PSE

Methane + Health Initiative

Methane Risk Map

Product Guide

Version | **2025.08.26**

Release Date | **August 26, 2025**

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Introduction

PSE Healthy Energy ("PSE") is an independent scientific research institute that specializes in bringing science to energy policy. Our mission is to generate energy and climate solutions that protect public health and the environment. At PSE, we design our research around real-world challenges and proactively connect our audiences with actionable, evidence-based information they can trust.

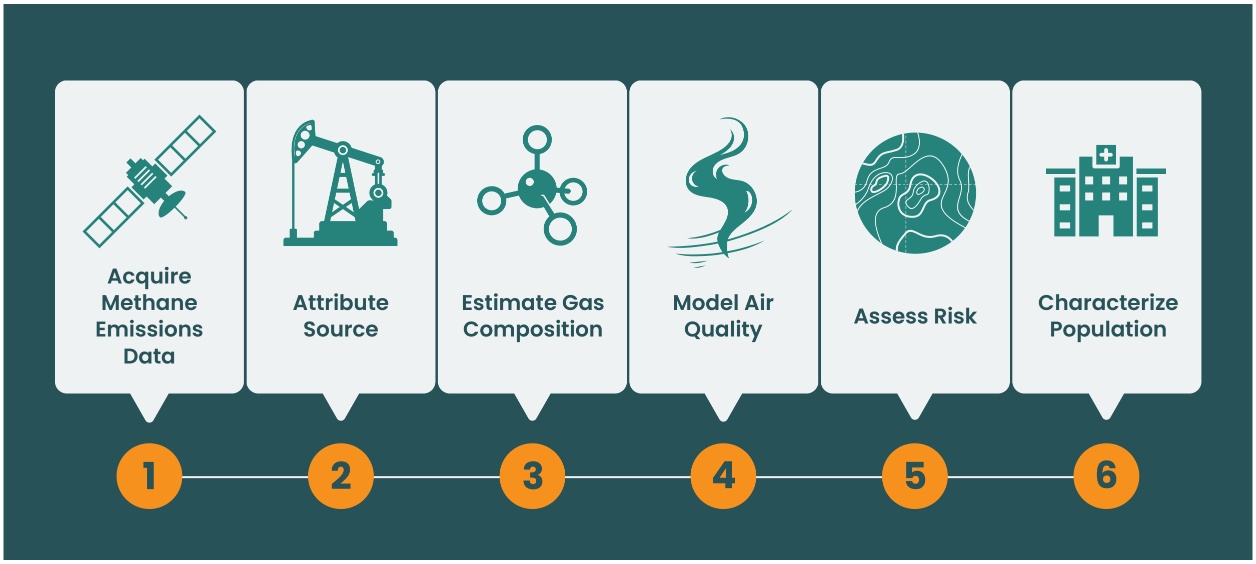
The Methane Risk Map ("MRM") is designed to illuminate a previously overlooked source of air pollution: non-combustion emissions from oil and gas facilities. In this context, non-combustion means that the gas was not burned before being released, including leaks or other inadvertent releases ('fugitive emissions') and routine industrial processes. Research has demonstrated that benzene and other hazardous air pollutants (HAPs) are present in natural gas across the oil and gas supply chain—including production[1], transmission[2], and end-use[3]—indicating that these non-combustion emissions may also degrade local air quality. Recent advances[4] in methane-sensing technology have allowed scientists, regulators, and other stakeholders to detect and quantify major non-combustion emissions since methane is the primary constituent of natural gas. While measuring methane emissions captures the climate impact of these emissions, the methane-linked HAP emissions remain unquantified, leaving a critical knowledge gap around their air quality impacts and public health risks. Furthermore, high concentrations of methane pose fire and explosion risk[5], which is not fully captured by emissions.

The MRM illuminates the impacts of the methane emissions events by leveraging our gas composition database, emissions data captured by satellite and aircraft-mounted methane-sensing technology, and regulatory-grade air quality modeling. By mapping the estimated concentrations of methane and methane-linked HAPs, the MRM estimates where these pollutants may exceed government-recommended limits and pose public health and safety hazards. For each event, the MRM characterizes nearby populations and sensitive facilities like childcare centers by overlaying Census and public health data.

Methods Summary

The MRM uses satellite and aircraft measurements of U.S. oil and gas methane emissions events alongside estimated gas composition data and dispersion modeling to estimate the potential safety and health risks of methane emissions events.

