Californians for Pesticide Reform (Sarah Aird)

What is your submittal about?

Please select one:
Pesticide group

Provide the name of the pesticide and, if possible, its Chemical Abstracts Service (CAS) Registry Number.

You may use DPR's CalPEST Public Search to look up the CAS Registry Number.
1,3-Dichloropropene (1,3-D / Telone) 542-75-6
Aluminum phosphide 20859-73-8
Carbon dioxide 124-38-9
Chloropicrin 76-06-2
Dazomet 533-74-4
Magnesium phosphide 12057-74-8
Metam-potassium (potassium N-methyldithiocarbamate) 137-41-7
Metam-sodium 137-42-8
Methyl bromide 74-83-9
Phosphine 7803-51-2
Propylene oxide 75-56-9
Sulfur dioxide 7446-09-5
Sulfuryl fluoride 2699-79-8

(Short Format) In one to three sentences, please describe your pesticide-related concern.

The description provided will appear in the online summary.
Fumigant pesticides should be prioritized as a class for continuous evaluation and mitigation action because they share a defining exposure pathway: they are designed to volatilize and disperse as gases, creating inhalation risks that can extend beyond the treated site and expose applicators, farmworkers, nearby residents, schoolchildren, and other community members. Their high-volume use, potential for off-site movement, and serious acute and chronic health hazards warrant class-based evaluation and action aimed at substantially reducing and ultimately eliminating uses that pose significant risks to human health.

(Long Format) Please describe your pesticide-related concern and why it should be a DPR priority.

What type of information should you include?

- **Who or what is affected** (e.g. worker, community, residential, consumer health, sensitive populations, environmental endpoint, pesticide use, or other human health or environmental concern)
- **Description of the situation of concern**, including use site (e.g., crop or residential), region, type of pesticide use and application method (e.g., ground spraying; soil fumigation; bait applications; etc.)

Exposure Pathway and Populations Affected
Fumigant pesticides should be prioritized as a group for comprehensive scientific evaluation and regulatory action because their defining characteristic—their ability to form toxic gases—is also a defining human exposure concern. Unlike pesticides intended to remain on a plant or soil surface, fumigants are designed to volatilize and move through soil, structures, or stored commodities. Consequently, inhalation exposure and off-site movement are inherent concerns associated with their use, affecting not only applicators and handlers but also farmworkers in nearby fields, residents, children attending schools near treated fields, and other people who live and work in agricultural communities.[1][2] DPR's own commissioned California Council on Science and Technology (CCST) review recognizes how the volatility of soil fumigants results in atmospheric emissions and potential nonoccupational bystander exposure, and identifies farmworkers, nearby rural communities, children, pregnant people, and older adults as populations of concern.[2] Independent peer-reviewed field and laboratory research likewise documents atmospheric emissions from major soil fumigants. Studies of 1,3-D and chloropicrin have directly measured volatilization from treated soils and describe limiting those emissions as important both for worker and bystander protection and for reducing air pollution.[3][4]

Scale and Geographic Concentration of Use
California uses extraordinarily large quantities of agricultural soil fumigants. In 2023 alone, approximately 8.6 million pounds of metam-potassium, 8.5 million pounds of chloropicrin, 7.0 million pounds of 1,3-dichloropropene (1,3-D), and 2.8 million pounds of metam-sodium were used statewide.[1] These chemicals are concentrated in agricultural regions including the Salinas and Pajaro Valleys, Santa Maria and Oxnard areas, and the San Joaquin Valley, where intensive agriculture frequently occurs near homes, schools, workplaces, and other community sites. DPR's own Air

Monitoring Network demonstrates that this exposure pathway is real: in 2023 it detected four fumigants—1,3-D, chloropicrin, methyl bromide, and methyl isothiocyanate (MITC)—in ambient air in agricultural communities.[5]

Continuing Community Exposure

More recent evidence shows that substantial concerns remain despite additional federal and California mitigation measures. Corrected DPR monitoring data identified additional historical 1,3-D concentrations that exceeded screening levels or regulatory targets.[6] OEHHA's 2024 analysis reported that annual-average 1,3-D concentrations measured during 2017-2022 in several high-use inland communities significantly exceeded 0.21 ppb, the average working-lifetime concentration corresponding to OEHHA's target occupational-bystander cancer risk of one in 100,000, including annual averages of 1.112 ppb in Parlier, 0.630 ppb in Shafter, and 0.315 ppb in Delhi.[7] OEHHA noted that these measurements predated DPR's January 2024 non-occupational bystander regulation and expected concentrations to decline under the newer controls. Nevertheless, in 2025 the annual average at DPR's Parlier monitoring station reached 0.35 ppb, exceeding DPR's 0.27-ppb regulatory monitoring threshold and triggering additional scientific review.[8] Historical monitoring also illustrates the potential for long-distance off-site movement of fumigants: DPR attributed a one-day 1,3-D concentration of 20.8 ppb measured at Sequoia Elementary School in Shafter in January 2020 to an application 7.5 miles away.[9]

Metam-sodium and metam-potassium likewise generate the volatile fumigant MITC, which continues to be detected in ambient air in California agricultural communities. DPR's 2024 monitoring detected MITC at quantifiable concentrations in Oxnard, Santa Maria, and Shafter, with a trace detection in Watsonville.[10] Although 2024 concentrations did not exceed DPR's health screening levels, MITC in Shafter reached approximately 85% of DPR's subchronic screening level and 83% of its chronic screening level.[10] EPA's 2008 reassessment concluded that inhalation exposure to MITC from metam-sodium and metam-potassium soil fumigation could pose risks of concern to bystanders, workers, and handlers and required extensive additional mitigation, including buffer zones, monitoring, respiratory protection, and other controls.[11] DPR's separate analysis of MITC monitoring also found detections in Salinas and Shafter during weeks when no MITC-generating pesticide use was reported within five miles of the monitoring stations, indicating that some detections may have originated from applications farther than five miles away.[12]

Mixtures and Cumulative Exposure

Fumigants should not be evaluated solely one chemical at a time. Soil fumigants are frequently used in mixtures, co-formulations, or pest-management programs involving multiple fumigants. Chloropicrin, for example, is commonly paired with 1,3-D, while metam-sodium and metam-potassium generate the same volatile fumigant, MITC. Scientific studies in California have documented that nearby fumigant use can predict concentrations in community air and that fumigant drift can occur over distances of several kilometers.[9][13] A UCLA analysis of 1,3-D, chloropicrin, and metam fumigants identified biologically plausible mechanisms through which combined exposures could increase oxidative stress, interfere with common cellular defense systems or DNA repair, and potentially produce greater genotoxic effects than would be predicted from evaluating each pesticide independently.[14] CCST independently identified this same gap, concluding that cumulative and synergistic effects of fumigant mixtures remain inadequately understood and recommending that DPR investigate additive or synergistic effects of fumigant mixtures and other agrochemicals.[2] Real-world exposure may therefore involve product mixtures, sequential applications, and emissions from different nearby fields—even where each individual application complies with its own restrictions.

Human Health Impacts

The human-health evidence extends beyond modeled exposure. California epidemiologic research has reported associations between greater childhood residential proximity to methyl bromide and chloropicrin use and lower IQ, and between prenatal proximity to methyl bromide use and adverse birth outcomes.[15][16] Two additional California studies reported associations between ambient methyl bromide or 1,3-D concentrations and asthma emergency-department visits, including associations among children and some racial and ethnic groups; because of methodological limitations, these studies are best viewed as suggestive rather than definitive evidence.[17][18] Historically, the first comprehensive U.S. surveillance study of agricultural pesticide drift found that fumigants were involved in only 8% of drift events but accounted for 45% of reported illnesses and 61% of nonoccupational cases, and five of the ten largest incidents involved California metam-sodium or chloropicrin applications.[19] Although those data largely predate stronger fumigant controls and should not be treated as estimates of current illness rates, they demonstrate the exceptional capacity of fumigants to produce large community-exposure events. In one example – in a 2005 Salinas chloropicrin drift incident, investigators identified 324 residents with symptoms possibly or probably related to exposure; cases occurred from 0.36 to 2.89 miles from the treated field, and reported effects included eye, respiratory, and systemic symptoms.[20]

The concern extends beyond agricultural soil fumigation. Sulfuryl fluoride is used extensively for whole-structure fumigation in California, creating occupational and accidental exposure risks; severe poisonings, neurological injury, and fatalities have been documented following structural fumigation exposures.[21] Commodity fumigants create additional occupational and bystander exposure pathways.

