July 19, 2024

Clerk's Office, California Air Resources Board
1001 I Street
Sacramento, CA 95814

RE: San Joaquin Valley State Implementation Plans

On behalf of the undersigned organizations please accept these comments regarding Discussion Item 24-4-2: Public Meeting to Consider the San Joaquin Valley 2024 State Implementation Plan for the 2012 12 µg/m3 Annual PM2.5 Standard, to Consider Amendments to the Agricultural Equipment Incentive Measure and the 1997 15 µg/m3 State Implementation Plan Revision, and to Hear an Implementation Update on the 2018 PM2.5 Plan.

The San Joaquin Valley has a long history of failing to attain federal Clean Air Act (CAA) standards on time. Similarly, both the San Joaquin Valley Air Pollution Control District (Valley Air) and the California Air Resources Board (CARB) have a long record of submitting plans late, seeking to delay attainment deadlines for as long as possible, and drafting insufficient plans that ultimately do not achieve the emission reductions claimed. This history of failure is exemplified by the recent announcement that CARB and Valley Air need yet another year to meet the more than a quarter-century-old 1997 annual National Ambient Air Quality Standard (NAAQS) for fine particle (PM2.5) pollution. This is the third straight delay in attainment for this standard, following the original 2015 attainment deadline. This request also comes six months after the U.S. EPA's December 14th, 2023 final approval of a state plan that ultimately failed to meet the 1997 standard two weeks later on December 31, 2023. EPA, CARB and Valley Air likely knew the state could once again fail to meet the 1997 PM2.5 standard by the extended deadline, but inexplicably continued to push inadequate plans forward to help the Valley avoid federal highway funding and other sanctions required under the Clean Air Act.

Moreover, following the submission of California's 2018 plan to meet the 2012 annual PM2.5 standard, EPA ultimately proposed to disprove that plan due to multiple inadequacies. CARB and Valley Air are now seeking to finalize a revised plan for the 2012 standard that contains many of the same flaws with only a few minor additional control measures. The state is also seeking to move the attainment deadline for the 2012 standard back an additional five years, from 2025 to 2030.

These repeated planning failures have resulted in an air pollution crisis and public health emergency for millions of Valley residents. The Valley is the most polluted air basin in the nation for PM2.5 pollution, negatively affecting the health and wellbeing of Valley residents and surrounding national parks and ecosystems. PM2.5 pollution is clearly linked to a variety of illnesses including immediate breathing problems, such as wheezing, coughing, asthma attacks, and increased susceptibility to respiratory infection, and heart and lung diseases significantly impacting the quality of life for Valley residents.[1] PM2.5 is also linked to the premature deaths of roughly 1,200 valley residents each year.[2] These illnesses impact not only the quality of life but also impact our economy with $498,014,124 in Emergency Department Visits, and $223,552,720 for each day that a Valley resident is hospitalized due to air pollution[3] These costs reflect additional burdens faced by those in the Valley, including lost work days, lost school days, and potentially significant reductions in crop yields and other environmental impacts due to the Valley's worst-in-the-nation PM2.5 pollution.

First and foremost, we respectfully request that the CARB not move forward with the proposed action to delay attainment with the 2012 Annual PM2.5 Standard for an additional five years until 2030, and instead prioritize immediate pollution reductions by remaining committed to the 2025 attainment deadline. The Valley's long history of failing to meet PM2.5 standards has shown that delay is not the answer to the Valley air quality issues, and we cannot trust that an additional five years under the Plan as currently proposed will get us any closer to delivering clean, breathable air for Valley residents. Given the numerous previous attainment failures, we are especially concerned by modeling showing the Valley will barely reach attainment in 2030 by only .02 μg/m3 at one monitoring site, leaving little to no margin for error.[4] Instead of delay, Valley Air and CARB should look to immediately implement additional, more stringent stationary, area, and mobile source control measures to get the Valley into attainment as expeditiously as possible and sooner than 2030.

In reviewing the control measures outlined in the SIP revision, we do not believe the state has met the Clean Air Act requirements necessary to be granted any delay under CAA §188(e), which requires a demonstration that "the Plan for the area includes the *most stringent measures* that are included in the implementation plan of any state, or are achieved in practice in any state, and can feasibly be implemented in the area."[5] The Control Measure Analysis in Appendix C of the Plan contains numerous flaws that arbitrarily and capriciously dismiss other feasible

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[1] Environmental Protection Agency, Health and Environmental Effects of Particulate Matter (PM), www.epa.gov/pm-pollution/health-and-Environmental-effects-particulate-matter-pm.

[2] California Air Resources Board, Clean-air plan for San Joaquin Valley first to meet all federal standards for fine particle pollution (January 24, 2019), https://ww2.arb.ca.gov/news/clean-air-plan-san-joaquin-valley-first-meet-all-federal-standards-fine-particle-pollution.

[3] Zarate-Gonzalez G, Brown P, Cisneros R. Costs of Air Pollution in California's San Joaquin Valley: A Societal Perspective of the Burden of Asthma on Emergency Departments and Inpatient Care. J Asthma Allergy. 2024;17:369-382
https://doi.org/10.2147/JAA.S455745

[4] *Valley Air District, 2024 Plan for the 2012 Annual PM2.5 Standard* (May 21, 2024) at 5-8.

[5] CAA §188(e)

measures, including measures that have been adopted into State Implementation Plans (SIPs) from other states or that have been achieved in practice elsewhere in the U.S that are more stringent than the District's. Furthermore, we believe CARB has room to require additional feasible controls for off-road mobile sources under its jurisdiction.

Valley Air and CARB claimed that the prior 2012 PM2.5 SIP proposal submitted in 2018 would meet attainment by 2025, only to now say that the Valley is modeled to fail attainment in 2025. Despite this, the state now seeks to submit a substantially similar plan without including any significant additional controls measures. Adopting and implementing additional, more stringent measures provides the best path forward to actually meeting the standard and protecting public health. The more stringent control measures that we believe the District is required to adopt include the following:

- **Ban Unnecessary Residential Wood Burning**: Residential burning of wood in fireplaces, wood stoves, and other devices is one of the largest remaining sources of PM2.5 pollution in the Valley, contributing 5.5 tons per day of direct PM2.5 emissions in winter months. The Valley Air District's current rules for residential wood burning only prohibit residential wood burning on days when air pollution levels exceed certain levels and have different requirements depending on the type of device and where in the Valley you live. These current rules are overly convoluted, difficult for Valley residents to follow and for the District to enforce, and have failed to achieve the emission reductions necessary to meet more stringent NAAQS requirements.

  For years now Tacoma-Pierce County, Washington and Santa Rosa, California have had more stringent rules in place that have prohibited all residential wood burning in non-EPA certified devices. These rules have been achieved in practice, are more stringent than the District's current rules for residential wood burning, and are entirely feasible given the District's current frequent prohibitions on wood burning on bad air quality days. Despite this reality, the District's MSM analysis improperly dismisses such rules as less stringent based on unreasonable interpretations that such requirements "are generally limited to fairly small jurisdictions with little to no enforceability."[6] . The District's interpretation is also contrary to recent statements from EPA staff, who noted that,

  > At least two other jurisdictions (Santa Rosa, California and the Tacoma-Pierce County Smoke Reduction Zone in Washington) have banned the use of uncertified heaters (except in sole source households), suggesting that such a measure may be technologically and economically feasible. We estimate that this measure would achieve an additional 0.34 tpd (annual average) emissions reductions.[7]

[6] *Valley Air District, 2024 Plan for the 2012 Annual PM2.5 Standard* (May 21, 2024) at C-223.
[7] EPA, *EPA Source Category and Control Measure Assessment and Reasoned Justification Technical Support Document*, at 82 (July 2023), *available at* https://downloads.regulations.gov/EPA-R09-OAR-2023-0477-0008/attachment_9.pdf.

Implementing a ban on all unnecessary residential wood burning in the Valley would be one of the fastest ways to reduce a sizable amount of Direct PM2.5 and could very well bring the Valley into attainment much sooner than 2030. Such a rule could of course contain a similar exemption to current District rules where wood burning is the sole source of heat, and if necessary could be expanded to cover low income households or who do not have an alternative affordable heat source. We also strongly recommend that all future incentive funds dedicated to residential wood burning replacement focus on providing alternative low emission heat sources like heat pumps for low-income or sole source of heat households.

- **Phase Out Dirty Off-road Agricultural Equipment:** Nitrogen Oxides (NOx) are one of the main ingredients in the formation of PM2.5 in the Valley. Diesel-fueled tractors, combines, and other off-road agricultural equipment produce approximately 22% of the NOx emissions and 17% of the PM emissions[8]. Despite their significant levels of pollution, they remain one of the only mobile sources in the state with no direct regulations requiring them to reduce pollution and phase out the dirtiest tier 0,1, or 2 equipment. Instead, since 2013 CARB has sought to reduce their emissions solely through incentive-based measures aimed at offering polluters funding to turn over their older diesel equipment. Moreover, the 2012 SIP revisions seek to double down on this incentive only strategy by including an even larger ask of the legislature to fund ag-equipment incentives at a time when the state is running a budget deficit. While the incentive based programs have had some success, it is time for the state to develop a backstop regulation with a firm deadline for when the dirtiest equipment must be replaced with cleaner technologies. Such a rulemaking would provide more certainty to industry on when they need to act. Moreover, such a rulemaking should be coupled with future incentives that should focus primarily on smaller, low-income farmers and on electrifying agricultural equipment where feasible.

- **Strengthen the Valley's Indirect Source Rule**: Warehouses, distribution centers, rail yards, and any other facilities that concentrate mobile source activity locally are regulated under Valley Air District's existing Indirect Source Rule (ISR). However, since the Valley's rule was last amended in 2017, the South Coast Air Management Control District has adopted a more stringent ISR that is technology forcing and applies to existing warehouses. The Valley Air District must adopt the more stringent ISR provisions implemented by the South Coast Air District to meet the Clean Air Act's most stringent measures requirement in the Valley. This includes updating the Valley's ISR rule to require the following more stringent measures:
    - Apply ISR requirements to all warehouses: including retroactive requirements for existing warehouses and new ones greater than 100,000 square feet.
    - Require warehouses to use compliance options to meet ISR obligations.
    - Require reporting of operations, compliance, and truck trip data.

[8]CEPAM https://www.arb.ca.gov/app/emsinv/fcemssumcat/fcemssumcat2016.php

The District's analysis of whether its outdated ISR program is the most stringent is sorely lacking. Thus we additionally ask that CARB staff undergo an additional more thorough comparison of the Valley Air and South Coast ISR programs to fully quantify which program is more stringent and identify areas in which feasible improvements can be made to the Valley Air's ISR program.

- **Require Additional NOx Controls for Certain Combustion Turbines, Boilers, Steam Generators, Process Heaters, and Internal Combustion Engines**: The Valley Air District must adopt the most stringent NOx controls for all sources in the Valley. This includes requiring controls like selective catalytic reduction, ultra-low NOx burners, or electrification for specific categories of fossil fuel-powered combustion turbines, boilers, steam generators, process heaters, and nonroad reciprocating internal combustion engines which are commonly used in oil and gas production and refining and in other industrial or agricultural processes. Such controls should be at least as strong as more stringent South Coast Air Management Control District rules for the same sources. For more information on specific control strategies for these sources please see the attached expert technical analysis by Megan Williams.

- **Include Measures to Reduce the Soil NOx Contribution to Overall PM2.5 Levels in the Valley:** As presented, the Emissions Inventory does not include a potentially significant source of concern, soil NOx from fertilized fields. Research has found that NOx levels in the Central Valley could be as much as 20-51% higher than currently included in the State's NOx budget when accounting for the contribution of soil NOx. This plan significantly underestimates the amount of NOx emissions that could be controlled through better management practices. Moreover, there are no proposed control measures for soil NOx in the District's strategy. To proceed with a plan that writes off soil NOx emissions contradicts the data and demonstrates that the Plan does not contain the most stringent measures available.