First, we access satellite and aircraft data on methane emissions events, extracting details on emissions rates and locations. Then, we use a unique statistical model to estimate the emissions rates of key HAPS, taking into account factors including gas type, geological basin, industry segment, associated equipment, and local gas composition data. We then use these emissions rates in a regulatory-grade Gaussian dispersion model to estimate the outdoor event-specific air concentrations of methane and hazardous air pollutants. We compare modeled air concentrations to national- and state-based benchmarks to evaluate both the short-term (acute) safety risk of methane and the short-term health risk of the emitted HAPS. Finally, our tool summarizes the characteristics of the residents and locations of childcare centers, schools, hospitals, nursing homes, and prisons within the areas of elevated health risks from each event.



How to Cite

PSE Healthy Energy (2025, August 26). Methane Risk Map. mrm.psehealthyenergy.org

Share how you are using the tool or get in touch for support using the data. Email a PSE scientist at: mrm@psehealthyenergy.org.

Release Notes

Version Name	Date	Important Features
2025.08.26	August 26th, 2025	Initial MRM release; includes upstream facilities. Gas composition modeling follows the methods of Rowland et al. 2025 and air quality modeling follows the methods of Bisogno et al. 2025.

- **Version 2025.08.26**
  - Data Collection:
    - Methane emissions data observed by Carbon Mapper January 1, 2016, to March 27, 2025 and retrieved from https://data.carbonmapper.org (Accessed 27 March 2025).
    - For the manuscript case studies[6], methane emissions data from both peer-reviewed literature and Carbon Mapper.
  - Inclusion Criteria:
    - Events attributed to oil and gas facilities by Carbon Mapper.
    - Events attributed to unambiguous onshore upstream oil and gas facilities by PSE
    - Contiguous US
  - Exclusion Criteria:
    - Events from basins not included in our gas composition database or state regulatory estimates at time of release.
      - Current models are unable to estimate gas composition for such sources.
    - Events with no visible infrastructure within 10 meters and visible flash-gas related infrastructure within 10 to 50 meters (aircraft only)
      - These events have increased uncertainty around the assignment of gas type due to nearby infrastructure (see Source Attribution).

Glossary

Acute Health Benchmark	The concentration of a pollutant, below which, if a person is exposed for an hour, no adverse health effects are anticipated.
Benzene	Hazardous air pollutant that occurs naturally in oil and natural gas. Acute inhalation exposure can cause headaches, dizziness, and irritation of the eyes, skin and respiratory tract. Chronic exposure can cause disorders in the blood. Classified by the US EPA as a human carcinogen (US EPA, 2016).
BTEX	Benzene, toluene, ethylbenzene, xylenes; these compounds are hazardous air pollutants and often co-occur in fossil fuels and combustion of fossil fuels.
Census Block	The smallest geographical unit for which the census collects data. It is bounded by visible features such as roads, streams, and railroad tracks, and by nonvisible boundaries such as property lines, city, township, school district, county limits and short line-of-sight extensions of roads.
Combustion Emissions	Emissions released from burning of material, e.g., burning natural gas for fuel. Combustion emissions are distinguished from non-combustion because burning material will chemically transform it.
Emissions rate	Unit describes the amount of a material released over time. Within MRM, kg/hour is used.
Ethylbenzene	Hazardous air pollutant that occurs naturally in oil and natural gas. Acute exposure causes respiratory and neurological effects (US EPA, 2016).
Flash Gas	Upstream gas emissions originating from liquid storage tanks and/or from liquid sources due to a reduction in pressure or increase in temperature.
Gas Type	Category of gas to characterize the gas source and composition. Can be flash or non-flash.
GC Tier	The degree of confidence in the gas composition, represented by one of three tiers (T1, T2, T3), where T1 represents the highest degree of confidence. T1 uses a representative speciated gas analysis from the same facility. T2 uses localized modeled gas composition. T3 uses broad modeled composition and regulatory speciation profiles.

Geometric Centroids	The spatial center of the relevant geographic boundaries
Hazardous Air Pollutants (HAPs)	Pollutants designated by the US Environmental Protection Agency that are known or suspected to cause cancer or other serious health effects, such as reproductive effects or birth defects, or adverse environmental effects.
Health Benchmark	The concentration of a health-damaging pollutant below which no adverse human health effects are anticipated; unique for each pollutant.
Health/Safety Risk	Exceedance of an associated benchmark, indicating an increased likelihood of an adverse health or safety outcome.
Health/Safety Risk Area	The area within the risk boundary, representing where modeled peak concentrations exceeded the health or safety benchmark.
Hexane	Hazardous air pollutant that occurs naturally in oil and natural gas. Acute inhalation exposure causes mild central nervous system effects. Chronic exposure is associated with polyneuropathy (US EPA, 2016).
Infrastructure	Refers to physical components (i.e. equipment) of oil and gas facilities that have the potential to emit fugitive methane emissions. This includes oil and gas wells, storage tanks, flare stacks, compressors, separators, and pipelines.
Methane	Greenhouse gas whose global warming potential is 84-87x that of carbon dioxide, on a 20-year timeframe. Primary constituent of natural gas.
Methane Emissions Event	Release of methane from a source at a specific moment in time.
Non-combustion Emissions	Emissions released directly from a material without combustion, such as release of a gas or vaporization of a liquid.
Non-flash Gas	Upstream natural gas from the wellhead or post liquid separation.
PPB	Parts per billion; a unit of concentration for molecules in air; based on the number of molecules, not the mass of molecules.
Receptor	Within air quality modeling, a location where the ground-level air concentrations are estimated.