Fumigant use also contributes to a second human-health pathway through air pollution. Several heavily used soil fumigants are emitted to the atmosphere as volatile organic compounds (VOCs). Independent peer-reviewed field research on 1,3-D and chloropicrin explicitly identifies fumigant emissions as VOC emissions that contribute to the formation of ground-level ozone.[4] Separate peer-reviewed research on pesticide VOCs confirms that volatile constituents of pesticide products can contribute to ground-level ozone formation and that different pesticide constituents vary substantially in their ozone-forming potential.[22] This matters for human health because ground-level ozone is itself a respiratory toxicant: a recent systematic review and meta-analysis of long-term ozone exposure found increased risks of all-cause, respiratory, COPD, cardiovascular, and congestive-heart-failure mortality with increasing warm-season ozone exposure, while an updated WHO-related systematic review found high-certainty evidence linking annual ozone exposure with respiratory mortality.[23][24] Reducing reliance on high-emitting fumigants therefore has the potential to reduce not only direct exposure to the fumigants themselves but also their contribution to a regional air pollutant with independently established health effects.

Fumigants also have climate-related health implications. Sulfuryl fluoride—the major structural fumigant—is itself a potent and persistent greenhouse gas. Peer-reviewed atmospheric-chemistry research estimated an atmospheric lifetime of approximately 36 years and a 100-year global-warming potential of about 4,780, meaning that pound-for-pound its warming effect over a century is thousands of times that of carbon dioxide.[25][26] Soil fumigation can create an additional climate impact indirectly by altering soil nitrogen cycling and increasing emissions of nitrous oxide (N_2O), another powerful greenhouse gas. Peer-reviewed field and laboratory studies found that chloropicrin and MITC fumigation significantly increased N_2O emissions, with effects persisting for weeks; mechanistic work found approximately a 12.6-fold increase in N_2O production following chloropicrin fumigation.[27][28] A later peer-reviewed study found maximum N_2O production rates increased 9.9-fold and 30-fold following dazomet fumigation in two different soils.[29] These studies do not establish that fumigation is a dominant source of California greenhouse-gas emissions, but they do show that fumigant use can contribute to climate change in measurable ways. PAN's scientific review describes a reinforcing cycle in which pesticide production and use contribute to greenhouse-gas emissions, while climate change can increase pest pressures and pesticide use.[30] That consequence is relevant to human health: climate change increases exposure to extreme heat and other health-threatening conditions, with the Lancet Countdown documenting rising heat-related mortality and other escalating climate-related health risks.[31]

Why Fumigants Should Be Prioritized as a Class
The combination of exceptionally high use, intentional volatility, documented off-site movement, repeated community exposure, measured air concentrations that have exceeded health-based benchmarks or triggered regulatory review, use of multiple fumigants in the same agricultural regions, unresolved mixture and cumulative-exposure concerns, serious acute and chronic hazards, and the disproportionate burden borne by agricultural workers and communities makes fumigants particularly appropriate for class-based SPARC prioritization. Add to this the emergence and reemergence of soilborne diseases in fumigation-dependent production systems,[32] and the extreme potency of some fumigants as greenhouse gases.[25][26] Together, these factors further underscore the long-term unsustainability of continued dependence on fumigation. The additional VOC/ozone and greenhouse-gas evidence strengthens the case for evaluating fumigants as a class because these are consequences of fumigant-dependent systems that are not captured by assessing the direct toxicology of each active ingredient in isolation.

Alternatives and Transition Strategies
The availability of alternatives should not be a prerequisite for DPR to phase out pesticides that present unacceptable threats to human health or the environment. DPR's responsibility to protect health should drive decisions about whether the most hazardous pesticides should remain in use; the role of alternatives is to help facilitate and accelerate the transition away from them.

Importantly, prioritizing fumigants does not mean waiting for a single chemical to replace each fumigant one-for-one. California already grows many of the same crops without soil fumigation, including in organic production. Fumigant-dependent production systems are often built around continuous or near-continuous monocropping, which, by design, creates conditions favorable to the buildup of soil-borne pathogens.[32][33] Unless those underlying cropping systems change, reliance on fumigation treats the recurring disease problem without addressing the production system that helps create and perpetuate it. Aside from the practice changes embodied in organic production that function primarily to prevent pest problems (e.g. crop rotations, intercropping, cover crops, organic soil amendments) a growing body of research demonstrates promising nonfumigant approaches to managing soil-borne pests.

DPR's own CCST review identified alternatives including steam treatment, anaerobic soil disinfestation, solarization, resistant varieties and rootstocks, sanitation, biological controls, soilless production systems, and combinations of these approaches. CCST found that no single alternative currently functions as a universal substitute across every crop, pest, and region, but also concluded that combinations of alternatives can be effective for particular production systems.[2] In strawberries, for example, studies reviewed by CCST found that steam treatment in pathogen-infested soils produced yield improvements comparable to methyl bromide/chloropicrin fumigation, while anaerobic soil disinfestation is already used commercially on more than 2,000 acres annually in California, predominantly in organic fields, and can produce yields similar to fumigated soil under appropriate conditions.[2][34][35] These conclusions are also supported by peer-reviewed research independent of DPR. California field trials of a mobile steam applicator found suppression of weeds and soilborne pathogens comparable to commercial chloropicrin/1,3-D treatment and favorable strawberry yields,[35] while multi-year California research on anaerobic soil disinfestation concluded that ASD can be a viable alternative to fumigation for control of some strawberry soilborne pathogens, with comparable yields under successful treatment conditions.[37]

The existence of successful organic and nonfumigant production systems is important evidence that fumigation is not inherently necessary to grow these crops. Rather than requiring a single "drop-in" replacement before acting, DPR should evaluate how combinations of cultural, biological, physical, and other nonfumigant practices can replace fumigant-dependent production systems. SPARC should therefore prioritize fumigants as a class, evaluate their cumulative and overlapping exposures rather than individual active ingredients in isolation, and accelerate a transition toward pest-management systems that prevent the need for routine use of highly volatile toxic chemicals.

Extending Class-Based Prioritization to Other High-Hazard Pesticides
In addition to the two priority classes we've recommended (organophosphates and fumigants), we also urge DPR and SPARC to apply the same class- or group-based approach to other categories of pesticides presenting serious health hazards, including prioritizing as a group for phaseout the carcinogenic multi-site fungicides mancozeb, chlorothalonil, and captan.

What scientific information or additional information supports your submittal?

DPR will collect pesticide use reports, pesticide illness reports, environmental and human health data for each submission; submitters do not need to provide this information. Description of DPR collected data can be found on slide 52 of August 7th SPARC Meeting Slides.

Attach supporting documents using the "Upload a File" option below.

Please provide a brief rationale for each file you attach. Explain why each attachment is being included and how it supports your submittal.
1. California Department of Pesticide Regulation. Pesticide Use Annual Report 2023 Data Summary. Sacramento, CA: California Department of Pesticide Regulation, 2025.

https://www.cdpr.ca.gov/wp-content/uploads/2025/08/2023_pur_annual_report.pdf

Description: DPR's annual pesticide-use report documents statewide agricultural pesticide use in 2023. It defines fumigants as volatile gas pesticides capable of penetrating soil, stored products, structures, and other sites, and provides statewide use trends for fumigant active ingredients. The underlying 2023 use data show approximately 8.6 million pounds of metam-potassium, 8.5 million pounds of chloropicrin, 7.0 million pounds of 1,3-dichloropropene, and 2.8 million pounds of metam-sodium used in California.

2. Simmons, Christopher, and Janet Broome. Fumigant Use in California and an Assessment of Available Alternatives: Phase I Report on 1,3-D and Chloropicrin. California Council on Science and Technology. Commissioned by the California Department of Pesticide Regulation. March 13, 2025.

https://ccst.us/reports/fumigant-use-in-california-and-an-assessment-of-available-alternatives-phase-i-report-on-13-d-and-chloropicrin/

Description: This independent, peer-reviewed assessment commissioned by DPR examines 1,3-D and chloropicrin, their health and environmental concerns, California use, and alternatives. The report discusses the inherent volatility and atmospheric emissions of fumigants, exposure of nearby

communities and workers, potentially vulnerable populations, deficiencies in understanding cumulative and synergistic effects, and available nonfumigant alternatives.

3. Ashworth, Daniel J., and Scott R. Yates. “Surface Irrigation Reduces the Emission of Volatile 1,3-Dichloropropene from Agricultural Soils.” Environmental Science & Technology 41, no. 7 (2007): 2231–2236. DOI: 10.1021/es062642d.

https://pubs.acs.org/doi/10.1021/es062642d

Description: This peer-reviewed study investigated volatilization of the soil fumigant 1,3-D under realistic soil conditions. The authors characterize 1,3-D as a VOC-containing fumigant released from soil to the atmosphere and found that surface irrigation reduced emissions by roughly half in the tested soil columns. It provides independent evidence of the atmospheric-emission pathway associated with this highly volatile soil fumigant.