- **Regulate Ammonia Sources:** Ammonia has been historically under-regulated and represents the cheapest opportunity for emission reductions. Dairies and other confined animal feeding operations (CAFOs) produce the majority of ammonia emissions in the San Joaquin Valley, and ammonia is a precursor to the formation of PM2.5. We should be actively decreasing ammonia sources rather than incentivizing dairy infrastructure that contributes to nonattainment. EPA agrees. On October 5th, 2022 EPA proposed disapproval of the original plan, in part, due to shortfalls in Valley Air's ammonia demonstration.[9] Instead of initiating a sufficient public process to identify potential controls for ammonia from sources like dairies and confined animal feeding operations (CAFOs), Valley Air and CARB staff worked behind the scenes to develop a supplemental report that was submitted to EPA as part of this SIP revision without notice

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[9] *Environmental Protection Agency, Clean Air Plans; 2012 Fine Particulate Matter Serious Nonattainment Area Requirements; San Joaquin Valley, California.* (October 5, 2022). https://www.federalregister.gov/documents/2022/10/05/2022-21492/clean-air-plans-2012-fine-particulate-matter-serious-nonattainment-area-requirements-san-joaquin

and an opportunity to comment.[10] As written, the supplemental report continues to demonstrate overly conservative cost and effectiveness estimates for ammonia controls. These should be thrown out in favor of a new report that goes through sufficient rounds of public input. For more information on potential controls for ammonia, please see the attached coalition Ammonia Control Measures in the San Joaquin Valley letter, submitted to CARB staff in March of 2023.

- **Provide Necessary Assurances That the State Implementation Plan Complies with Title VI of the Civil Rights Act of 1964:** In 2020, sensors in both Bakersfield and Fresno showed annual PM2.5 values above 20 μg/m3—166 percent of the revised 2012 annual standard and more than four times the World Health Organization's guideline value. Moreover, because of recent increases in climate-driven wildfires, real world PM2.5 levels in the Valley are trending up. These failures are only part of the environmental justice catastrophe that has been allowed to persist in the Valley—a region in which the majority of people are Latino and who experience severe income inequality in comparison to more wealthy, more white, and more healthy places to live in California. Given the severity of the PM2.5 problem, the delay in achieving reductions until the last minute, the significant racial disparity, the magnitude of public health harm and deaths, and the history of failure, the Air District must be accountable under Title VI. Most significantly, the necessary assurances must demonstrate that the requested 5-year extension requested pursuant to section 188(e)—instead of more aggressive reductions to attain by 2025—does not violate Title VI.

  As was done with the ammonia supplement report, following EPA's proposed disapproval of the Valley's original 2019 plan for the 2012 Pm2.5 standard – partially on the grounds that the plan contained an insufficient Title VI analysis – Valley Air and CARB developed a wholly insufficient supplemental Title VI report without any public notice or opportunity to comment. We urge CARB to go back to the drawing board and work with the public to develop a new Title VI analysis that properly addresses the numerous and profound environmental and civil rights injustices throughout the Valley, as opposed to treating it as a simple box checking exercise for SIP approval purposes.

- **Increased Public Participation in Annual Board Updates:** In January 2019 when the CARB adopted the San Joaquin Valley Integrated 2018 PM2.5 State Implementation Plan, Board members requested annual updates on progress. While advocates and residents assumed at the time that such updates would be in the form of CARB board agenda items with opportunities for public comments, CARB staff has subsequently skipped giving updates entirely or provided them as simple memos to the board. We strongly request that CARB continue providing annual updates on the status of PM2.5 attainment in the Valley, and that such annual updates be explicitly included as a CARB agenda item open for public participation.

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[10] See Generally,

Fast action on reducing PM2.5 pollution is not only beneficial to the health of Valley residents but also the economy. The Valley Air District must not delay any longer and provide economic and health protection by committing to immediate and stringent action.

We request this letter and its attachment in their entirety be added to the District's PM2.5 Plan in the Comments and Responses Appendix and not only summarized for inclusion by District staff. 40 CFR Part 51, Appendix V, Criteria for Determining the Completeness of Plan Submissions, Section 2.1(h) states the compilation of public comments and the State's response thereto must be included in plan submissions for review by EPA in order to be determined complete. Since CARB historically endorses the District's submission, we believe this section is applicable to Plan comments submitted to the District, and our comments should be retained in full. Additionally, the option to only respond to and include significant comments is not found in 40 CFR Part 51.

Sincerely,

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Clean Water Action

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REVIEW OF SAN JOAQUIN VALLEY AIR POLLUTION CONTROL DISTRICT PM2.5 SIP REVISION: NOx CONTROL ANALYSIS[1]

JUNE 17, 2024

Combustion Turbines

According to EPA's evaluation of the combustion turbine source category in the San Joaquin Valley Air District (VAD), "[o]ver 85% of NOx emissions for this category are attributable to natural gas-fired combustion turbines used for electricity generation and combined heat and power (cogeneration)."[2] The VAD, in its recent control measure evaluation asserts that "[m]ost of the gas turbines in the San Joaquin Valley are already equipped with SCR systems to reduce NOx emissions."[3] The VAD Appendix C analysis does not include an inventory of sources and controls to support this claim.

As evidence that there likely *are* gas turbines operating in the VAD without SCR, a review of EPA's "Updated List of Stationary Combustion Turbines Subject to the Stationary Combustion Turbine NESHAP – October 2023" identified several natural gas-fired units at cogeneration facilities in the VAD without SCR installed, as shown in Table 1. Of the 19 natural gas turbines in the dataset that are located in the VAD (i.e., in Fresno County, San Joaquin County, and the western portion of Kern County in the VAD), 10 of the turbines do not have SCR control, according to EPA.[4] Eight of these turbines are listed with capacities of 75 megawatts (MW) each, one with capacity of 45 MW, and two with no capacity listed. These turbines either do not have any controls listed or are controlled with "Dry Low NOx" combustion; none list SCR as permitted controls.

Four of these turbines are at the Sycamore Cogeneration Facility in Kern County. EPA National Emission Inventory (NEI) data for this facility show it emitted 52 tons of NOx in 2020 and was the fourth highest emitter of NOx from electricity generating facilities in the VAD, as shown in Table 2.[5] According to EPA's Enforcement and Compliance History Online (ECHO), this facility currently has significant Clean Air Act violations, has been in

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[1] Prepared by Megan Williams, under contract to the National Parks Conservation Association. Ms. Williams has worked in air quality policy and engineering for over 20 years, including as an independent consultant to government and non-profit organizations, as an environmental engineer in the EPA's Region 8 Air Program, and as a permit engineer in the Wisconsin Department of Natural Resource's Air Management Program.

[2] EPA Source Category and Control Measure Assessment and Reasoned Justification Technical Support Document: Proposed Contingency Measures Federal Implementation Plan for the Fine Particulate Matter Standards for San Joaquin Valley, California (July 2023) at 36 ("2023 EPA TSD")

[3] SJVUAPCD Appendix C: District Control Measure Evaluations Draft 2024 Plan for the 2012 Annual PM2.5 Standard (April 26, 2024) at C-160 ("VAD Appendix C")

[4] *See* EPA Stationary Combustions Turbines: National Emission Standards for Hazardous Air Pollutants (NESHAP), Additional Resources: [Updated List of Stationary Combustion Turbines Subject to the Stationary Combustion Turbine NESHAP - October 2023 (xlsx)]

[5] *See* EPA National Emissions Inventory (NEI) Data [Online 2020 NEI Data Retrieval Tool]

noncompliance in all quarters during the past three years, and has had three formal enforcement actions in the past five years.[6] The facility is located north of Bakersfield. Within a 5-mile radius of the facility, 62% of residents are people of color[7] and 56% live in low-income households.[8] More stringent NOx standards in the VAD could help to further mitigate community impacts from this source category.

In its recent technical support document (TSD), EPA conducted a review of the RACT/BACT/LAER Clearinghouse (RBLC) and found that "many combustion turbines that generate electricity can achieve lower limits than [the VAD's] Rule 4703:

- Gas-fired units; 2 ppm for combined cycle units, 2.5 ppm for simple cycle units"[9]

EPA also found that "[t]he SCAQMD requires most combustion turbines greater than 0.3 MW to install SCR and meet either 2 ppm or 2.5 ppm NOx limits. Relevant exceptions include: gas compressor units that will need SCR but have a higher limit of 3.5 ppm NOx (beginning in 2024)…"[10]

In its evaluation of control measures, the VAD concluded that meeting lower limits in line with the South Coast Air Quality Management District (SCAQMD)—i.e., 2 ppm for combined cycle and 2.5 ppm for simple cycle unit—would not be cost-effective because "District Rule 4703 currently requires units to meet limits as low as 3 ppmv, and as such, adopting the slightly lower SCAQMD limits would in many cases result in only a 1 ppmv marginal improvement in NOx emissions reductions and therefore would not be cost effective."[11]

While the VAD Rule 4703 requires some units (i.e., combined cycle units choosing the "enhanced compliance" option) meet limits as low as 3 ppmv, there may be a significant number of other gas turbines that currently meet higher limits and, therefore, it could be beneficial and cost effective for these turbines to meet stricter limits in line with SCAQMD rules, and also with current rules in the Ventura County Air Pollution Control District (VCAPCD), as outlined below:

- Gas turbines in the VAD that are between 0.3 – 3 MW are currently required to meet a limit of 9 ppmv.

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[6] *See* EPA Enforcement and Compliance History Online (ECHO) Detailed Facility Report (last accessed June 6, 2024)

[7] Percent of individuals who list their racial status as a race other than white alone and/or list their ethnicity as Hispanic or Latino. EPA ECHO Detailed Facility Report (last accessed June 6, 2024).

[8] Defined as living in households where the income is less than or equal to twice the Federal poverty level. EPA ECHO Detailed Facility Report (last accessed June 6, 2024).

[9] 2023 EPA TSD at 38.

[10] 2023 EPA TSD at 38-39

[11] *See, e.g.,* VAD Appendix C at C-157

- The SCAQMD Rules 1134 (NOx emission from stationary gas turbines) and 1135 (NOx emissions from EGUs) require natural gas-fired turbines in this size category meet stricter limits of 2 ppmv (combined cycle) or 2.5 ppmv (simple cycle).
  - Applying these more stringent measures would result in a 72–78% reduction over the current VAD standard for these emissions sources.
- The SCAQMD rule 1109.1 (NOx emissions from petroleum refineries and related operations) require all natural gas-fired turbines at refineries meet a limit of 2 ppmv.
  - Applying these more stringent measures would result in a 78% reduction over the current VAD standard for these emissions sources.
- The VCAPCD Rule 74.23 (Stationary Gas Turbines) applies to any stationary natural gas-fired turbine ≥ 0.3 MW, with a NOx standard of 2.5 ppmv for units emitting on or after January 1, 2024.[12]
  - Applying this more stringent measures would result in a 72% reduction over the current VAD standard for any gas turbine ≥ 0.3 MW.
- The magnitude of potential emissions reductions from units in this size range (0.3 – 3 MW) depends on how many of these turbines operate in the VAD; even though they are smaller units there could be a significant number of them operating now and / or in the future.

- Gas turbines in the VAD that are between 3 – 10 MW and operate <877 hr/yr are required to meet a limit of 9 ppmv.
  - The SCAQMD Rules 1134 (NOx emission from stationary gas turbines) and 1135 (NOx emissions from EGUs) require natural gas-fired turbines in this category meet stricter limits of 2 ppmv (combined cycle) or 2.5 ppmv (simple cycle).[13]
    - Applying these more stringent measures would result in a 72–78% reduction over the current VAD standard for these emissions sources.
  - The SCAQMD rule 1109.1 (NOx emissions from petroleum refineries and related operations) require all natural gas-fired turbines at refineries meet a limit of 2 ppmv.
    - Applying these more stringent measures would result in a 78% reduction over the current VAD standard for these emissions sources.

[12] There are exemptions for: laboratory equipment; units operated exclusively for fire fighting and/or flood control; low-use (units operating <200 hr/yr); emergency standby units; and during certain start-up, planned shutdown, or unplanned load changes.
[13] Note, SCAQMD Rules 1134 and 1135 have "Low-Use" exemptions for gas turbines installed prior to April 5, 2019 (Rule 1134) and November 2, 2018 (Rule 1135).

