

An alternative link to an Excel spreadsheet is available here:
https://www.dropbox.com/scl/fi/xqp4wfx9aryfsgz5udpu2/Budget-Tool.xlsx?rlkey=a1zbu9q5o4k22lape4kkp8nz&dl=0
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