4. Gao, Suduan, Thomas J. Trout, and Sally Schneider. “Evaluation of Fumigation and Surface Seal Methods on Fumigant Emissions in an Orchard Replant Field.” Journal of Environmental Quality 37, no. 2 (2008): 369–377. DOI: 10.2134/jeq2007.0088.

https://doi.org/10.2134/jeq2007.0088

Description: This peer-reviewed California field study measured emissions of both 1,3-D and chloropicrin following soil fumigation. The authors identify fumigant VOC emissions as contributing to formation of ground-level ozone and discuss reducing emissions as important for worker and bystander exposure as well as air pollution.

5. California Department of Pesticide Regulation. Air Monitoring Network Results for 2023. Sacramento, CA: California Department of Pesticide Regulation, 2024.

https://www.cdpr.ca.gov/wp-content/uploads/2024/12/2023_amn_results-2024.pdf

Description: DPR monitored pesticides in Oxnard, Shafter, Santa Maria, and Watsonville. Four fumigants were detected at quantifiable concentrations: 1,3-D, chloropicrin, methyl bromide, and MITC, demonstrating ongoing ambient-air exposure pathways in California agricultural communities.

6. California Department of Pesticide Regulation. “DPR Statement on CDFA Laboratory Error.” February 13, 2025; updated February 25, 2025.

https://www.cdpr.ca.gov/2025/02/13/dpr-statement-on-cdfa-laboratory-error/

Description: CDFA informed DPR that a laboratory calculation error had caused methyl bromide and 1,3-D concentrations to be underreported in DPR air samples collected between February 2011 and November 2024. After correction, DPR identified additional historical 1,3-D readings that exceeded screening levels or regulatory targets.

7. California Office of Environmental Health Hazard Assessment. Updated Recommendation to Mitigate Cancer Risk for Occupational Bystanders from 1,3-Dichloropropene. June 11, 2024.

https://oehha.ca.gov/sites/default/files/media/downloads/proposition-65/document/memo13-d07124pdf.pdf

Description: OEHHA developed health-based recommendations intended to reduce occupational-bystander cancer risk from 1,3-D to one in 100,000. OEHHA calculated that an average working-lifetime exposure concentration of 0.21 ppb corresponds to that target risk. The memo reports that annual-average ambient concentrations measured during 2017–2022 in Parlier, Shafter, and Delhi were 1.112, 0.630, and 0.315 ppb, respectively, and states that these values significantly exceeded 0.21 ppb. OEHHA noted that these monitoring data predated DPR’s January 2024 non-occupational-bystander regulation and expected concentrations to be lower under the newer controls.

8. California Department of Pesticide Regulation. “Statement From the California Department of Pesticide Regulation on 1,3-D Monitoring Data and Regulatory Review.” July 8, 2026.

https://www.cdpr.ca.gov/2026/07/08/statement-from-the-california-department-of-pesticide-regulation-on-13-d-monitoring-data-and-regulatory-review/

Description: DPR reported that the annual-average 1,3-D concentration at its Parlier monitoring site reached 0.35 ppb in 2025, above DPR’s 0.27-ppb regulatory monitoring threshold. The exceedance triggered additional scientific review of monitoring trends, pesticide-use data, and whether additional regulatory action may be warranted. DPR emphasizes that 0.27 ppb is a regulatory evaluation trigger rather than its health-effects threshold.

9. Californians for Pesticide Reform. Cancer-Causing Pesticide 1,3-Dichloropropene (1,3-D) in California Air: DPR’s Proposed Regulation Fails to Protect Public Health. January 2023.

https://www.pesticidereform.org/wp-content/uploads/2023/01/13-D-Report-Jan_2023-FINAL.pdf

Description: This report compiles California 1,3-D monitoring and use information. It reports that a one-day concentration of 20.8 ppb measured at Sequoia Elementary School in Shafter in January 2020 originated from a 1,3-D application 7.5 miles away, according to DPR. The report cites an analysis by DPR scientist Minh Pham, “A summary of notable detections at Shafter AMN site in 2020,” which was not publicly available on DPR’s website. The distance attribution is therefore documented here through CPR’s citation to DPR’s underlying analysis.

10. California Department of Pesticide Regulation. Air Monitoring Network Results for 2024. Sacramento, CA: California Department of Pesticide Regulation, 2025.

https://www.cdpr.ca.gov/wp-content/uploads/2025/11/2024_amn_report_2025.pdf

Description: DPR’s 2024 Air Monitoring Network measured pesticides in Oxnard, Santa Maria, Shafter, and Watsonville. MITC was detected at quantifiable concentrations in Oxnard, Santa Maria, and Shafter and as a trace detection in Watsonville. No MITC concentration exceeded DPR’s

acute, subchronic, or chronic screening levels, although the highest concentrations measured in Shafter reached approximately 85.3% of the subchronic screening level and 83.3% of the chronic screening level.

11. U.S. Environmental Protection Agency. Reregistration Eligibility Decision for Methyldithiocarbamate Salts—Metam Sodium/Potassium and MITC. Office of Pesticide Programs. July 9, 2008.

https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P1000VXU.TXT

Description: EPA's reassessment evaluated inhalation risks associated with metam-sodium, metam-potassium, and their major volatile breakdown product MITC. EPA concluded that MITC inhalation exposure from soil fumigation could pose risks of concern to bystanders, workers, and handlers and required extensive additional mitigation, including buffer zones, posting, emergency preparedness, monitoring, respiratory protection, fumigant management plans, and other controls.

12. California Department of Pesticide Regulation. Correlating Agricultural Use with Ambient Air Concentrations of Methyl Isothiocyanate During the Period of 2011–2014.

https://www.cdpr.ca.gov/wp-content/uploads/2024/10/methyl_isothiocyanate.pdf

Description: DPR examined relationships between ambient MITC concentrations and reported applications of MITC-generating pesticides around monitoring stations in Salinas, Shafter, and Ripon. DPR found MITC detections during weeks in which no MITC-precursor use was reported within five miles, particularly in Salinas and Shafter, and concluded that some detections may have resulted from applications farther than five miles away. The analysis also documented a Salinas MITC detection four days after an application approximately 4.75 miles from the monitoring station.

13. Li, LinYing, Bruce B. Johnson, and Randy Segawa. "Empirical Relationship between Use, Area, and Ambient Air Concentration of Methyl Bromide." Journal of Environmental Quality 34, no. 2 (2005): 420–428. DOI: 10.2134/jeq2005.0420a.

https://pubmed.ncbi.nlm.nih.gov/15758093/

Description: This peer-reviewed California study examined the relationship between reported methyl-bromide use and measured ambient-air concentrations. The strongest relationship occurred when pesticide use was aggregated over a 7 × 7-mile area surrounding the monitoring location, providing evidence that community-air concentrations of a volatile fumigant can be influenced by applications over a broad surrounding agricultural area.

14. Zaunbrecher, Virginia, Dale Hattis, Ron Melnick, Susan Kegley, Timothy Malloy, and John Froines. Exposure and Interaction: The Potential Health Impacts of Using Multiple Pesticides. UCLA Sustainable Technology & Policy Program, February 17, 2016.

https://law.ucla.edu/sites/default/files/PDFs/Publications/Emmett%20Institute/_CEN_EMM_PUB_Exposure%20and%20Interaction.pdf

Description: This UCLA analysis uses 1,3-D, chloropicrin, and metam-sodium as a case study of pesticide-mixture exposure. It identifies biologically plausible mechanisms through which combined exposures could affect common detoxification and antioxidant pathways, oxidative stress, DNA damage, mutagenicity, and DNA repair. The report does not claim that specific synergistic health effects have been proven in humans; rather, it identifies mixture effects as an important unresolved regulatory concern.

15. Gunier, Robert B., Asa Bradman, Rosemary Castorina, Nina T. Holland, Dylan Avery, Kim G. Harley, and Brenda Eskenazi. "Residential Proximity to Agricultural Fumigant Use and IQ, Attention and Hyperactivity in 7-Year Old Children." Environmental Research 158 (2017): 358–365. DOI: 10.1016/j.envres.2017.06.036.

https://pmc.ncbi.nlm.nih.gov/articles/PMC5557382/

Description: This CHAMACOS study examined children living in California's Salinas Valley and estimated residential proximity to methyl bromide, chloropicrin, metam-sodium, and 1,3-D applications during pregnancy and childhood. Greater childhood proximity to methyl bromide and chloropicrin use was associated with lower Full-Scale IQ at age seven. The authors cautioned that the findings require confirmation in larger studies.

16. Gemmill, Alison, Robert B. Gunier, Asa Bradman, Brenda Eskenazi, and Kim G. Harley. "Residential Proximity to Methyl Bromide Use and Birth Outcomes in an Agricultural Population in California." Environmental Health Perspectives 121, no. 6 (2013): 737–743. DOI: 10.1289/ehp.1205682.

https://pmc.ncbi.nlm.nih.gov/articles/PMC3672911/

Description: This CHAMACOS study evaluated pregnancies in California's Salinas Valley. Greater residential proximity to methyl-bromide use during the second trimester was associated with indicators of restricted fetal growth, including lower birth weight, shorter birth length, and smaller head circumference. The observational study does not establish causation but identifies pregnancy and fetal development as potential areas of concern.