    - The VCAPCD Rule 74.23 (Stationary Gas Turbines) applies to any stationary natural gas-fired turbine ≥ 0.3 MW, with a NOx standard of 2.5 ppmv for units emitting on or after January 1, 2024.[14]
        - Applying this more stringent measure would result in a 72% reduction over the current VAD standard for gas turbines between 3 – 10 MW and that operate between 200 – 877 hr/yr.
    - The magnitude of potential emissions reductions from low-use units in this size range depends on how many of these turbines operate in the VAD; even though they only operate 10% of the time there could be a significant number of them operating now and / or in the future.

- Simple cycle gas turbines in the VAD that are > 10 MW and operate <200 hr/yr are required to meet a limit of 25 ppmv.
    - The SCAQMD Rules 1134 (NOx emission from stationary gas turbines) and 1135 (NOx emissions from EGUs) require natural gas-fired turbines in this category meet stricter limits of 2 ppmv (combined cycle) or 2.5 ppmv (simple cycle).[15]
        - Applying these more stringent measures would result in a ≥90% reduction over the current VAD limit for these low-use emissions sources.
    - The SCAQMD rule 1109.1 (NOx emissions from petroleum refineries and related operations) require all natural gas-fired turbines at refineries meet a limit of 2 ppmv.
        - Applying this more stringent measure would result in a 92% reduction over the current VAD limit for these low-use emissions sources.
    - The magnitude of potential emissions reductions from low-use units in this size range depends on how many of these turbines operate in the VAD; even though they only operate less than 200 hours per year there could be a significant number of them operating now and / or in the future.

- Pipeline gas turbines[16] in the VAD that are between 3 – 10 MW are required to meet a limit between 8 – 12 ppmv.
    - The SCAQMD Rule 1134 (NOx emissions from stationary gas turbines) has a standard of 3.5 ppmv for "compressor gas turbine" units.[17]
        - This reflects a 50–70% potential reduction over the current VAD limit for turbines used for this application.

[14] There are exemptions for: laboratory equipment; units operated exclusively for fire fighting and/or flood control; low-use (units operating <200 hr/yr); emergency standby units; and during certain start-up, planned shutdown, or unplanned load changes.
[15] Note, SCAQMD Rules 1134 and 1135 have "Low-Use" exemptions for gas turbines installed prior to April 5, 2019 (Rule 1134) and November 2, 2018 (Rule 1135).
[16] Defined as "any simple cycle stationary gas turbine used to transport gases or liquids in a pipeline."
[17] Defined as "a stationary gas turbine used to transport gases or liquids in a pipeline."

- The magnitude of potential emissions reductions from these types of units in this size range depends on how many of these turbines operate in the VAD; even though they are relatively small in size there could be a significant number of them operating now and / or in the future.

The VAD's district control measures evaluation includes cost effectiveness analyses of retrofitting existing gas turbines with SCR for four scenarios. The VAD determined potential NOx emissions reductions by "taking the difference between the potential emissions and the emissions reductions that could be reliably achieved by retrofitting the system with the latest SCR technology capable achieving 2.0 ppmv NOx @ 15% O2 for cogeneration turbines and 2.5 ppmv NOx @ 15% O2 for simple cycle turbines."[18] The VAD evaluation then provides the calculation used to determine these emissions reductions.[19] The emissions reductions that are presented in the Cost Effectiveness Results Tables for the four scenarios, however, are less than calculated values using the equation provided in Appendix C, and are also less than estimates using an alternative EPA method, as shown in Table 3.[20] Table 3 shows that emissions reductions could be 2 ½ to 3 times higher than what is shown in the Cost Effectiveness Results tables in Appendix C. This potential underestimate of emissions reductions means that the cost effectiveness of the scenarios evaluated would be lower (i.e., they would be more cost effective than what is presented in the VAD's evaluation).

In the VAD's evaluation of the VCAPCD Rule 74.23, it describes an alternate compliance option that "exempts units from meeting the limits under certain conditions, including unfavorable cost effectiveness."[21] And in its evaluation of the SCAQMD rules it describes "a near-limit exemption" that would apply in cases where small additional emissions reductions would not be cost effective. Similar provisions could be included in stricter VAD standards in order to allow for limited exemptions for units that are already meeting strict standards—i.e., for those units where additional emissions reductions would not be great enough to be cost effective, as determined by the VAD. The VCAPCD allows for an alternative compliance option, but the owner or operator must get Division approval and emissions reductions must be equivalent "at the facility site or nearby community" and is only available as an option for units that will otherwise meet Best Available Retrofit Control Technology requirements and that can demonstrate that the cost of compliance exceeds "the established cost effectiveness threshold of the District."[22] The SCAQMD's "near-limit exemption" described by the VAD in its evaluation of district control measures does not appear as a specific provision in any of the SCAQMD rules that apply to gas turbines but such a provision could be incorporated into more stringent VAD rules in order to allow for limited exceptions while maintaining the most stringent measures for the district.

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[18] VAD Appendix C at C-161
[19] *Id.*
[20] EPA Alternative Control Techniques Document – NOx Emissions from Stationary Gas Turbines Appendix A, available online at: https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=2000HING.txt
[21] VCAPCD Rule 74.23 B.6.d.
[22] VCAPCD Rule 74.23 B.6.d.

Finally, Colorado—in its recent rules for smaller natural gas-fired reciprocating internal combustion engines (RICE)—compiled a detailed inventory of existing sources across the state as part of its rulemaking process. This was useful in assessing the applicability of the proposed rules, how many engines would be impacted, and the potential for actual emissions reductions.

Boilers, Process Heaters, and Steam Generators (> 5 MMBtu)

EPA identified a few source categories in the SCAQMD rules that are subject to more stringent limits than what is required in the VAD rules, including the following:

- Units 20 – 75 MMBtu/hr (that are not fire tube units) must meet a NOx limit of 5 ppmv in SCAQMD Rule 1146, compared to a limit of 7 ppmv in the VAD Rule 4306. While it may not be cost effective to install SCR for units already meeting the 7 ppmv limit, the VAD could allow for near-limit exemptions for these units in order to maximize the number of current and future units in this size category that would be required to meet a limit of 5 ppmv.

- Refinery process heaters with a total rated heat input > 40.0 MMBtu/hr and ≤ 110 MMBtu/hr must meet a NOx limit of 15 ppmv (or 9 ppmv for "replacement units") in the VAD Rule 4306 (Table 2), compared to a limit of 5 ppmv in the SCAQMD Rule 1109.1. And while there are alternative compliance options for some units in the SCAQMD Rule—e.g., including an interim limit of 18 ppmv—there could very well be many sources in the VAD currently meeting a 15 ppmv limit that could cost effectively meet a lower limit of 5 ppmv. The VAD could allow for certain limited exceptions where controlling these process heaters to meet a limit of 5 ppmv is not cost effective. The VAD Rule 4320 NOx limit for this source category is 5 ppmv, in line with more stringent the SCAQMD limits, but allows operators to pay a fee and meet certain particulate matter control requirements in lieu of meeting the 5 ppmv NOx standard. In order to ensure that more units that can technically and cost effectively meet a NOx limit of 5 ppmv are required to meet such a limit, the VAD should consider the lower limits in rule 4306 for these units and / or remove the option in rule 4320 that allows for operators to pay a fee and avoid rigorous control and associated material emissions reductions.
  - EPA pointed out that the VAD does not clearly define what constitutes a "replacement unit." The district should, at a minimum, clarify its definition in line with what the SCAQMD outlines in Rule 1109.1 – i.e., the cumulative replacement of either 50 percent of or more of the burners or replaces burners that represent 50 percent or more of the heat input of the unit.

As with the gas turbine source category, the magnitude of potential emissions reductions from boilers, steam generators, and process heaters depends on how many operate in the VAD; a detailed inventory of sources could help inform and determine the benefits that could be gained from stricter limits for these sources. As previously mentioned, Colorado—in its recent rules for smaller natural gas-fired reciprocating internal combustion engines (RICE)—compiled a detailed inventory of existing sources across the state as part of its rulemaking process, which was useful in assessing the applicability of the proposed rules, how many engines would be impacted, and the potential for actual emissions reductions.

Reciprocating Internal Combustion Engines (RICE) – Nonroad Engines

EPA identified several areas where the SCAQMD rules for RICE require more stringent limits than what is required in the VAD, including the following:

- Lean-burn waste gas-fueled RICE used for non-agricultural operations are required to meet a NOx limit of 11 ppmv in the SCAQMD, compared to a limit of 40 ppmv (or 93% reduction) in the VAD. The VAD does not put forth any reason why this lower standard could not be achieved in the VAD.
    - Applying the more stringent SCAQMD measure for these RICE would result in a 74% reduction over the current VAD limit for these engines.

- Lean-burn RICE used for agricultural operations are required to meet a NOx limit of 11 ppmv in the SCAQMD, compared to a limit of 43 ppmv (or 0.6 g/bhp/hr) in the VAD.
    - The VAD evaluation indicates that there are no lean-burn RICE used for agricultural operations in the SCAQMD. Presumably the SCAQMD set its current standard based on a review of technically feasible and cost effective requirements for all of the sources it regulates. The SCAQMD has different compliance schedules for agricultural engines, indicating it contemplated the potential different challenges that RICE employed in agricultural applications (as opposed to other applications) may pose. The SCAQMD did not provide any exemptions for lean-burn RICE used for agricultural operations, indicating that it expects any agricultural lean-burn RICE operating in the district to meet the standard of 11 ppmv. The VAD, in its evaluation of district control measures, discusses the "rural and expansive" environment of the VAD, in contrast to the more urban environment of the SCAQMD but does not specify what technical limitation this distinction presents for these particular lean-burn RICE. While electric engines may not be feasible in some of the more rural agricultural applications in the VAD this environment would not necessarily preclude the use of SCR to reduce NOx emissions from gas-fired RICE in order to achieve a lower NOx standard. The VAD could provide for certain limited exceptions for situations where the installation of SCR on these RICE used for agricultural operations would not be cost effective.
        - Applying the more stringent SCAQMD measure for these RICE would result in a 73% reduction over the current VAD limit for these engines.

- Existing diesel engines that are currently required to only meet EPA Tier 3 standards in the VAD would be required to meet the stricter EPA Tier 4 standards in the SCAQMD. Again, the VAD evaluation indicates that there are no stationary non-emergency diesel internal combustion engines in the SCAQMD, but presumably the SCAQMD set its current standard based on a review of technically feasible and cost effective requirements for all of the sources it regulates or would potentially regulate and therefore expects any such engines to be able to meet EPA Tier 4 standards. The VAD should require all existing diesel engines to meet EPA Tier 4 standards.

As with the other two source categories reviewed, the magnitude of potential emissions reductions from the engines in this source category depends on how many operate in the VAD; a detailed inventory of sources could help inform and determine the benefits that could be gained from stricter limits for RICE. As previously mentioned, Colorado—in its recent rules for smaller natural gas-fired RICE—compiled a detailed inventory of existing sources across the state as part of its rulemaking process, which was useful in assessing the applicability of the proposed rules, how many engines would be impacted, and the potential for actual emissions reductions. EPA points out that engines in the VAD used in the food and agricultural sector contribute 64% of NOx emissions, e.g., from water pumps used in crop fields. Applying stricter standards to these engines, in line with what is already required in the SCAQMD, would result in meaningful emissions reductions even if some exceptions would need to be considered in order to achieve the most stringent measures possible.