17. Gharibi, Hamed, Marcela R. Entwistle, Donald Schweizer, Pooya Tavallali, Chia Thao, and Ricardo Cisneros. "Methyl-Bromide and Asthma Emergency Department Visits in California, USA from 2005 to 2011." Journal of Asthma 57, no. 11 (2020): 1227–1236. DOI: 10.1080/02770903.2019.1645167.

https://pubmed.ncbi.nlm.nih.gov/31311358/

Description: This bidirectional case-crossover study evaluated asthma emergency-department visits in Central and Southern California in relation to ambient methyl-bromide concentrations. The authors reported positive associations among children ages 6–18, Hispanic patients, and non-Hispanic Black patients, although not among every population group. The findings are appropriately characterized as suggestive rather than definitive evidence of causation.

18. Gharibi, Hamed, Marcela R. Entwistle, Donald Schweizer, Pooya Tavallali, and Ricardo Cisneros. "The Association between 1,3-Dichloropropene and Asthma Emergency Department Visits in California, USA from 2005 to 2011: A Bidirectional-Symmetric Case Crossover Study." Journal of

Asthma 57, no. 6 (2020): 601–609. DOI: 10.1080/02770903.2019.1590596.

https://pubmed.ncbi.nlm.nih.gov/30938205/

Description: This study examined asthma emergency-department visits and short-term ambient 1,3-D concentrations in Central and Southern California. The authors reported increased odds of asthma emergency-department visits during particular seasons and among several demographic groups. Exposure-assessment limitations and the observational design mean the findings should be considered suggestive rather than definitive.

19. Lee, Soo-Jeong, Louise Mehler, John Beckman, Brienne Diebolt-Brown, Joanne Prado, Michelle Lackovic, Justin Waltz, Prakash Mulay, Abby Schwartz, Yvette Mitchell, Stephanie Moraga-McHaley, Rita Gergely, and Geoffrey M. Calvert. “Acute Pesticide Illnesses Associated with Off-Target Pesticide Drift from Agricultural Applications: 11 States, 1998–2006.” Environmental Health Perspectives 119, no. 8 (2011): 1162–1169. DOI: 10.1289/ehp.1002843.

https://pmc.ncbi.nlm.nih.gov/articles/PMC3237344/

Description: This multistate surveillance study identified 2,945 cases associated with 643 agricultural pesticide-drift events. Although soil fumigants were involved in only about 8% of events, they accounted for approximately 45% of all illness cases and 61% of nonoccupational cases; five of the ten largest incidents involved California metam-sodium or chloropicrin applications. The data largely predate stronger fumigant controls and should not be treated as estimates of current illness rates.

20. Barry, Terrell, Michel Oriel, MaryLou Verder-Carlos, Louise Mehler, Susan Edmiston, and Michael O’Malley. “Community Exposure Following a Drip-Application of Chloropicrin.” Journal of Agromedicine 15, no. 1 (2010): 24–37. DOI: 10.1080/10599240903389599.

https://pubmed.ncbi.nlm.nih.gov/20390729/

Description: This peer-reviewed investigation examined a 2005 chloropicrin exposure incident near residential neighborhoods in Salinas. Investigators identified 324 residents with symptoms possibly or probably related to exposure; cases occurred between 0.36 and 2.89 miles from the treated field. The study provides direct evidence that fumigant emissions can move well beyond a treated field and cause acute community health effects.

21. Barreau, Tracy, Sumi Hoshiko, Rick Kreutzer, Svetlana Smorodinsky, and John Talarico. “Sulfuryl Fluoride Poisonings in Structural Fumigation, a Highly Regulated Industry—Potential Causes and Solutions.” International Journal of Environmental Research and Public Health 16, no. 11 (2019): 2026. DOI: 10.3390/ijerph16112026.

https://pmc.ncbi.nlm.nih.gov/articles/PMC6603922/

Description: California public-health researchers reviewed sulfuryl-fluoride poisonings associated with structural fumigation. The paper documents mechanisms through which exposure can occur despite extensive regulation and describes serious effects including respiratory injury, seizures, neurological injury, and death at sufficiently high exposures.

22. Zeinali, Mazyar, Laura L. McConnell, Cathleen J. Hapeman, Anh Nguyen, Walter F. Schmidt, and Cody J. Howard. “Volatile Organic Compounds in Pesticide Formulations: Methods to Estimate Ozone Formation Potential.” Atmospheric Environment 45, no. 14 (2011): 2404–2412. DOI: 10.1016/j.atmosenv.2011.02.015.

https://doi.org/10.1016/j.atmosenv.2011.02.015

Description: This peer-reviewed study examined VOC constituents in pesticide formulations and methods for estimating their ozone-forming potential. The authors explain that pesticide VOCs can contribute to ground-level ozone and that VOC mass alone does not fully capture ozone-forming potential because compounds differ substantially in atmospheric reactivity.

23. Sun, Haitong Zhe, Pei Yu, Changxin Lan, Michelle W. L. Wan, Sebastian Hickman, Jayaprakash Murulitharan, Huizhong Shen, Le Yuan, Yuming Guo, and Alexander T. Archibald. “Cohort-Based Long-Term Ozone Exposure-Associated Mortality Risks with Adjusted Metrics: A Systematic Review and Meta-Analysis.” The Innovation 3, no. 3 (2022): 100246. DOI: 10.1016/j.xinn.2022.100246.

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24. Kasdagli, Maria-Iosifina, Pablo Orellano, Román Pérez Velasco, and Evangelia Samoli. “Long-Term Exposure to Nitrogen Dioxide and Ozone and Mortality: Update of the WHO Air Quality Guidelines Systematic Review and Meta-Analysis.” International Journal of Public Health 69 (2024): 1607676. DOI: 10.3389/ijph.2024.1607676.

https://pmc.ncbi.nlm.nih.gov/articles/PMC11527649/

Description: This updated systematic review and meta-analysis evaluated long-term ozone exposure and mortality. It found an association between annual ozone exposure and respiratory mortality and rated the certainty of that evidence as high, providing strong support for the human-health importance of chronic ozone exposure.

25. Papadimitriou, Vassilis C., et al. “Experimental and Theoretical Study of the Atmospheric Chemistry and Global Warming Potential of SO_2F_2.” The Journal of Physical Chemistry A 112, no. 49 (2008): 12657–12666. DOI: 10.1021/jp806368u.

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chemistry. Using an atmospheric lifetime of approximately 36 years, the authors calculated a 100-year global-warming potential of approximately 4,780, providing independent scientific support for characterizing sulfuryl fluoride as an unusually climate-potent greenhouse gas.

26. Mühle, Jens, et al. “Sulfuryl Fluoride in the Global Atmosphere.” Journal of Geophysical Research: Atmospheres 114 (2009): D05306. DOI: 10.1029/2008JD011162.

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27. Spokas, Kurt, Dong Wang, and Rodney T. Venterea. “Greenhouse Gas Production and Emission from a Forest Nursery Soil Following Fumigation with Chloropicrin and Methyl Isothiocyanate.” Soil Biology & Biochemistry 37, no. 3 (2005): 475–485. DOI: 10.1016/j.soilbio.2004.08.010.

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28. Spokas, Kurt, Dong Wang, Rodney T. Venterea, and Michael J. Sadowsky. “Mechanisms of N_2O Production Following Chloropicrin Fumigation.” Applied Soil Ecology 31, nos. 1–2 (2006): 101–109. DOI: 10.1016/j.apsoil.2005.03.006.

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Description: This peer-reviewed mechanistic study found that N_2O production increased approximately 12.6-fold following chloropicrin fumigation in the tested soil. The authors found that microbial activity accounted for most of the chloropicrin-induced N_2O production, helping explain the mechanism underlying the increased emissions.

29. Fang, Wensheng, Dongdong Yan, Xianli Wang, Bin Huang, Xiaoning Wang, Jie Liu, Xiaoman Liu, Yuan Li, Canbin Ouyang, Qiuxia Wang, and Aocheng Cao. “Responses of Nitrogen-Cycling Microorganisms to Dazomet Fumigation.” Frontiers in Microbiology 9 (2018): 2529. DOI: 10.3389/fmicb.2018.02529.

https://doi.org/10.3389/fmicb.2018.02529

Description: This peer-reviewed study investigated dazomet fumigation in two different agricultural soils. Maximum N_2O-production rates increased approximately 9.9-fold in one soil and 30-fold in the other during the first ten days after treatment, demonstrating that fumigation-related N_2O effects are not limited to chloropicrin.