TABLE 1: NATURAL GAS-FIRED TURBINES IN EPA'S OCT 2023 TURBINE NESHAP LIST THAT ARE LOCATED IN THE SAN JOAQUIN VALLEY AIR POLLUTION CONTROL DISTRICT (THOSE HIGHLIGHTED DO NOT HAVE SCR FOR NOx CONTROL)

FACILITY_NAME	COUNTY	LAT	LON	EMISSION_UNIT_DESCRIPTION	Capacity (MW)	Permit Emission Controls
BADGER CREEK LIMITED	Kern	35.4840424	-119.0302	COGEN #001	49	SCR, CO Catalyst, Steam Injection
BEAR MOUNTAIN LIMITED	Kern	35.4189274	-118.92624	NATURAL GAS TURBINE	48	SCR, Oxidation Catalyst, Steam Injection
CHALK CLIFF LIMITED	Kern	35.0973099	-119.39154	NG TURBINE	49	SCR and Steam Injection
COALINGA COGENERATION CO	Fresno	36.1807959	-120.38841	NATURAL GAS COGENERATION	43	SCR
KERN RIVER COGENERATION CO	Kern	35.4405323	-118.96136	NATURAL GAS TURBINE UNIT #1	75	Dry Low NOx
KERN RIVER COGENERATION CO	Kern	35.4405356	-118.96137	NATURAL GAS TURBINE UNIT #2	75	Dry Low NOx
KERN RIVER COGENERATION CO	Kern	35.4405367	-118.96137	NATURAL GAS TURBINE UNIT #3	75	Dry Low NOx
KERN RIVER COGENERATION CO	Kern	35.4405334	-118.96136	NATURAL GAS TURBINE UNIT #4	75	Dry Low NOx
LIVE OAK LIMITED	Kern	35.5928145	-118.95912	GAS TURBINE	35	SCR, Oxidation Catalyst, Steam Injection
MCKITTRICK LIMITED	Kern	35.3161842	-119.65944	NG TURBINE	48	Steam Injection, Oxidation Catalyst, SCR
MID-SET COGENERATION COMPANY	Kern	35.1940931	-119.57086	NATURAL GAS TURBINE COGENERATION	48	SCR, Water Injection
MIDSUN PARTNERS L.P. COGENERAT	Kern	35.2273185	-119.62998	GAS TURBINE		
OILDALE ENERGY, LLC	Kern	35.4188673	-119.01145	GAS TURBINE		Steam Injection, Oxidation Catalyst, SCR
RIPON COGENERATION	San Joaquin	37.7310801	-121.12492	49.9 MW COGEN	50	SCR, Steam Injection
SYCAMORE COGENERATION CO	Kern	35.4515068	-118.9848	COGEN/TURBINE #3	75	Dry Low NOx
SYCAMORE COGENERATION CO	Kern	35.4511266	-118.98484	COGEN/TURBINE #4	75	Dry Low NOx
SYCAMORE COGENERATION CO	Kern	35.4522846	-118.98475	COGEN/TURBINE #1	75	Dry Low NOx
SYCAMORE COGENERATION CO	Kern	35.4518913	-118.98477	COGEN/TURBINE #2	75	Dry Low NOx
DEXZEL, INC.	Kern	35.4408877	-119.01297	TURBINE		

TABLE 2: EPA NATIONAL EMISSION INVENTORY 2020 NOx EMISSIONS FROM ELECTRICAL GENERATING FACILITIES IN THE SAN JOAQUIN VALLEY AIR POLLUTION CONTROL DISTRICT

State-County	NOx Emissions (Tons) [NEI]	Site Name
CA - Kern	102	PASTORIA ENERGY FACILITY, LLC
CA - Kern	70	ELK HILLS POWER LLC
CA - Kern	52	SUNRISE POWER CO
CA - Kern	52	SYCAMORE COGENERATION FACILITY
CA - San Joaquin	48	DTE STOCKTON, LLC
CA - Madera	46	AMPERSAND CHOWCHILLA BIOMASS LLC
CA - Kern	42	CXA LA PALOMA, LLC
CA - Merced	41	MERCED POWER, LLC
CA - Stanislaus	34	WALNUT ENERGY CENTER AUTHORITY
CA - San Joaquin	31	MRP SAN JOAQUIN ENERGY, LLC
CA - Kern	26	MT POSO COGENERATION COMPANY, LLC
CA - Fresno	25	PANOCHE ENERGY CENTER LLC
CA - San Joaquin	16	NORTHERN CALIFORNIA POWER
CA - Stanislaus	13	MODESTO IRRIGATION DISTRICT
CA - Stanislaus	12	TURLOCK IRRIGATION DISTRICT
CA - Fresno	4	ALGONQUIN POWER SANGER LLC
CA - Kern	3	BEAR MOUNTAIN LIMITED
CA - Kings	3	MRP SAN JOAQUIN ENERGY, LLC
CA - Fresno	2	MIDWAY PEAKING LLC
CA - San Joaquin	2	NORTHERN CALIFORNIA POWER AGENCY
CA - Kern	2	LIVE OAK LIMITED
CA - Kern	2	BADGER CREEK LIMITED
CA - Fresno	2	CALCO GEN LLC
CA - Kings	1	MRP SAN JOAQUIN ENERGY, LLC
CA - Fresno	1	MALAGA POWER, LLC
CA - Fresno	1	CAL PEAK POWER - PANOCHE, LLC
CA - San Joaquin	1	MODESTO IRRIGATION DISTRICT
CA - San Joaquin	1	ALTAGAS RIPON ENERGY INC
CA - Fresno	1	WESTERN CO-GEN, LLC
CA - Stanislaus	0.4	TURLOCK IRRIGATION DISTRICT
CA - Kern	0.3	DELANO ENERGY CENTER LLC
CA - Fresno	0.3	FRESNO COGENERATION PARTNERS
CA - Fresno	0.2	WELLHEAD POWER PANOCHE, LLC.
CA - Fresno	0.2	KINGSBURG COGEN FACILITY
CA - Fresno	0.1	PACIFIC GAS & ELECTRIC CO
CA - Madera	0.03	MADERA POWER, LLC
CA - Kern	0.02	KERN RIVER COGENERATION FACILITY
CA - Fresno	0.02	PACIFIC GAS & ELECTRIC CO
CA - Fresno	0.01	RIO BRAVO FRESNO
CA - Kern	0.01	COVANTA DELANO INC
CA - Tulare	0.003	SOUTHERN CALIFORNIA EDISON
CA - Kern	0.002	AERA ENERGY LLC

TABLE 3: NOx EMISSIONS REDUCTIONS ESTIMATES (TONS/YEAR)

SCENARIO	VAD APPENDIX C TABLES (pp. C-163–167)	VAD APPENDIX C EQUATION (p. C-161)	EPA METHOD*
1. Retrofit of units less than 3 MW with an SCR system capable of achieving 2 ppmv NOx @ 15% O2 Heat Input Rate 30 MMBtu/hr	1.26	3.37	3.68
2. Retrofit for a modern SCR system for units between 3 MW to 10 MW to comply with 2 ppmvd NOx @ 15% O2 Heat Input Rate 51.7 MMBtu/hr	0.93	2.49	2.72
3. Retrofit of an SCR system for units greater than 10 MW simple cycle unit to comply with 2.5 ppmvd NOx @ 15% O2 Heat Input Rate 500 MMBtu/hr	7.48	20.04	21.90
4. Retrofit of an SCR system for units greater than 10 MW combined cycle to comply with 2 ppmvd NOx @ 15% O2 Heat Input Rate 1,100 MMBtu/hr	19.74	52.92	57.82

EPA's ***Alternative Control Techniques Document -- NOx Emissions from Stationary Gas Turbines*** includes an Appendix (A) with the Agency's method for converting exhaust concentration levels to a NOx mass flow rate (in lb/hr), based on turbine manufacturer data. *See* https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=2000HING.txt (Appendix A)

March 10, 2023

Via Electronic Mail

Edie Chang
Deputy Executive Officer
California Air Resources Board
1001 I St #2828
Sacramento, CA 95814
E: edie.chang@arb.ca.gov

Re: Ammonia Control Measures in the San Joaquin Valley

Dear Ms. Chang,

As you know, on October 5, 2022, the U.S. Environmental Protection Agency (EPA) proposed to partially disapprove California's Serious area plan for the 2012 national ambient air quality standards (NAAQS) for fine particulate matter ($PM_{2.5}$) in the San Joaquin Valley. As part of this proposed disapproval, EPA concluded that the State's precursor demonstration for ammonia failed to demonstrate that the adoption of reasonable ammonia control measures would not significantly contribute to attainment of the NAAQS. In particular, EPA observed that the State did not have a proper basis for its conclusion that it would be implausible to reduce ammonia emissions by more than 30% given that the State had not conducted a meaningful analysis of the feasibility of ammonia control measures. EPA therefore concluded "that ammonia must be regulated as a $PM_{2.5}$ precursor for the 2012 annual $PM_{2.5}$ NAAQS in the [Valley]."

The State subsequently withdrew its plan, and it is now subject to a statutory deadline of June 27, 2023 to finalize and submit a best available control measures (BACM) analysis, among other things. Given EPA's conclusion that ammonia must be regulated as a $PM_{2.5}$ precursor, we expect that this BACM analysis will include an evaluation of control measures to regulate ammonia.

The signatories to this letter write to implore the State to conduct a thorough, open-minded, and rigorous analysis of potential ammonia control measures as part of its BACM analysis. We have long seen agricultural emissions, including ammonia emissions, go largely unregulated in the San Joaquin Valley. Many of us have pointed out how this lack of regulation contributes to the current public health and environmental justice crisis in the Valley, where a disproportionately low-income and Latino population breathes the dirtiest air in the nation. We hope that EPA's proposed disapproval will lead the State and Air District to recognize that a robust $PM_{2.5}$ plan in the Valley requires meaningful regulation of agriculture in general and of ammonia in particular.

Several of our organizations met with your office on December 7, 2022 and January 20, 2023, and during those meetings you requested that we provide input regarding potential ammonia mitigation strategies. In response, we have commissioned an analysis of potential ammonia controls on San Joaquin Valley dairies by two experts in food, climate, and air quality, Nina Domingo, PhD, and Kimberly Colgan, PhD, trained at the University of Minnesota. Their analysis is attached as Exhibit A, and their respective CVs are attached as Exhibits B and C.

This analysis discusses mitigation strategies that do not appear to have been broadly implemented in the San Joaquin Valley. It focuses primarily on measures that have been implemented in dairies elsewhere to demonstrate beyond doubt the feasibility of regulating a large proportion of agricultural ammonia in the Valley. It also presents a few options that, while not yet widely implemented in dairies, have been studied in dairy cattle or have been implemented in pork and poultry production.

We encourage and expect CARB to discuss these measures in its forthcoming BACM analysis. While we do not endorse any one measure over another at this time, we encourage CARB to investigate these measures holistically with regard to local, regional and global air pollutant impacts, water quality impacts, and impacts on local communities. After CARB has had an opportunity to review the attached analysis, we request the opportunity to meet to discuss these measures and CARB's plans for the BACM submission.

Thank you for your attention to this important public health and civil rights matter. We look forward to further engagement in the coming months as you put together your BACM analysis. Should you have any questions, or if you wish to schedule a meeting or discuss the issues raised in this letter and the attached analysis, please reach out to Gregory Muren in Earthjustice's California Regional Office at 415-217-2000 or gmuren@earthjustice.org.

Sincerely,

Kevin Hamilton
Central California Asthma Collaborative

Nayamin Martinez
Central California Environmental Justice Network

Dr. Catherine Garoupa
Central Valley Air Quality Coalition

Greg Muren
Mustafa Saifuddin
Earthjustice

Matt Holmes
Little Manila Rising

Mark Rose
National Parks Conservation Association

Gordon Nipp
Sierra Club, Kern-Kaweah Chapter

cc: Martha Guzman, Regional Administrator, Region IX, U.S. Environmental Protection Agency
Liane Randolph, Chair, California Air Resources Board
Samir Sheikh, Executive Director/APCO, San Joaquin Valley Air Pollution Control District

Exhibit A

MITIGATING AMMONIA EMISSIONS FROM DAIRIES IN THE SAN JOAQUIN VALLEY

Prepared by: *Kimberly Colgan and Nina Domingo*

Summary

Agriculture is responsible for over 80% of ammonia (NH_3) emissions in the US. NH_3 acts as a precursor to fine particulate matter ($PM_{2.5}$) formation, and long-term exposure to $PM_{2.5}$ is the largest environmental mortality risk in the US and worldwide. Among US states, California has the greatest number of air quality-related deaths caused from agricultural ammonia emissions, which are largely released via livestock waste management and fertilizer application. In California, about 30% of air quality-related health impacts from agriculture can be attributed to direct emissions from waste management of dairies, many of which are located in the San Joaquin Valley (SJV). Here, we compile strategies that have been used elsewhere to mitigate emissions from dairies, and include details on emissions reductions, cost-effectiveness, avoided deaths, climate impacts, and other potential tradeoffs and co-benefits. We also present additional mitigation strategies that, while not yet broadly implemented in dairies, demonstrate significant potential to effectively reduce ammonia emissions. Based on our analysis, it appears feasible to mitigate a large proportion of ammonia emissions from dairies in the San Joaquin Valley.