30. Sharma, Asha, Margaret Reeves, and Calista Washburn. Pesticides and Climate Change: A Vicious Cycle. Pesticide Action Network North America, 2023.

https://www.panna.org/wp-content/uploads/2023/02/202301ClimateChangeEngFINAL.pdf

Description: This scientific review examines the two-way relationship between pesticides and climate change. It reviews greenhouse-gas emissions associated with pesticide production, transport, use, and environmental effects, including the fossil-fuel basis and energy intensity of synthetic pesticide manufacture. The report notes that manufacturing 1 kilogram of pesticide requires, on average, about 10 times more energy than manufacturing 1 kilogram of nitrogen fertilizer, while also discussing greenhouse-gas emissions associated with both pesticide and fertilizer use. It further reviews evidence that climate change can increase pest pressures and pesticide use, creating a reinforcing “vicious cycle,” and discusses pesticide reduction and agroecological approaches as climate and resilience strategies.

31. Romanello, Marina, et al. “The 2024 Report of the Lancet Countdown on Health and Climate Change: Facing Record-Breaking Threats from Delayed Action.” The Lancet 404, no. 10465 (2024): 1847–1896. DOI: 10.1016/S0140-6736(24)01822-1.

https://pubmed.ncbi.nlm.nih.gov/39488222/

Description: This major peer-reviewed synthesis tracks the human-health effects of climate change globally. It documents rising heat exposure, heat-related mortality, drought, extreme-weather exposure, food insecurity, and other health threats. It does not concern fumigants specifically; it supports why an independently demonstrated contribution to climate forcing is relevant to a human-health prioritization framework.

32. Holmes, Gerald J., Seyed Mojtaba Mansouripour, and Shashika S. Hewavitharana. “Strawberries at the Crossroads: Management of Soilborne Diseases in California Without Methyl Bromide.” Phytopathology 110, no. 5 (2020): 956–968. DOI: 10.1094/PHYTO-11-19-0406-IA.

https://pubmed.ncbi.nlm.nih.gov/32075499/

Description: This peer-reviewed review examines the history and management of soilborne disease in California strawberry production. The authors explain that fumigation allowed strawberries to be grown annually without rotation and that the California strawberry-production system subsequently evolved around fumigation as a cornerstone. The review discusses crop rotation, sanitation, resistant cultivars, and other systems-based approaches to disease management.

33. Subbarao, K. V., Z. Kabir, F. N. Martin, and S. T. Koike. “Management of Soilborne Diseases in Strawberry Using Vegetable Rotations.” Plant Disease 91, no. 8 (2007): 964–972. DOI: 10.1094/PDIS-91-8-0964.

https://pubmed.ncbi.nlm.nih.gov/30780429/

Description: This peer-reviewed California field study compared vegetable rotations with standard fumigation in strawberry production. Broccoli and Brussels-sprout rotations reduced populations of Verticillium dahliae and reduced Verticillium-wilt severity, demonstrating that changes to the cropping system itself can directly suppress important soilborne disease.

34. University of California Statewide Integrated Pest Management Program. “Non-Fumigant Alternatives for Soil Disinfestation: Strawberry Pest Management Guidelines.”

https://ipm.ucanr.edu/agriculture/strawberry/non-fumigant-alternatives-for-soil-disinfestation/

Description: UC IPM describes integrated nonfumigant strawberry strategies including resistant cultivars, sanitation, solarization, steam treatment, anaerobic soil disinfestation, soilless media, and other approaches. It reports commercial-scale use of rice-bran-based ASD in California, predominantly in organic production, and describes conditions under which strawberry yields can be similar to those from fumigated soil.

35. Muramoto, Joji, Carol Shennan, Graeme Baird, Margherita Zavatta, Steven T. Koike, Mark P. Bolda, Oleg Daugovish, Surendra K. Dara, Karen Klonsky, and Mark Mazzola. “Optimizing Anaerobic Soil Disinfestation for California Strawberries.” Acta Horticulturae 1044 (2014): 215–220. DOI: 10.17660/ActaHortic.2014.1044.25.

https://doi.org/10.17660/ActaHortic.2014.1044.25

Description: This peer-reviewed California study reports that anaerobic soil disinfestation using rice bran was consistently effective at suppressing Verticillium dahliae and produced strawberry yields comparable with fumigant controls under appropriate coastal California conditions. It provides independent support for ASD as a practical nonfumigant approach.

36. Fennimore, Steven A., Frank N. Martin, Thomas C. Miller, Janet C. Broome, Nathan Dorn, and Ian Greene. “Evaluation of a Mobile Steam Applicator for Soil Disinfestation in California Strawberry.” HortScience 49, no. 12 (2014): 1542–1549. DOI: 10.21273/HORTSCI.49.12.1542.

https://doi.org/10.21273/HORTSCI.49.12.1542

Description: This peer-reviewed California study tested steam soil disinfestation in research and commercial strawberry fields. Steam significantly suppressed weeds and soilborne pathogens at levels comparable to commercial chloropicrin/1,3-D treatment and supported favorable strawberry production, directly bolstering the argument that physical nonfumigant approaches can substitute for fumigation in some production systems.

37. Shennan, Carol, et al. “Anaerobic Soil Disinfestation Is an Alternative to Soil Fumigation for Control of Some Soilborne Pathogens in Strawberry Production.” Plant Pathology 67 (2018): 51–66. DOI: 10.1111/ppa.12721.

https://doi.org/10.1111/ppa.12721

Description: This peer-reviewed California research evaluated anaerobic soil disinfestation in strawberry production using controlled-environment experiments and field trials. ASD controlled several important soilborne pathogens, and in three of four field trials produced marketable fruit yields equivalent to fumigation. The authors concluded that ASD can be a viable alternative for control of some soilborne pathogens while emphasizing that efficacy depends on pathogen, temperature, and treatment conditions.

Question 5. What scientific information or additional information supports your submittal?

References. Please note that the reference numbers listed below match the corresponding citations used throughout our responses to Question 4.

1. **California Department of Pesticide Regulation. Pesticide Use Annual Report 2023 Data Summary. Sacramento, CA: California Department of Pesticide Regulation, 2025.**

   https://www.cdpr.ca.gov/wp-content/uploads/2025/08/2023_pur_annual_report.pdf

   Description: DPR's annual pesticide-use report documents statewide agricultural pesticide use in 2023. It defines fumigants as volatile gas pesticides capable of penetrating soil, stored products, structures, and other sites, and provides statewide use trends for fumigant active ingredients. The underlying 2023 use data show approximately 8.6 million pounds of metam-potassium, 8.5 million pounds of chloropicrin, 7.0 million pounds of 1,3-dichloropropene, and 2.8 million pounds of metam-sodium used in California.

2. **Simmons, Christopher, and Janet Broome. Fumigant Use in California and an Assessment of Available Alternatives: Phase I Report on 1,3-D and Chloropicrin. California Council on Science and Technology. Commissioned by the California Department of Pesticide Regulation. March 13, 2025.**

   https://ccst.us/reports/fumigant-use-in-california-and-an-assessment-of-available-alternatives-phase-i-report-on-13-d-and-chloropicrin/

   Description: This independent, peer-reviewed assessment commissioned by DPR examines 1,3-D and chloropicrin, their health and environmental concerns, California use, and alternatives. The report discusses the inherent volatility and atmospheric emissions of fumigants, exposure of nearby communities and workers, potentially vulnerable populations, deficiencies in understanding cumulative and synergistic effects, and available nonfumigant alternatives.

3. **Ashworth, Daniel J., and Scott R. Yates. "Surface Irrigation Reduces the Emission of Volatile 1,3-Dichloropropene from Agricultural Soils." Environmental Science & Technology 41, no. 7 (2007): 2231–2236. DOI: 10.1021/es062642d.**

   https://pubs.acs.org/doi/10.1021/es062642d

   Description: This peer-reviewed study investigated volatilization of the soil fumigant 1,3-D under realistic soil conditions. The authors characterize 1,3-D as a VOC-containing fumigant released from soil to the atmosphere and found that surface irrigation reduced emissions by roughly half in the tested soil columns. It provides independent evidence of the atmospheric-emission pathway associated with this highly volatile soil fumigant.

4. **Gao, Suduan, Thomas J. Trout, and Sally Schneider. "Evaluation of Fumigation and Surface Seal Methods on Fumigant Emissions in an Orchard Replant Field." Journal of Environmental Quality 37, no. 2 (2008): 369–377. DOI: 10.2134/jeq2007.0088.**

   https://doi.org/10.2134/jeq2007.0088

   Description: This peer-reviewed California field study measured emissions of both 1,3-D and chloropicrin following soil fumigation. The authors identify fumigant VOC emissions as contributing to formation of ground-level ozone and discuss reducing emissions as important for worker and bystander exposure as well as air pollution.

5. **California Department of Pesticide Regulation. Air Monitoring Network Results for 2023. Sacramento, CA: California Department of Pesticide Regulation, 2024.**

   https://www.cdpr.ca.gov/wp-content/uploads/2024/12/2023_amn_results-2024.pdf

   Description: DPR monitored pesticides in Oxnard, Shafter, Santa Maria, and Watsonville. Four fumigants were detected at quantifiable concentrations: 1,3-D, chloropicrin, methyl bromide, and MITC, demonstrating ongoing ambient-air exposure pathways in California agricultural communities.

6. **California Department of Pesticide Regulation. "DPR Statement on CDFA Laboratory Error." February 13, 2025; updated February 25, 2025.**

   https://www.cdpr.ca.gov/2025/02/13/dpr-statement-on-cdfa-laboratory-error/

   Description: CDFA informed DPR that a laboratory calculation error had caused methyl bromide and 1,3-D concentrations to be underreported in DPR air samples collected between February 2011 and November 2024. After correction, DPR identified additional historical 1,3-D readings that exceeded screening levels or regulatory targets.

7. **California Office of Environmental Health Hazard Assessment. Updated Recommendation to Mitigate Cancer Risk for Occupational Bystanders from 1,3-Dichloropropene. June 11, 2024.**

   https://oehha.ca.gov/sites/default/files/media/downloads/proposition-65/document/memo13-d07124pdf.pdf

   Description: OEHHA developed health-based recommendations intended to reduce occupational-bystander cancer risk from 1,3-D to one in 100,000. OEHHA calculated that an average working-lifetime exposure concentration of 0.21 ppb corresponds to that target risk. The memo reports that annual-average ambient concentrations measured during 2017–2022 in Parlier, Shafter, and Delhi were 1.112, 0.630, and 0.315 ppb, respectively, and states that these values significantly exceeded 0.21 ppb. OEHHA noted that these monitoring data predated DPR's January 2024 non-occupational-bystander regulation and expected concentrations to be lower under the newer controls.

8. **California Department of Pesticide Regulation. "Statement From the California Department of Pesticide Regulation on 1,3-D Monitoring Data and Regulatory Review." July 8, 2026.**

   https://www.cdpr.ca.gov/2026/07/08/statement-from-the-california-department-of-pesticide-regulation-on-13-d-monitoring-data-and-regulatory-review/

   Description: DPR reported that the annual-average 1,3-D concentration at its Parlier monitoring site reached 0.35 ppb in 2025, above DPR's 0.27-ppb regulatory monitoring threshold. The exceedance triggered additional scientific review of monitoring trends, pesticide-use data, and whether additional regulatory action may be warranted. DPR emphasizes that 0.27 ppb is a regulatory evaluation trigger rather than its health-effects threshold.

9. **Californians for Pesticide Reform. Cancer-Causing Pesticide 1,3-Dichloropropene (1,3-D) in California Air: DPR's Proposed Regulation Fails to Protect Public Health. January 2023.**

   https://www.pesticidereform.org/wp-content/uploads/2023/01/13-D-Report-Jan_2023-FINAL.pdf

   Description: This report compiles California 1,3-D monitoring and use information. It reports that a one-day concentration of 20.8 ppb measured at Sequoia Elementary School in Shafter in January 2020 originated from a 1,3-D application 7.5 miles away, according to DPR. The report cites an analysis by DPR scientist Minh Pham, "A summary of notable detections at Shafter AMN site in 2020," which was not publicly available on DPR's website. The distance attribution is therefore documented here through CPR's citation to DPR's underlying analysis.

10. **California Department of Pesticide Regulation. Air Monitoring Network Results for 2024. Sacramento, CA: California Department of Pesticide Regulation, 2025.**

    https://www.cdpr.ca.gov/wp-content/uploads/2025/11/2024_amn_report_2025.pdf

    Description: DPR's 2024 Air Monitoring Network measured pesticides in Oxnard, Santa Maria, Shafter, and Watsonville. MITC was detected at quantifiable concentrations in Oxnard, Santa Maria, and Shafter and as a trace detection in Watsonville. No MITC concentration exceeded DPR's acute, subchronic, or chronic screening levels, although the highest concentrations measured in Shafter reached approximately 85.3% of the subchronic screening level and 83.3% of the chronic screening level.

11. **U.S. Environmental Protection Agency. Reregistration Eligibility Decision for Methyldithiocarbamate Salts—Metam Sodium/Potassium and MITC. Office of Pesticide Programs. July 9, 2008.**

    https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P1000VXU.TXT

Description: EPA's reassessment evaluated inhalation risks associated with metam-sodium, metam-potassium, and their major volatile breakdown product MITC. EPA concluded that MITC inhalation exposure from soil fumigation could pose risks of concern to bystanders, workers, and handlers and required extensive additional mitigation, including buffer zones, posting, emergency preparedness, monitoring, respiratory protection, fumigant management plans, and other controls.

12. **California Department of Pesticide Regulation. Correlating Agricultural Use with Ambient Air Concentrations of Methyl Isothiocyanate During the Period of 2011–2014.**

    https://www.cdpr.ca.gov/wp-content/uploads/2024/10/methyl_isothiocyanate.pdf

    Description: DPR examined relationships between ambient MITC concentrations and reported applications of MITC-generating pesticides around monitoring stations in Salinas, Shafter, and Ripon. DPR found MITC detections during weeks in which no MITC-precursor use was reported within five miles, particularly in Salinas and Shafter, and concluded that some detections may have resulted from applications farther than five miles away. The analysis also documented a Salinas MITC detection four days after an application approximately 4.75 miles from the monitoring station.

13. **Li, LinYing, Bruce B. Johnson, and Randy Segawa. "Empirical Relationship between Use, Area, and Ambient Air Concentration of Methyl Bromide." Journal of Environmental Quality 34, no. 2 (2005): 420–428. DOI: 10.2134/jeq2005.0420a.**

    https://pubmed.ncbi.nlm.nih.gov/15758093/

    Description: This peer-reviewed California study examined the relationship between reported methyl-bromide use and measured ambient-air concentrations. The strongest relationship occurred when pesticide use was aggregated over a 7 × 7-mile area surrounding the monitoring location, providing evidence that community-air concentrations of a volatile fumigant can be influenced by applications over a broad surrounding agricultural area.

14. **Zaunbrecher, Virginia, Dale Hattis, Ron Melnick, Susan Kegley, Timothy Malloy, and John Froines. Exposure and Interaction: The Potential Health Impacts of Using Multiple Pesticides. UCLA Sustainable Technology & Policy Program, February 17, 2016.**

    https://law.ucla.edu/sites/default/files/PDFs/Publications/Emmett%20Institute/_CEN_EMM_PUB_Exposure%20and%20Interaction.pdf

    Description: This UCLA analysis uses 1,3-D, chloropicrin, and metam-sodium as a case study of pesticide-mixture exposure. It identifies biologically plausible mechanisms through which combined exposures could affect common detoxification and antioxidant pathways, oxidative stress, DNA damage, mutagenicity, and DNA repair. The report does not claim that specific synergistic health effects have been proven in humans; rather, it identifies mixture effects as an important unresolved regulatory concern.

15. **Gunier, Robert B., Asa Bradman, Rosemary Castorina, Nina T. Holland, Dylan Avery, Kim G. Harley, and Brenda Eskenazi. "Residential Proximity to Agricultural Fumigant Use and IQ, Attention and Hyperactivity in 7-Year Old Children." Environmental Research 158 (2017): 358–365. DOI: 10.1016/j.envres.2017.06.036.**

https://pmc.ncbi.nlm.nih.gov/articles/PMC5557382/

Description: This CHAMACOS study examined children living in California's Salinas Valley and estimated residential proximity to methyl bromide, chloropicrin, metam-sodium, and 1,3-D applications during pregnancy and childhood. Greater childhood proximity to methyl bromide and chloropicrin use was associated with lower Full-Scale IQ at age seven. The authors cautioned that the findings require confirmation in larger studies.

16. **Gemmill, Alison, Robert B. Gunier, Asa Bradman, Brenda Eskenazi, and Kim G. Harley. "Residential Proximity to Methyl Bromide Use and Birth Outcomes in an Agricultural Population in California." Environmental Health Perspectives 121, no. 6 (2013): 737–743. DOI: 10.1289/ehp.1205682.**

https://pmc.ncbi.nlm.nih.gov/articles/PMC3672911/

Description: This CHAMACOS study evaluated pregnancies in California's Salinas Valley. Greater residential proximity to methyl-bromide use during the second trimester was associated with indicators of restricted fetal growth, including lower birth weight, shorter birth length, and smaller head circumference. The observational study does not establish causation but identifies pregnancy and fetal development as potential areas of concern.