1. Introduction

Harms from ammonia emissions

Agriculture is responsible for over 80% of NH_3 emissions in the US (Behera et al. 2013). As recognized by the EPA, NH_3 acts as a precursor to fine particulate matter ($PM_{2.5}$) formation. Long-term exposure to particulate matter has negative impacts on our cardiovascular and respiratory systems, and can lead to asthma, chronic obstructive pulmonary disease, lung cancer, strokes, heart disease, heart attacks, respiratory infections, and more (WHO, 2022; Guthrie et al. 2018). As poor air quality is known to pose the greatest environmental mortality risk globally, efforts to improve $PM_{2.5}$ concentrations are key to improving public health (Stanaway et al., 2018).

A recent study found that agricultural air pollution in the United States contributed to 17,900 deaths per year (Domingo et al., 2021). The study, which was conducted by an EPA-funded research center (i.e., Center for Air Climate and Energy Solutions), quantified the air quality-related health impacts of US agriculture using primary and secondary precursor $PM_{2.5}$ emissions data from the EPA's 2014 National Emissions Inventory (CACES, n.d). The study uses three reduced-form chemical transport models, which have been evaluated against a state-of-the-science chemical transport model (i.e., WRF-Chem), to estimate the impact of emissions on air quality-related deaths (Gilmore et al., 2019). Results suggest that California leads the country with the greatest number of air quality-related deaths (1,690 deaths per year) caused by agricultural ammonia emissions--750 deaths more than the second leading state (Domingo et al., 2021).

Agricultural air quality damages are largely driven by ammonia, which is largely released via livestock waste management and fertilizer application (EPA, 2021). In California, about 30% of air quality-related health impacts from agriculture can be attributed to direct emissions from waste management of dairy production (Domingo et al., 2021). Many of the dairies in California are located in the SJV, with almost 90% of all milk cows located in the SJV (USDA/NASS, 2022). Several studies demonstrate that strategies for reducing NH_3 emissions from agriculture are among the most effective for reducing PM concentrations, especially during the winter time (Pinder et al., 2007).

In section 2, we replicate the methods from Domingo et al. (2021) using the latest 2017 National Emissions Inventory (2017 NEI) to get updated estimates of air quality-related deaths from dairy farming in California as well as estimate the lives that could be saved by adopting on-farm interventions.

Significantly reducing NH_3 emissions from dairy production is feasible

Governments are already monitoring and regulating agricultural ammonia emissions. To meet the goals of their Clean Air Program, the European Union (EU) passed the National Emission Ceilings Directive in 2016, requiring emissions reductions for five air pollutants, one of which is ammonia (EU Directive; 2016). European member states are creating their own regulations to meet the emissions reduction requirements of the directive. Many of the strategies discussed in Table 1 are already widely adopted across parts of Europe to mitigate ammonia emissions.

There are a large, and growing, number of publications and reviews showcasing emerging and adopted technologies and strategies to improve air quality and reduce ammonia emissions. These works reviewing ammonia mitigation strategies often include the costs of implementation, trade-offs with water pollution and greenhouse gas (GHG) emissions, and strategy feasibility (Newell Price et al., 2011; Guthrie et al., 2018; Zhang et al., 2019; Buckley et al., 2020).

Dairy production interventions primarily target ammonia emissions from waste management as it is the primary source of air quality-related health damages. Ammonia emissions from dairy production can be reduced through strategies such as improving livestock feed to reduce excreted nutrients, altering manure storage and handling practices to prevent NH_3 emissions, and improving land application practices have been effectively implemented in some operations (Domingo et al. 2021; Eory et al., 2018; Guthrie et al., 2018; Preece et al., 2017; Bittman et al., 2014; Newell Price et al., 2011; Webb et al., 2010; Cole et al., 2006; Cole et al., 2005).

Dairy production in the San Joaquin Valley

To determine the local mitigation potential and feasibility of ammonia reduction strategies, it is important to consider the characteristics of dairy farming in the San Joaquin Valley. Almost 90% of California's mature dairy cows are in the San Joaquin Valley, and over 65% of all of the cattle and calves in the state reside in the SJV (USDA/NASS, 2022). Approximately 75% of mature dairy cows in the region are raised in freestall housing, while the rest are raised mainly in outdoor corrals with shaded areas (Mullinax et al., 2020). Frequent scraping from freestall housing and corrals is done to prevent the build up of powdery dust and to remove manure, and to comply with the Conservation Management Practices Program of the San Joaquin Valley Air Pollution Control District (SJVAPCD) (SJVAPCD, 2004). Dairy animal feeding operations are required to either flush the milking parlor before, during or after milking, as well as flush or scrape freestall flush lanes before, during or after milking, or at least three times a day (SJVAPCD, 2006). Flush water lagoon systems are commonly used for collecting and storing manure (CARB, 2017), and just under three-fourths of dairy herds in the region separate solids from liquid manure (Mullinax et al., 2020).

The political environment in California affects the decision-making and production practices of farmers in the San Joaquin Valley. State-level goals to reduce greenhouse gas emissions have helped popularize digesters to help reduce methane emissions (CA Climate Crisis Act, 2022; CARB, n,d.; CA Global Warming Solutions Act, 2006). Region-level emissions regulations and recommendations from the SJVAPCD influence dairy production in the valley. Relevant guidance on dairy production and ammonia emissions from the SJVAPCD include rule 4550, 4565, and their 2004 handbook to minimize particulate matter. Rule 4550 (Conservation Management Practices) requires that farmers choose one conservation management practice in corral/manure handling and one in overall management/feeding (SJVAPCD, 2006). Rule 4565 (Biosolids, Animal Manure, and Poultry Litter Operations) requires that at qualifying management facilities, biosolids, animal manure, and poultry litter are directly injected into the soil within 3 hours, incorporated within 3 hours, or covered within 3 hours, where these materials are going to be applied to the soil (SJVAPCD; 2007). Rule 4570 (Confined Animal Facilities) has permit applications for dairy confined animal facilities that include required mitigation measures and additional mitigation measures that farmers must select one or more of at different stages of the production process including: feed, silage, milk parlor, freestall barn, corral, land application, liquid manure, and solid manure (SJVAPCD; 2019). The Air Quality Handbook for Conservation Management Practices for San Joaquin Valley on dairies and feedlots published in 2004 outlines strategies to help reduce particulate matter for different aspects of dairy production including: corral/manure handling; overall manure management/feeding; unpaved roads; and unpaved vehicle/equipment traffic areas (SJVAPCD, 2004).

Strategies that would significantly decrease ammonia emissions, but significantly alter production approaches like decreasing stocking numbers, as well as converting land used for dairy production to unmaintained lands, cropland production, commercial woodlands, biomass cropping, and extensive grazing production systems were excluded from this analysis (Newell Price et al., 2011).

2. Methodology for ammonia mitigation strategies table compilation

This analysis builds on the work done by the EPA and USDA in their 2017 “Agricultural Air Quality Conservation Measures Reference Guide for Poultry and Livestock Production Systems”, hereafter referred to as “EPA/USDA Reference Guide”. Strategies to reduce ammonia were primarily extracted from three reviews (EPA/USDA, 2017; Newell Price et al., 2011; Guthrie et al., 2018). These strategies are then categorized in 5 groups: Nutrition and Feed Management; Manure Management; Animal Confinement; Land Application; and Other. Details on ammonia emissions reductions, avoided deaths, likely uptake, cost of adoption, and potential tradeoffs for each strategy are discussed for each strategy reviewed.

Table 1 is limited to measures that have already been successfully implemented in dairy operations. Commonly cited strategies to mitigate ammonia emissions that have not been broadly used in the context of dairy production systems are discussed in section 4, below..

2.1 Estimating the mitigation potential of strategies to reduce ammonia emissions
The ranges of ammonia mitigation for each strategy were extracted from appendix 1 of the EPA/USDA Reference Guide. Where the listed strategy was too broad to determine, more specific strategies in that intervention area were listed, and the corresponding mitigation ranges from ammonia mitigation literature were used. For example, "Litter Amendments and Manure Additives" is quite broad, so here we use "Acidify Manure" and "Add Straw to Cattle Housing" instead, as these are more specific, and describe a specific strategy in this intervention area that farmers can implement to achieve ammonia emissions reductions. These more specific strategies are associated with their own mitigation ranges, and these are noted in the table in the "Resources" column, and updated accordingly.

As interventions to reduce emissions in one stage may affect emissions in another stage, it is important to note that the emission reduction potential of each strategy in this review will vary depending on whether other strategies have been adopted. For example, adopting one of the mitigation strategies in nutrition and feed management is likely to reduce the nitrogen inefficiencies, and reduce the amount of nitrogen that would need to be mitigated in other dairy production stages further down the life cycle (e.g. waste management and land application).

There is limited scientific literature on the ammonia reductions that can be achieved by adopting more than one of these mitigation strategies at the same time, although a combination of interventions across stages of the dairy production life cycle will be needed to ensure the maximum feasible amount of emissions reductions are achieved.

2.2 Estimating costs of ammonia mitigation strategies
Cost estimates are predominately extracted from Newell Price et al. (2011) and Guthrie et al. (2018). Newell Price et al. does not specify what year their currency estimates are reported on, so 2011 £ estimates are used, as it is the year of the report publication. Guthrie reports cost estimates in 2018 £. Costs estimates in £ were converted from their base year estimate using the average corresponding exchange rate (2011: 1 GBP to 1.6041 USD; 2018: 1 GBP to 1.3349 USD) into USD. Then, base year USD estimates were converted to 2023 USD using the corresponding rates of change in the consumer price index, and rounded to the hundreds place for annual farm-level cost estimates. This same approach was used to update abatement cost estimates from Zhang et al. (2019) and Buckley et al. (2020) into 2023 USD estimates.

2.3 Calculating lives saved from adopting ammonia mitigation strategies
Following the methods of Domingo et al. (2021), we estimate the lives saved from adopting ammonia mitigation strategies, which we describe briefly here. First, we estimated the number of deaths from dairy cattle waste management in a business-as-usual scenario. To do this, we obtained county-level annual emissions inventories of primary and secondary precursor $PM_{2.5}$

from the 2017 NEI. Using the source classification codes within the 2017 NEI, we then filtered for emissions that were released from dairy cattle operations, specifically pertaining to livestock waste management, in California. To further allocate dairy cattle waste emissions by waste management stage (e.g., confinement, handling and storage, and land application), we first run the Carnegie Mellon University Farm Emissions Model (from which the 2017 NEI livestock waste management emissions are derived) to obtain county-level distribution of emissions by livestock waste management stage and then apply that distribution to our set of 2017 NEI emissions.

We input the spatially explicit emissions inventory data into three reduced-complexity chemical transport models (RCMs): Air Pollution Emission Experiments and Policy v3, EASIUR (Estimating Air pollution Social Impact Using Regression), and Intervention Model for Air Pollution. These models allow us to follow the causal pathway of emissions to $PM_{2.5}$ concentrations to air quality-related health impacts. All three models include simplified representations of atmospheric chemistry and physics, which reduce computational demands relative to traditional chemical transport models. These models were designed to enable rapid policy analysis and have been evaluated against a state-of-the-science chemical transport model (i.e., WRF-Chem) (Gilmore et al., 2019).

To estimate the number of avoided deaths from different interventions to dairy cattle waste management, we generated spatially explicit inventories for each intervention scenario and compared them to the business-as-usual scenario for current production practices and diets, modeling the resulting changes in $PM_{2.5}$ concentrations and annual deaths.

2.4 Estimating the impacts of ammonia reduction strategies on greenhouse gasses

Estimates of the GHG impacts of ammonia reduction strategies were extracted from Newell Price et al. 2011 and the EPA/USDA Reference Guide. If more recent studies on the strategy highlight a different magnitude or direction of the impact on carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), then the range is updated, and the resource providing the estimate is noted in the "Resources" column.

2.5 Discussing the potential trade-offs associated with ammonia reduction strategies

Trade-offs were filled in first from Newell Price et al. 2011 and Guthrie et al. 2018. Where other studies comment on potential trade-offs of ammonia mitigation strategies, they are noted in the resources column. Resources on existing established relationships in agriculture and sustainability are also noted to support other potential trade-offs identified that are not covered in these air quality-centered works.

Table 1: An overview of proven dairy production interventions including details on emissions reductions, cost of adoption, avoided deaths, and potential tradeoffs with other environmental impacts. Here, we color-code ammonia mitigation strategies based on emissions reduction potential, cost-effectiveness, feasibility, potential trade-offs and co-benefits, and the current SJV regulatory context. The color coding scale for strategies is as follows: green we fully recommend, yellow with some reservation, orange with much reservation, and red we do not recommend as an ammonia mitigation strategy. Baseline number of air quality-related deaths from dairy farming in California: 510 deaths/year. The range of avoided deaths per year corresponds to the range of potential ammonia mitigation. *Alternative cost estimates were provided when cost per kg of ammonia reduced was not available in literature.

CATEGORY	STRATEGY	DESCRIPTION	AMMONIA MITIGATION	COST PER KG OF AMMONIA REDUCED[1]	LIKELY AVOIDED DEATHS PER YEAR	IMPACT TO GHGS	NOTABLE BENEFITS & TRADEOFFS	RESOURCES
Nutrition and Feed Management	Decrease Crude Protein Concentration in Feed	Decrease crude protein concentration of feed	30-50%	-$4 to $4 -$28[2] -$16.8[3]	199 (range: 149-249)	CO_2: ~ CH_4: - N_2O: -	decreased potential for water pollution; strong likelihood of cost savings	EPA/USDA, 2017; EPA Disapproval; Buckley et al. 2020; Zhang et al. 2019
	Group and Phase Feeding	Manage livestock in smaller groups with similar nutritional needs to reduce the amount of excess nitrogen they are fed	15-45%	-$4 to $4	149 (range: 75-223)	CO_2: ~ CH_4: - N_2O: -	decreased potential for water pollution	EPA/USDA, 2017
	Feed Processing and Delivery	Decrease feed particle size to increase nitrogen digestibility and reduce nitrogen excreted in manure	20%	$0.75-1.50 per ton of feed*[4]	99	CO_2: (+/-) CH_4: - N_2O: -	potential to increase digestive disturbances in cattle; potential to lose nutrients as dust	EPA/USDA, 2017 CPM, n.d.
Animal Confinement	Add Straw Bedding to Cattle Housing	Add additional straw to cattle housing, focusing on wetter and dirtier areas of the house	0-50%	-$1 to $2	98 (range: 0-196)	CO_2: + CH_4: ~ N_2O: (-)	reduced potential for water pollution; may require change in animal housing operations; potential unavailability or high costs of straw	Newell Price et al. 2011; Guthrie et al. 2018
	Frequent Manure Scraping	Increase the frequency with which manure is scraped from animal	0-20%	-	13 (range: 0-26)	CO_2: + CH_4: ~ N_2O: +	ammonia emissions are increased at stages post-animal confinement by a small but	Newell Price et al. 2011

[1] Estimates from Guthrie et al. 2018, unless noted otherwise.
[2] Cost estimates from Buckley et al. 2020.
[3] Cost estimates from Zhang et al. 2019.
[4] Cost estimate from CPM n,d.

		housing					non-negligible amount; increased potential for water pollution	
	Oil Spray/ Sprinkling	Sprinkle vegetable oil in animal production areas so that particles that stick to the droplets settle onto the building surfaces	0-30%	-	19 (range: 0-39)	insufficient available information	potential to compete with food oil, increasing global demand (deforestation, human rights violations, etc), increased potential for laborer falls/injuries	EPA/USDA, 2017
Manure Management	Manure & Slurry Storage Covers	Install solid or floating covers on slurry and manure stores	50-95%	$1 to $9 $2[8] $0.30 - $11[9]	192 (range: 132-252)	CO_2: - CH_4: --- N_2O: +	increased potential for water pollution; logistical issues with lagoons and existing storage tanks	EPA/USDA, 2017; EPA n,d.; Buckley et al. 2020
	Acidification of Slurry and Manure	Acidify slurry to address the generation of air emissions by changing the pH of manure to prevent gasses from forming	50-60%	$9 $36[8]	216 (range: 197-236)	CO_2: ~ CH_4: -- N_2O: (+/-)	potential to acidify soils; safety concerns if handling concentrated acids; potential to reduce water pollution	EPA/USDA, 2017; Cao et al. 2020; Sokolov et al. 2021; Buckley et al. 2020
	Solid Liquid Separation	Separate suspended solids from the rest of the slurry	0-10%	-	13 (range: 0-26)	CO_2: + CH_4: ~ N_2O: (-/+)	decreased potential for water pollution; new equipment investment costs; a SJV mitigation measure for dairy CAFs	EPA/USDA, 2017; SJVAPCD, 2019
	On-Farm Composting	Compost solid manure on farm	-10-10%	-	0 (range: -26-26)	CO_2: + CH_4: + N_2O: (-/+)	decreased potential for water pollution	EPA/USDA, 2017
Land Application	Injection	Inject slurry into the soil	70-90%	-$1 to $3	77 (range: 67-87)	CO_2: + CH_4: ~ N_2O: (+)	new machine investment cost; increased potential for water pollution; already a dairy CAF recommended mitigation measure in the SJV	EPA/USDA, 2017; SJVAPCD, 2019
	Incorporation	Incorporate manure into the soil using plows, discs, or tines	20-90%	-$1 to $4	53 (range: 19-87)	CO_2: ~ CH_4: ~ N_2O: (+)	potential to decrease crop yields; increased potential for water pollution	EPA/USDA, 2017
	Banding	Apply slurry in a series of narrow bands to the land	30-40%	-$1 to $3	34 (range: 29-39)	CO_2: + CH_4: ~ N_2O: (+)	potential to increase labor; new machine investment costs; increased potential for water pollution	EPA/USDA, 2017

	Timing of Land Application	Immediate incorporation of manure (within a few minutes - 70-90%), or within 4 hours (45-65%)	45-90%	$1 to $4	65 (range: 43-87)	CO_2: ~ CH_4: ~ N_2O: (+)	increased need for labor; logistics challenges with application timing; increased potential for water pollution	EPA/USDA, 2017
Other	Tree shelter belts	Plant tree shelter belts around slurry storage and animal housing facilities	0-10%	-	25 (range: 0-50)	CO_2: ~ CH_4: ~ N_2O: ~	years to grow tall, dense shelter; loss of farmland area; already a CMP recommended by the SJVAPCD	Newell Price et al. 2011; Guthrie et al. 2018; SJVAPCD, 2004
	Improved Livestock Genetics	Stock dairy cows with improved production efficiency and health attributes	0-10%	-	25 (range: 0-50)	CO_2: ~ CH_4: - N_2O: -	decreased potential for water pollution	Newell Price et al. 2011

Table Key (Impact to GHGs):

Change in GHGs	Negligible (~)	Low (- or +)	Moderate (-- or ++)	High (--- or +++)
Average Percent	0	10	40	70
Range Percent	0	1 to 30	20 to 80	50 to 90

Uncertainty is denoted by parenthesis. Studies that have shown both positive and negative results are shown by (-/+) notation.

3. Discussion of proven emission mitigation strategies

It is important to note that this analysis is limited to measures that have already been successfully implemented in dairy operations, and that it is likely that emerging ammonia mitigation strategies or those that have been demonstrated in other types of animal agricultural operations could have even greater ammonia mitigation potential.

Nutrition and Feed Management

Of the different types of interventions, feed-based interventions such as group and phase feeding, use of feed additives, decreasing the size of food particles, and changing feed formulation are the most certain to result in overall reductions of ammonia emissions as they reduce the amount of ammonia produced in manure, thereby reducing ammonia emissions in all following waste management stages (e.g., animal confinement, manure handling and storage, land application). In addition, feed-based interventions have also been identified to be among the most cost-effective and have higher likelihood of uptake than other types of interventions (Guthrie et al., 2018).

Adopting diets with lower crude protein concentrations is estimated to reduce ammonia emissions by 30-50%. Improving nitrogen efficiency by switching to diets with lower crude protein concentrations is modeled to avoid 199 deaths in California every year. This improved feed efficiency will also reduce the potential for water pollution and greenhouse gas emissions. While some caution that adopting diets with lower crude protein concentrations will have negative impacts on milk yields, many studies have shown that reducing excess crude protein in dairy feeds can reduce nitrogen excretion while maintaining milk yields, increasing overall N efficiency (Colmenero & Broderick, 2006; Guimarães et al., 2018; Katongole & Yan, 2020). Older works estimating the abatement costs of this strategy find low, but positive abatement costs. In contrast, more recent works on this topic find significant cost savings with the implementation of this strategy with savings ranging from $4 to $28 per kilogram of abated ammonia (Guthrie et al. 2018; Zhang et al. 2019; Buckley et al. 2020). The San Joaquin Valley Air Pollution Control District already recommends limiting the crude protein concentrations in swine feed as a mitigation measure, highlighting the feasibility for a regulated limit on the crude protein concentration in dairy feed (SJVAPCD, 2019b). Adopting diets with lower crude protein concentrations is likely to lead to cost-savings for farmers, reduced GHG emissions, reduced water pollution, and avoid a large number of deaths, resulting in the strategy receiving a green rating.

Group and phase feeding is estimated to reduce ammonia emissions by 15-45%. Through this strategy, livestock with similar nutritional needs are grouped and fed together to reduce the amount of surplus nitrogen fed to livestock, reducing the amount of ammonia in manure. This strategy is modeled to avoid 149 deaths in California per year. Dairies are often grouped together by milk yields, so implementing this strategy is practical (Newell Price et al. 2011). This strategy is already an established practice in many farms across the United Kingdom, in some dairies and most poultry operations (Newell Price et al. 2011). The costs associated with the adoption of group and phase feeding are low, with some estimates suggesting that the adoption of this strategy would save farmers money (Guthrie et al. 2018). This strategy would also likely reduce water pollution, as well as nitrous oxide and methane emissions. Because of the significant ammonia reductions, potential to decrease water and climate pollution, and the established nature of this strategy, it is coded as green in Table 1.

Improving feed processing and delivery by decreasing feed particle size to increase nitrogen digestibility, and thus reduce the amount of nitrogen excreted in manure, is estimated to reduce ammonia emissions by 20% and is modeled to avoid 99 deaths in California, annually. This strategy is estimated to cost $0.75-1.50 on maintenance and energy per ton of feed (CPM, n,d.). This strategy is associated with small reductions in GHG emissions, but has the potential to increase digestive disturbances, such as bloat, in cattle, and the potential to increase dust (EPA/USDA, 2017). Because of this, we code this strategy as yellow.

Animal Confinement

Adding straw bedding to cattle housing is estimated to reduce ammonia emissions from housing by 0-50%, and is modeled to avoid around 98 deaths in California per year. Adding more straw to cattle housing, in particular in wetter and dirtier areas of the house, can help create a physical barrier between urine and the air and facilitate the immobilization of readily available nitrogen (Newell Price et al. 2011). Additionally, the added volume from the straw will increase the total amount of farmyard manure produced (Newell Price et al. 2011). This strategy is likely to increase CO_2 emissions and have an uncertain impact on nitrous oxide emissions, but reduce the potential for water pollution. This strategy might require a change in animal housing, making it less feasible. If straw is expensive or unavailable, this strategy will be difficult to adopt. If appropriate animal housing already exists, and straw is inexpensive and available, this strategy is likely to be one of the more cost effective, ranging from a cost savings of $1 to a $2 expense per kilogram of ammonia reduced. Because of these potential logistical difficulties and the trade-offs between other dimensions of environmental wellbeing, we assign this strategy an orange ranking.