17. **Gharibi, Hamed, Marcela R. Entwistle, Donald Schweizer, Pooya Tavallali, Chia Thao, and Ricardo Cisneros. "Methyl-Bromide and Asthma Emergency Department Visits in California, USA from 2005 to 2011." Journal of Asthma 57, no. 11 (2020): 1227–1236. DOI: 10.1080/02770903.2019.1645167.**

https://pubmed.ncbi.nlm.nih.gov/31311358/

Description: This bidirectional case-crossover study evaluated asthma emergency-department visits in Central and Southern California in relation to ambient methyl-bromide concentrations. The authors reported positive associations among children ages 6–18, Hispanic patients, and non-Hispanic Black patients, although not among every population group. The findings are appropriately characterized as suggestive rather than definitive evidence of causation.

18. **Gharibi, Hamed, Marcela R. Entwistle, Donald Schweizer, Pooya Tavallali, and Ricardo Cisneros. "The Association between 1,3-Dichloropropene and Asthma Emergency Department Visits in California, USA from 2005 to 2011: A Bidirectional-Symmetric Case Crossover Study." Journal of Asthma 57, no. 6 (2020): 601–609. DOI: 10.1080/02770903.2019.1590596.**

https://pubmed.ncbi.nlm.nih.gov/30938205/

Description: This study examined asthma emergency-department visits and short-term ambient 1,3-D concentrations in Central and Southern California. The authors reported increased odds of asthma emergency-department visits during particular seasons and among several demographic groups. Exposure-assessment limitations and the observational design mean the findings should be considered suggestive rather than definitive.

19. **Lee, Soo-Jeong, Louise Mehler, John Beckman, Brienne Diebolt-Brown, Joanne Prado, Michelle Lackovic, Justin Waltz, Prakash Mulay, Abby Schwartz, Yvette Mitchell, Stephanie Moraga-McHaley, Rita Gergely, and Geoffrey M. Calvert. "Acute Pesticide Illnesses Associated with Off-Target Pesticide Drift from Agricultural Applications: 11 States, 1998–2006." Environmental Health Perspectives 119, no. 8 (2011): 1162–1169. DOI: 10.1289/ehp.1002843.**

    https://pmc.ncbi.nlm.nih.gov/articles/PMC3237344/

    Description: This multistate surveillance study identified 2,945 cases associated with 643 agricultural pesticide-drift events. Although soil fumigants were involved in only about 8% of events, they accounted for approximately 45% of all illness cases and 61% of nonoccupational cases; five of the ten largest incidents involved California metam-sodium or chloropicrin applications. The data largely predate stronger fumigant controls and should not be treated as estimates of current illness rates.

20. **Barry, Terrell, Michel Oriel, MaryLou Verder-Carlos, Louise Mehler, Susan Edmiston, and Michael O'Malley. "Community Exposure Following a Drip-Application of Chloropicrin." Journal of Agromedicine 15, no. 1 (2010): 24–37. DOI: 10.1080/10599240903389599.**

    https://pubmed.ncbi.nlm.nih.gov/20390729/

    Description: This peer-reviewed investigation examined a 2005 chloropicrin exposure incident near residential neighborhoods in Salinas. Investigators identified 324 residents with symptoms possibly or probably related to exposure; cases occurred between 0.36 and 2.89 miles from the treated field. The study provides direct evidence that fumigant emissions can move well beyond a treated field and cause acute community health effects.

21. **Barreau, Tracy, Sumi Hoshiko, Rick Kreutzer, Svetlana Smorodinsky, and John Talarico. "Sulfuryl Fluoride Poisonings in Structural Fumigation, a Highly Regulated Industry—Potential Causes and Solutions." International Journal of Environmental Research and Public Health 16, no. 11 (2019): 2026. DOI: 10.3390/ijerph16112026.**

    https://pmc.ncbi.nlm.nih.gov/articles/PMC6603922/

    Description: California public-health researchers reviewed sulfuryl-fluoride poisonings associated with structural fumigation. The paper documents mechanisms through which exposure can occur despite extensive regulation and describes serious effects including respiratory injury, seizures, neurological injury, and death at sufficiently high exposures.

22. **Zeinali, Mazyar, Laura L. McConnell, Cathleen J. Hapeman, Anh Nguyen, Walter F. Schmidt, and Cody J. Howard. "Volatile Organic Compounds in Pesticide Formulations: Methods to Estimate Ozone Formation Potential." Atmospheric Environment 45, no. 14 (2011): 2404–2412. DOI: 10.1016/j.atmosenv.2011.02.015.**

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potential of approximately 4,780, providing independent scientific support for characterizing sulfuryl fluoride as an unusually climate-potent greenhouse gas.

26. **Mühle, Jens, et al. "Sulfuryl Fluoride in the Global Atmosphere." Journal of Geophysical Research: Atmospheres 114 (2009): D05306. DOI: 10.1029/2008JD011162.**

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    https://doi.org/10.1016/j.apsoil.2005.03.006

    Description: This peer-reviewed mechanistic study found that N_2O production increased approximately 12.6-fold following chloropicrin fumigation in the tested soil. The authors found that microbial activity accounted for most of the chloropicrin-induced N_2O production, helping explain the mechanism underlying the increased emissions.

29. **Fang, Wensheng, Dongdong Yan, Xianli Wang, Bin Huang, Xiaoning Wang, Jie Liu, Xiaoman Liu, Yuan Li, Canbin Ouyang, Qiuxia Wang, and Aocheng Cao. "Responses of Nitrogen-Cycling Microorganisms to Dazomet Fumigation." Frontiers in Microbiology 9 (2018): 2529. DOI: 10.3389/fmicb.2018.02529.**

    https://doi.org/10.3389/fmicb.2018.02529

    Description: This peer-reviewed study investigated dazomet fumigation in two different agricultural soils. Maximum N_2O-production rates increased approximately 9.9-fold in one soil and 30-fold in the other during the first ten days after treatment, demonstrating that fumigation-related N_2O effects are not limited to chloropicrin.

30. **Sharma, Asha, Margaret Reeves, and Calista Washburn. *Pesticides and Climate Change: A Vicious Cycle.* Pesticide Action Network North America, 2023.**

https://www.panna.org/wp-content/uploads/2023/02/202301ClimateChangeEngFINAL.pdf

Description: This scientific review examines the two-way relationship between pesticides and climate change. It reviews greenhouse-gas emissions associated with pesticide production, transport, use, and environmental effects, including the fossil-fuel basis and energy intensity of synthetic pesticide manufacture. The report notes that manufacturing 1 kilogram of pesticide requires, on average, about 10 times more energy than manufacturing 1 kilogram of nitrogen fertilizer, while also discussing greenhouse-gas emissions associated with both pesticide and fertilizer use. It further reviews evidence that climate change can increase pest pressures and pesticide use, creating a reinforcing "vicious cycle," and discusses pesticide reduction and agroecological approaches as climate and resilience strategies.

31. **Romanello, Marina, et al. "The 2024 Report of the Lancet Countdown on Health and Climate Change: Facing Record-Breaking Threats from Delayed Action." The Lancet 404, no. 10465 (2024): 1847–1896. DOI: 10.1016/S0140-6736(24)01822-1.**

https://pubmed.ncbi.nlm.nih.gov/39488222/

Description: This major peer-reviewed synthesis tracks the human-health effects of climate change globally. It documents rising heat exposure, heat-related mortality, drought, extreme-weather exposure, food insecurity, and other health threats. It does not concern fumigants specifically; it supports why an independently demonstrated contribution to climate forcing is relevant to a human-health prioritization framework.

32. **Holmes, Gerald J., Seyed Mojtaba Mansouripour, and Shashika S. Hewavitharana. "Strawberries at the Crossroads: Management of Soilborne Diseases in California Without Methyl Bromide." Phytopathology 110, no. 5 (2020): 956–968. DOI: 10.1094/PHYTO-11-19-0406-IA.**

https://pubmed.ncbi.nlm.nih.gov/32075499/

Description: This peer-reviewed review examines the history and management of soilborne disease in California strawberry production. The authors explain that fumigation allowed strawberries to be grown annually without rotation and that the California strawberry-production system subsequently evolved around fumigation as a cornerstone. The review discusses crop rotation, sanitation, resistant cultivars, and other systems-based approaches to disease management.

33. **Subbarao, K. V., Z. Kabir, F. N. Martin, and S. T. Koike. "Management of Soilborne Diseases in Strawberry Using Vegetable Rotations." Plant Disease 91, no. 8 (2007): 964–972. DOI: 10.1094/PDIS-91-8-0964.**

https://pubmed.ncbi.nlm.nih.gov/30780429/

Description: This peer-reviewed California field study compared vegetable rotations with standard fumigation in strawberry production. Broccoli and Brussels-sprout rotations reduced populations of Verticillium dahliae and reduced Verticillium-wilt severity, demonstrating that changes to the cropping system itself can directly suppress important soilborne disease.