Frequent manure scraping is estimated to reduce ammonia emissions from animal housing by up to 20%, and is modeled to avoid 13 deaths in California each year. This strategy is likely to increase CO_2 and N_2O emissions by a small amount due to increases in energy consumption and the increase in reactive nitrogen in the slurry. This increase in reactive nitrogen will also likely lead to increased water pollution and ammonia emissions from the post-animal confinement stages of the dairy production life cycle. Because of the small potential to reduce ammonia emissions, the extra energy and labor required to scrape more frequently, and the increases in greenhouse gas emissions, we code this strategy as orange. (Newell Price et al. 2011)

Vegetable oil spray/sprinkling is estimated to reduce ammonia emissions from housing between 0-30%, and avoid 19 deaths in California, annually. This ammonia mitigation strategy uses vegetable oil, which is also often used as a food product, in particular a food product associated with global trade and deforestation (Pendrill et al. 2019). The connections between deforestation, increased GHG emissions, human rights violations, and the loss of land tenure for Indigenous people and women is well-known (Walker et al., 2020; FAO & FILAC, 2021). Because of these relationships, we do not recommend this strategy and code it red in this analysis. Additionally, we caution that this strategy is used predominantly in swine buildings, and may not be a suitable strategy to mitigate ammonia emissions in the SJV dairy production context (Iowa State University Extension, 2014).

Manure Management

The installation of manure storage covers are estimated to reduce methane emissions from manure management by 50-95%, and modeled to avoid 192 deaths in California per year. The adoption of manure storage covers is likely to be one of the more inexpensive ammonia mitigation strategies, with costs ranging from $0.30 - $9 per kilogram of ammonia reduced, and annual dairy farm costs estimated to be around $1500 a year. This strategy is likely to reduce methane emissions, but has the potential to slightly increase water pollution as less N will have volatilized, and has increased likelihood of ending up in waterways (Newell Price et al. 2011). Covering manure with semi-permeable covers, or natural or induced crusts is a recommended practice by the EPA to reduce methane emissions from livestock manure, and they estimate that this will lead to an 80% relative reduction in methane emissions (EPA, n,d.). N_2O emissions may also slightly increase (Newell Price et al 2011), though one study suggests that such trade-offs may be minimized through the use of straw covers (which are less effective at reducing NH_3 emissions) (Kupper et al. 2020). Slurry storage facilities are mandated by regulation to be covered in the Netherlands and Denmark (Guthrie et al. 2018). A survey on 2010 EU member states' agricultural production methods of farms found that all solid manure storage facilities in Belgium, Denmark, and Slovakia as well as their liquid manure storage facilities, are covered. Additionally, the survey found that 69% of slurry manure storage facilities and 87% of liquid manure storage facilities were covered (EuroStat, 2016). These high adoption rates highlight the feasibility of this ammonia mitigation method. Because of the significant reductions in ammonia emissions, high feasibility, significant relative reductions in methane emissions, and low cost we code this strategy as green in Table 1.

The acidification of slurry and manure is estimated to reduce ammonia emissions from manure management by 50-60%. Adding additives such as phosphoric acid (H_3PO_4), hydrogen sulfide (H2S), and sulfuric acid (H_2SO_4) to slurry and manure is modeled to avoid approximately 216 deaths in California per year. The European Union (EU) has set a limit for ammonia emissions, and to comply with its limit, Denmark has included the acidification of stored slurry as a method to reduce its ammonia emissions (European Commission; 2016; Sommer & Knudsen, 2021). As a result, about 20% of slurry in Denmark is now acidified before application, highlighting this strategy's feasibility (Kelly-Edwards, 2018). The estimated costs of this intervention range from $9-36 per kilogram of ammonia reduction, making it one of the more expensive strategies. Handling concentrated acids poses safety concerns for farm workers. While this strategy has the potential to significantly reduce methane emissions, it is likely to have mixed effects on nitrous oxide emissions, and has the potential to acidify the soils the manure is applied to. A review from 2015 highlights the widespread adoption of slurry acidification, but also highlights the need for more research on the long-term impacts on soil (Fangueiro et al., 2015). More recent work from the UK on the application of acidified slurry to croplands found limited medium and long term impacts on soil acidification, as well as reduced ammonia emissions without increasing nitrate concentrations or nitrous oxide emissions (Langley, 2022). While emerging research is hopeful, because of the relative scarcity of the study of the water and climate impacts, as well as the potential safety concerns and high cost, we code this strategy yellow in Table 1.

Solid liquid separation is estimated to reduce ammonia emissions from manure management by 0-10%, and is modeled to avoid 13 deaths in California each year. This strategy is already recommended as a liquid manure mitigation measure in the dairy operations by the SJV Air Pollution Control District (SJVAPCD, 2019a). Solid liquid separation would likely have mixed effects on nitrous oxide emissions and increase CO_2 emissions, but would likely decrease water pollution. Separate suspended solids from the rest of the slurry would require investments in new equipment, and would likely require changes in farm infrastructure. Because of the low potential to mitigate ammonia emissions, and potential to increase CO_2 and N_2O emissions, we do not recommend this strategy to reduce ammonia emissions, and code it as orange.

Composting solid manure on-farm is estimated to have the potential to decrease ammonia emissions from manure management by 10%, or increase ammonia emissions by 10%. Additionally, this strategy is associated with increases in carbon dioxide and methane emissions. While this strategy has the potential to decrease water pollution, we do not recommend this strategy be implemented as an ammonia mitigation strategy as it has the potential to increase ammonia emissions, and code it red in Table 1. Quickly and properly transporting manure to off-farm, state-of-the-art, well-managed, compost facilities that capture emissions could help mitigate the climate and public health concerns associated with on-farm manure composting.

Land Application

There are numerous ways to apply slurry to land. Broadcast application of slurry is the default to which band application, incorporation, and injection are compared in this review. As only one of these methods would likely be adopted as a mitigation method at each farm, we recommend injection as it has the highest average ammonia mitigation potential, and is modeled to avoid the largest number of deaths (avoiding 77 deaths in California, annually), and is not likely to decrease crop yields unlike incorporation. Some studies have shown that injecting slurry into the soil can increase N_2O emissions, however, such emissions may be reduced by adding nitrification inhibitors such as 3,4-dimethylpyrazole phosphate or dicyandiamide (Chadwick et al., 2011). Injection is already a recommended land application mitigation measure for dairy concentrated animal feeding operations in the SJV (SJVAPCD, 2006). For these reasons, we code injection as green, and incorporation and banding as yellow in Table 1.

Incorporating manure immediately (within a few minutes of excretion) is shown to mitigate ammonia emissions from land application by 70-90%, while incorporation within four hours of excretion is shown to mitigate ammonia emissions by 45-65% (Guthrie et al. 2018). In the UK in regions where required by law, the uptake was only moderate to high (Newell Price et al., 2011). The increased labor and logistical planning of application timing make this strategy largely infeasible in dairy operations where manure is being flushed frequently, a manure management practice common in the San Joaquin Valley. This strategy is also associated with increased potential for water pollution. Due to these reasons, we code this strategy as yellow.

Other
Planting tree shelter belts around slurry storage and animal housing facilities is estimated to reduce ammonia emissions by 10%, and to avoid 25 deaths in California, annually. The potential for water pollution is also likely to be reduced. Notable trade-offs associated with this strategy include the loss of farmland available for cultivation, and the large amount of time needed to grow tall, dense shelter (Newell Price et al., 2011). This strategy is already recommended to dairy and cattle farmers in the SJV through the Conservation Management Practices Program, thus it is likely the San Joaquin Valley Air Pollution Control District has deemed this strategy feasible. Despite the low ammonia mitigation ranges associated with this strategy, we code it here as green, as it is already a recommended conservation practice, and is associated with many other benefits.

Farmers stocking animals with improved genetic resources is modeled to reduce ammonia emissions by 0-10%, and avoid 25 deaths in California each year. Increased focus on breeding programs that prioritize heritable traits like health, fertility, and reduced residual feed intake can help increase the efficiency and longevity of dairy cows. Stocking cows with improved health, fertility, and production efficiency characteristics is likely to lead to reductions in GHG emissions and water pollution, as well as significant reductions in farmer costs. This strategy is feasible, as farmers generally select for breeds they perceive to be better (Newell Price et al. 2011). There is movement in the livestock genetics space to adopt genetically modified cows that reduce emissions. It is important to note that these types of interventions have trade-offs with social and economic aspects of sustainability like ethical concerns of patents on life, and regulations around breed requirements transferring wealth to large agricultural corporations, and the potential to further consolidation in agriculture. Because of these potential concerns, we code this strategy as orange in Table 1.

4. Discussion of promising emission mitigation strategies

Table 2: An overview of promising dairy production interventions. Here, we highlight strategies to reduce ammonia emissions that have been successfully implemented in other livestock production systems, and emerging ammonia reduction strategies in dairy production. Because these strategies are less established, we do not provide separate discussion of costs, lives saved, GHG impacts, and tradeoffs.

STRATEGY	DESCRIPTION	DISCUSSION OVERVIEW	RESOURCES
Biofilters & Bioscrubbers	Install an air filtration system that channels the pollutant-laden air to a biofilter where microorganisms break down the pollutants.	EPA/USDA Reference Guide estimates that 45-75% reductions in ammonia emissions at the confinement and manure management stages are possible in livestock production. Requires enclosed systems which would use energy to cool animal housing. To our knowledge, these have not been used in farm-scale dairy production to date. N2O emissions and water pollution are potential drawbacks of this strategy.	EPA/USDA, 2017
Wet Scrubbers	Install wet scrubbers that use either water droplets or chemical (e.g., acidic) droplets to capture	EPA/USDA Reference Guide estimates that 70-90% reduction in ammonia emissions from animal confinement are possible in livestock production systems. Requires enclosed systems that would	EPA/USDA, 2017

	pollutants.	require energy.	
Feed Additives	Commercial blends of essential oils are added to feed to reduce NH_3, though the exact mechanism that results in NH_3 reductions is not established	EPA/USDA Reference Guide estimates that 20-70% reductions in ammonia emissions are possible. limited commercially available options; uncertainty in how this strategy would impact water pollution, climate.	EPA/USDA, 2017

The EPA/USDA Reference Guide estimates that 45-75% reductions in ammonia emissions at the confinement and manure management stages are possible in livestock production with the adoption of biofilters. Morral et al. 2019 reviews biotechnologies, including biofilters and bioscrubbers, used to mitigate ammonia emissions. Field-scale studies in Germany found that bioscrubbers treating exhaust air from swine houses had an overall ammonia removal efficiency of 79% (Liu et al. 2016). Two-series connected bioscrubbers have also been used in German swine production to remove ammonia (up to 86%) and methane (up to 35% overall average removal) (Liu et al. 2017). To our knowledge, this technology has not been used to date in dairy production contexts, but the success in field-scale swine operations highlights the potential of this technology in enclosed dairy production systems.

The EPA/USDA Reference Guide estimates that 70-90% reduction in ammonia emissions from animal confinement are possible in livestock production systems with the adoption of wet scrubbers. Wet scrubbers used in deep-pit swine systems across the four seasons ranged from 76-97% ammonia removal efficiencies, while scrubbers used in poultry manure management systems ranged from 63-80% (Ohio State, 2013). To our knowledge, this technology has not been used to date in dairy production contexts, but the success in field-scale swine operations, and poultry manure management highlights the potential of this technology in enclosed dairy production systems.

Feed additives are estimated to reduce ammonia emissions by 20-70%, which has a greater potential to mitigate ammonia emissions of any of the reviewed proven strategies. There are a limited number of commercially available feed additives, and these additives are generally composed of a blend of essential oils. The exact mechanism through which essential oil blends reduce NH_3 is not well-established, though some experts believe that hyper-NH_3-producing bacteria may be sensitive to essential oils or that essential oils are improving nutrient efficiency (Carrazco et al., 2020). The impacts on GHG emissions are likely to be negligible, or result in small methane emission reductions, although this relationship is not well-established. Though this emerging strategy has a higher average ammonia reduction than many of the proven strategies shown in Table 1, it does not have the same established research and farm-scale evidence base that other feed management strategies do.

5. Other Considerations

Thinking into the future

Regulations to mitigate ammonia emissions should also require new farm infrastructure (like new animal housing facilities and manure storage systems) to meet more stringent, low-ammonia emission criteria. More strict regulations that apply to new-build farm infrastructure is already the regulatory approach taken for ammonia emissions in the Netherlands (Guthrie et al. 2018).

Additionally, to help ensure that ammonia reduction targets are met, government support is also needed to adopt best practices and technologies. Existing frameworks to have social support to meet adopted regulations can help inform new support programs in the SJV. One such framework is the "peer-to-peer" farmer network for support to share knowledge, and this framework also has financial incentives to support the adoption of new technologies to mitigate ammonia emissions (Guthrie et al. 2018).

Trade-offs with GHG mitigation technologies

State-level goals to reduce greenhouse gas emissions have helped popularize digesters to help reduce methane emissions (CA Climate Crisis Act, 2022; CARB, n,d.; CA Global Warming Solutions Act, 2006). The potential for digesters to increase ammonia emissions is well known. The EPA/USDA Reference Guide gives a range of -50 to 30% reductions of ammonia emissions for anaerobic digesters. Holly et al. 2017 found that while anaerobic digesters reduced methane emissions, they also resulted in over an 80% increase in ammonia emissions from waste storage (Holly et al. 2017). While there are different types of digester technologies, this is a significant trade-off, and we recommend a precautionary approach to ensure that GHG reductions do not significantly increase air-quality related deaths. Slowing the adoption of anaerobic digesters, and diversifying the state's approach to reduce methane--and agricultural GHGs more broadly--is recommended. In particular, we recommend focusing on strategies that reduce feed inefficiencies in the first place, like improved feeding strategies and selecting for livestock breeds with better health, fertility, and feed efficiencies.

6. Conclusion

Modeling suggests ammonia emissions from California agriculture are responsible for almost 1,700 deaths every year. In California, about 30% of air quality-related health impacts from agriculture can be attributed to direct emissions from waste management of dairies, many of which are located in the SJV. Analyses show that the monetary value of the social benefits of reducing ammonia emissions are far greater than the costs of abating them (Giannakis et al. 2019; Zhang et al. 2020). Regulation of ammonia emissions across all member states of the European Union, and farm surveys that show high adoption rates of strategies to mitigate ammonia across different production contexts illustrate the feasibility of mitigating ammonia emissions.

Here, among strategies that have been broadly implemented in dairies, we fully recommend 5 ammonia mitigation strategies: decreasing crude protein concentrations in feed; group and phase feeding; slurry and manure storage covers; injection; and tree shelter belts. These 5 strategies can all be adopted together to reduce ammonia emissions at numerous stages of the dairy production life cycle.

There are 5 demonstrated ammonia mitigation strategies that we recommend with some reservation (see the discussion section for more detail): decreasing feed particle size; acidification of slurry and manure; incorporation; banding; and timing of land application. All of these except incorporation and banding could be adopted in addition to the 5 ammonia strategies that we recommend without reservation. In the event that injection is not ultimately required by regulation, we recommend that incorporation or banding is required to replace traditional broadcasting land application methods.

There are 3 strategies that we recommend with much reservation: adding straw bedding to cattle housing; solid liquid separation; and improved livestock genetics. We recommend that farmers do look to adopt dairy cows with improved health, fertility, and feed efficiencies, but that regulatory bodies also consider the social and economic aspects of sustainability associated with regulating genetics.

We do not recommend oil spray/sprinkling or composting as ammonia mitigation strategies because of the small potential to decrease ammonia emissions, and the trade-offs associated with their adoption.

We also recommend giving consideration to strategies that have been demonstrated to be effective in other livestock production systems that utilize enclosed animal housing and manure management systems, such as biofilters and wet scrubbers, and to emerging ammonia mitigation strategies, such as feed additives.

Because nutrition and feed management strategies have the potential to affect ammonia emissions at every stage of the dairy production life cycle, regulations should focus on feed. While there is a lack of research on how adopting multiple strategies at once will impact ammonia emission reductions, implementing even one of these strategies could reduce total dairy lifecycle ammonia emissions by more than 33% on average. Stacking additional mitigation strategies onto one or more feed management strategies will have additional ammonia reductions, and has the potential to avoid more premature deaths.

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Zhang, X., Gu, B., van Grinsven, H., Lam, S. K., Liang, X., Bai, M., & Chen, D. (2020). Societal benefits of halving agricultural ammonia emissions in China far exceed the abatement costs. *Nature communications*, *11*(1), 4357. https://doi.org/10.1038/s41467-020-18196-z

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Exhibit B

NINA GABRIELLE G. DOMINGO, PhD

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EDUCATION

Ph.D. Bioproducts & Biosystems, Science, Engineering & Management
Minor in Science, Technology, and Environmental Policy
University of Minnesota – Twin Cities
Dissertation: Air quality-related health impacts of food
B.S. Industrial & Systems Engineering, *with Distinction*
University of Minnesota – Twin Cities

WORK EXPERIENCE

Research Scientist **2022 – present**
Amazon, Sustainability Science and Innovation
Sustainability Consultant **2021 – 2022**
TASA Analytics
Clients: Microsoft, MN Metropolitan Council
Postdoctoral Researcher **2021 – 2022**
Yale University, Center on Climate Change and Human Health
Postdoctoral Researcher **2021**
University of Minnesota – Twin Cities, Department of Bioproducts & Biosystems Engineering
Summer Research Associate **2020**
Chicago Council on Global Affairs, Center on Global Food and Agriculture
Graduate Research Assistant **2017 – 2021**
Department of Bioproducts & Biosystems Engineering, University of Minnesota – Twin Cities

RESEARCH PUBLICATIONS

S. Balasubramanian, **N. Domingo**, N. Hunt, M. Gittlin, K. Colgan, J. Marshall, A. Robinson, I. Azevedo, S. Thakrar, M. Clark, C. Tessum, P. Adams, S. Pandis, J. Hill. The food we eat, the air we breathe: A review of the fine particulate matter-induced air quality health impacts of the global food system. Accepted in Environmental Research Letters.

N. Domingo, S. Balasubramanian, S. Thakrar, M. Clark, P. J. Adams, J.D. Marshall, N. Muller, S. Pandis, S. Polasky, A. L. Robinson, C.W. Tessum, D. Tilman, P. Tschofen, J.D. Hill. Air quality-related health impacts of food. Proc. Natl. Acad. Sci. U.S.A. 118 (20) e2013637118.

M. Clark, **N. Domingo**, K. Colgan, S. Thakrar, D. Tilman, J. Lynch, I. Azevedo, J.D. Hill. 2020. Global food system emissions could preclude achieving the 1.5°C and 2°C climate change targets. Science. 370: 705-708.

LEADERSHIP AND OUTREACH

Board Member **2021 – present**
Twin Cities Food Justice
Graduate Cohort Co-founder and Leader **2020 – 2021**
IonE, University of Minnesota
Climate Lead **2019 – 2021**
Global Shapers (World Economic Forum)

Exhibit C

Kimberly Colgan

Seattle, WA 98115 colga005@umn.edu

EDUCATION

Doctor of Philosophy in Bioproducts and Biosystems, Science, Engineering & Management
University of Minnesota-Twin Cities — AUGUST 2022
Minor in Applied Economics. Emphasis in Science, Technology, and Environmental Policy.
Wilcke Graduate Fellow.

Bachelor of Science in Industrial Engineering — MAY 2017
University of Minnesota-Twin Cities
Minor in Environmental Sciences, Policy, and Management.

RESEARCH & WORK EXPERIENCE

Greenhouse Gas Engineer — **February 2023 - PRESENT**
Air Quality Program — WASHINGTON STATE DEPARTMENT OF ECOLOGY

Researcher — **September 2022 - December 2022**
Bioproducts and Biosystems Engineering Department — UNIVERSITY OF MINNESOTA

Graduate Teaching Instructor — **Summer 2022**
Bioproducts and Biosystems Engineering Department — UNIVERSITY OF MINNESOTA

Graduate Teaching & Research Assistant — **September 2017–August 2022**
Bioproducts and Biosystems Engineering Department — UNIVERSITY OF MINNESOTA

Virtual Student Federal Service (VSFS) eIntern — **September 2020–May 2021**
Bureau of Development, Democracy, and Innovation — USAID

PUBLICATIONS

Global food system emissions could preclude achieving the 1.5°C and 2°C climate change targets M. Clark, N. Domingo , **K. Colgan**, S. Thakrar, D. Tilman, J. Lynch, I. Azevedo, J. Hill.
Science 2020 - DOI: 10.1126/science.aba7357

The food we eat, the air we breathe: a review of the fine particulate matter-induced air quality health impacts of the global food system S. Balasubramanian, N. Domingo, N. Hunt, M. Gittlin, **K. Colgan**, J. Marshall, A. Robinson, I. Azevedo, S. Thakrar, M. Clark, C. Tessum, P. Adams, S. Pandis and J. Hill
Environmental Research Letters 2021 - DOI: 10.1088/1748-9326/ac065f

GUEST LECTURES

Climate Change Policy — SPRING 2019, 2020, 2021, & 2022
Natural Resource Consumption and Sustainability - ESPM 3607 — UMN-TC

Food Systems, Sustainable Development Goals, Climate, & COVID-19 — SPRING 2020
COVID-19 & the UN SDGs: Resilience, Connections, & Threats - SUST 3480/5480 — UMN-Morris

Industrial Ecology — SPRING 2019
Natural Resource Consumption and Sustainability - ESPM 3607 — UMN-TC

CONFERENCES & PROFESSIONAL ENGAGEMENT

Institute on the Environment Renewable Energy Cohort - Member FALL 2021–SPRING 2022
University of Minnesota

Food Systems Challenge: Innovation Retreat - Student Representative NOVEMBER 2021
Nisswa, MN

Sustainable Energy Opportunities in the Food System Workshop - Participant JULY 2020
National Renewable Energy Laboratory & Colorado State University

UMN Global Convergence Laboratory 2019 - Member JANUARY 2019
Puerto Rico

United Nations Climate Change Conference (COP24) - UMN Delegate DECEMBER 2018
Katowice, Poland

Borlaug Summer Institute on Global Food Security - Participant SUMMER 2018
Purdue University

FELLOWSHIPS & AWARDS

Best Overall Poster & Presenter - NSF-USDA INFEWS PI Workshop FEBRUARY 2022
Won Best Overall Poster & Presenter with Dr. Natalie Hunt in the Early Career Poster Session at the National Science Foundation - United States Department of Agriculture *Innovations at the Nexus of Food, Energy and Water Systems* Principal Investigator Workshop

Second Place in Ecology & Environment - AAAS Annual Meeting FEBRUARY 2021
Graduate Student Eposter Competition at the American Association for the Advancement of Science Annual Meeting 2020–2021

Wilcke Fellow FALL 2019–SUMMER 2021
Sustainable Agriculture Fellowship awarded by the Bioproducts and Biosystems Engineering Department at the University of Minnesota

Markhart Scholar SPRING 2016
Sustainable Agriculture Fellowship awarded by the Department of Horticultural Science at the University of Minnesota

SERVICE & VOLUNTEER WORK

Undergraduate Mentor - College of Science and Engineering FALL 2018–PRESENT
Member - American Academy for the Advancement of Science FALL 2019–PRESENT
Plant-Rich Diet Team Lead - MN350 SPRING 2021–SUMMER 2022
Food Systems Team Volunteer - MN350 SUMMER 2020–SUMMER 2022
Student Advisory Committee - Future Campus Dining Task Force FALL 2019–SPRING 2022
Environmental Policy Expert - Minneapolis Political Campaigns SPRING 2021–WINTER 2021
Department Representative - Council of Graduate Students FALL 2020–SPRING 2021
Alt. Department Representative - Graduate Student Board FALL 2020–SPRING 2021