34. **University of California Statewide Integrated Pest Management Program. "Non-Fumigant Alternatives for Soil Disinfestation: Strawberry Pest Management Guidelines."**

    https://ipm.ucanr.edu/agriculture/strawberry/non-fumigant-alternatives-for-soil-disinfestation/

    Description: UC IPM describes integrated nonfumigant strawberry strategies including resistant cultivars, sanitation, solarization, steam treatment, anaerobic soil disinfestation, soilless media, and other approaches. It reports commercial-scale use of rice-bran-based ASD in California, predominantly in organic production, and describes conditions under which strawberry yields can be similar to those from fumigated soil.

35. **Muramoto, Joji, Carol Shennan, Graeme Baird, Margherita Zavatta, Steven T. Koike, Mark P. Bolda, Oleg Daugovish, Surendra K. Dara, Karen Klonsky, and Mark Mazzola. "Optimizing Anaerobic Soil Disinfestation for California Strawberries." Acta Horticulturae 1044 (2014): 215–220. DOI: 10.17660/ActaHortic.2014.1044.25.**

    https://doi.org/10.17660/ActaHortic.2014.1044.25

    Description: This peer-reviewed California study reports that anaerobic soil disinfestation using rice bran was consistently effective at suppressing Verticillium dahliae and produced strawberry yields comparable with fumigant controls under appropriate coastal California conditions. It provides independent support for ASD as a practical nonfumigant approach.

36. **Fennimore, Steven A., Frank N. Martin, Thomas C. Miller, Janet C. Broome, Nathan Dorn, and Ian Greene. "Evaluation of a Mobile Steam Applicator for Soil Disinfestation in California Strawberry." HortScience 49, no. 12 (2014): 1542–1549. DOI: 10.21273/HORTSCI.49.12.1542.**

    https://doi.org/10.21273/HORTSCI.49.12.1542

    Description: This peer-reviewed California study tested steam soil disinfestation in research and commercial strawberry fields. Steam significantly suppressed weeds and soilborne pathogens at levels comparable to commercial chloropicrin/1,3-D treatment and supported favorable strawberry production, directly bolstering the argument that physical nonfumigant approaches can substitute for fumigation in some production systems.

37. **Shennan, Carol, et al. "Anaerobic Soil Disinfestation Is an Alternative to Soil Fumigation for Control of Some Soilborne Pathogens in Strawberry Production." Plant Pathology 67 (2018): 51–66. DOI: 10.1111/ppa.12721.**

    https://doi.org/10.1111/ppa.12721

Description: This peer-reviewed California research evaluated anaerobic soil disinfestation in strawberry production using controlled-environment experiments and field trials. ASD controlled several important soilborne pathogens, and in three of four field trials produced marketable fruit yields equivalent to fumigation. The authors concluded that ASD can be a viable alternative for control of some soilborne pathogens while emphasizing that efficacy depends on pathogen, temperature, and treatment conditions.

California Fumigant Active Ingredients: 2023 Use and Current Registration

Scope: active ingredients with reported California fumigant use greater than zero in DPR's 2023 fumigant-use series and that remain listed in DPR's current active-ingredient database as of September 10, 2026. Carbon disulfide and diallyl disulfide had small 2023 reported use but are not currently listed as active ingredients, so they are excluded.

Active ingredient	CAS registry no.	2023 lb used	Current active CA products	Primary 2023 counties / concentration	Major 2023 CA uses / pattern
Potassium N-methyldithiocarbamate (metam-potassium)	137-41-7	8,633,739	3	Heavily concentrated in the San Joaquin Valley and Central Coast intensive-crop regions.	Pre-plant soil fumigant that generates MITC; major patterns include processing tomatoes, carrots, strawberries, onions, sweet potatoes, peppers and general pre-plant soil fumigation.
Chloropicrin	76-06-2	8,515,832	30	Strongly concentrated in the Central Coast and other intensive fumigant-use areas; Monterey, Santa Barbara and Ventura are major-use counties, with additional San Joaquin Valley use.	Pre-plant soil fumigant/fungicide, often alone or in mixtures with 1,3-D; especially strawberries, nurseries, vegetables and other high-value crops.
1,3-Dichloropropene (1,3-D / Telone)	542-75-6	7,023,406	19	San Joaquin Valley and Central Coast; especially Fresno/Merced/Kern and coastal fumigant-use counties such as Monterey, Santa Barbara and Ventura.	Pre-plant soil fumigant for nematodes and soil-borne disease; major uses include almonds/orchard replanting, strawberries, carrots, sweet potatoes, grapes and other high-value crops.
Sulfuryl fluoride	2699-79-8	3,071,223	4	Predominantly urban/structural use, especially Southern California population centers (Los Angeles, Orange, San Diego and surrounding counties), with use statewide.	Whole-structure fumigation for drywood termites and other wood-destroying pests; also certain commodity fumigation uses. DPR/CCST estimated 78,834 California structures were fumigated in 2023.
Metam-sodium	137-42-8	2,800,317	9	Concentrated in intensive vegetable/root-crop production areas, especially the San Joaquin Valley and some coastal production counties.	Pre-plant soil fumigant that generates methyl isothiocyanate (MITC); major patterns include carrots, potatoes, processing tomatoes, onions, peppers and strawberries.

Active ingredient	CAS registry no.	2023 lb used	Current active CA products	Primary 2023 counties / concentration	Major 2023 CA uses / pattern
Methyl bromide	74-83-9	1,676,651	25	Use persists in multiple counties; important concentrations include quarantine/commodity fumigation in Los Angeles/port areas and nursery or exempted agricultural uses in counties such as Merced, Stanislaus, San Joaquin and Siskiyou.	Largely phased out for ordinary agricultural use, but still used under quarantine/pre-shipment and other exemptions; commodity/shipping fumigation, nursery/propagative material and some remaining soil fumigation.
Sulfur dioxide	7446-09-5	226,956	1	Strongly associated with California table-grape production and storage, particularly San Joaquin Valley grape counties such as Fresno, Kern and Tulare.	Post-harvest fumigation of table grapes to control fungal decay (especially Botrytis) during storage/handling.
Propylene oxide	75-56-9	168,176	1	Concentrated at food/commodity treatment and processing facilities rather than field applications.	Post-harvest/commodity fumigant and microbial-control treatment for certain processed foods, nuts, spices and related commodities.
Carbon dioxide	124-38-9	115,473	5	Scattered; use is tied more to storage/processing facilities than to field-crop acreage.	Controlled-atmosphere/commodity fumigation and pest suppression in stored products and enclosed spaces.
Aluminum phosphide	20859-73-8	83,696	15	Primarily agricultural/storage areas of the Central Valley, with additional use statewide.	Stored-commodity and space fumigation (grain, nuts, processed foods/feed); also burrowing-rodent control. Releases phosphine gas on contact with moisture.
Magnesium phosphide	12057-74-8	18,521	4	Primarily Central Valley agricultural/storage areas and commodity-handling facilities; some statewide use.	Stored-commodity and space fumigation; generates phosphine gas. Also labeled on some products for burrowing-rodent control.
Phosphine	7803-51-2	15,380	4	Commodity-storage/processing areas, including Central Valley and port/warehouse locations.	Direct phosphine-gas fumigation of stored agricultural commodities, food/feed and enclosed storage/processing spaces.

Active ingredient	CAS registry no.	2023 lb used	Current active CA products	Primary 2023 counties / concentration	Major 2023 CA uses / pattern
Dazomet	533-74-4	11,078	19	Low-volume and geographically scattered compared with the major soil fumigants.	Soil/plant-bed fumigation and sterilant uses in nurseries, turf/landscape and pre-plant settings; some registered products also have industrial antimicrobial/preservative uses.

Notes and sources

- 2023 pounds: California DPR, Pesticide Use Annual Report 2023, 'Use Trends of Fumigants: Pounds Applied.'
- Current product counts: California DPR Product/Label Database, 'Actively Registered Active Ingredients by Common Name,' checked September 10, 2026. Counts are products containing the AI, not necessarily only products whose fumigant use drove the 2023 PUR total.
- County/concentration and use-pattern descriptions are concise syntheses of 2023 PUR patterns, DPR fumigant materials, labels, and California use literature; they are not exhaustive county rankings.
- DPR 2023 fumigant pounds source: https://www.cdpr.ca.gov/wp-content/uploads/2025/08/2023_fumigants_pounds_applied.pdf
- DPR current active ingredient/product counts: https://apps.cdpr.ca.gov/docs/label/actai.cfm
- DPR 2023 annual report: https://www.cdpr.ca.gov/wp-content/uploads/2025/08/2023_pur_annual_report.pdf