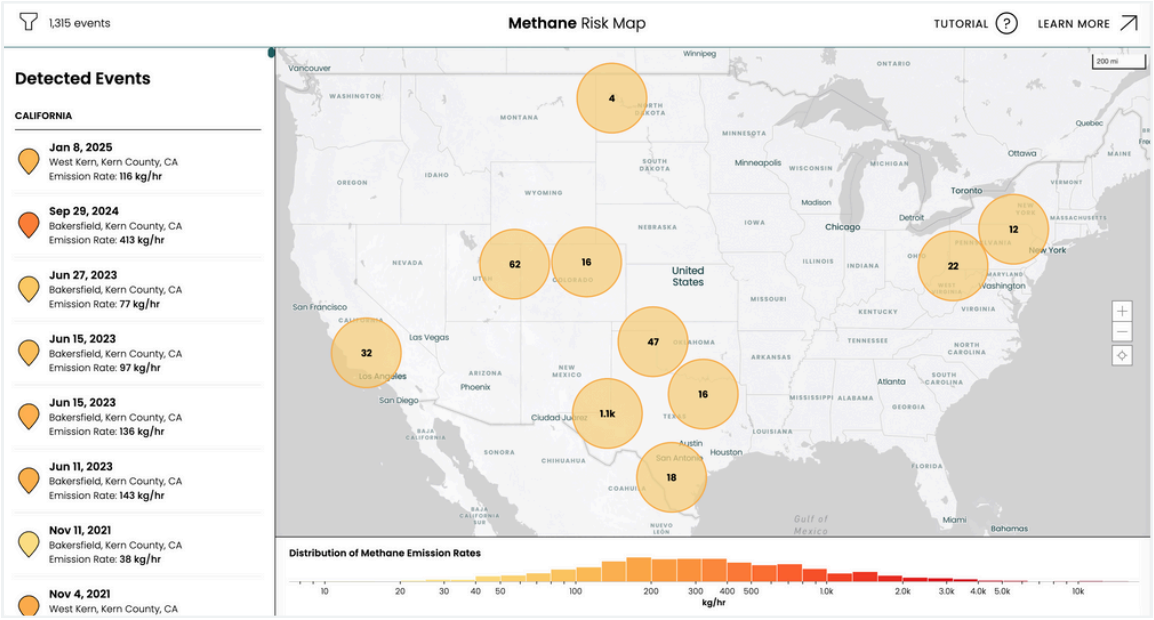
Safety Benchmark	The concentration of a compound at or above which exposed individuals face risk of an immediate, severe event, such as fire, explosions, or suffocation.suffocation, fire, safety, or other immediate non-health events could occur.
Sector	The natural gas industry is commonly divided into three sectors: Upstream (natural gas exploration and production), Midstream (transmission and storage), Downstream (distribution).
Segment	Industry segments for Petroleum and Natural Gas Systems as defined by the Greenhouse Gas Reporting Program (GHGRP) Subpart W. Segments include: Onshore Production, Offshore Production, Gathering and Boosting, Natural Gas Processing, Natural Gas Transmissions Compression, Natural Gas Transmission Pipeline, Underground Natural Gas Storage, Liquified Natural Gas (LNG) Import/Export, LNG Storage, and Natural Gas Distribution.
Sensitive Facilities	Facilities whose occupants are more susceptible to the adverse effects of exposure to air pollution, such as childcare centers, schools, hospitals, nursing homes, and prisons.
Source Attribution	Attribution of on-the-ground infrastructure to individual emission events. This may include information such as: Sector Segment Infrastructure Gas type.
Speciated Gas Composition Analysis	Report from an accredited laboratory reporting concentrations of individual constituents of a gas mixture such as natural gas. In our database, a speciated analysis will include concentrations of at least one hazardous air pollutant.
Toluene	Hazardous air pollutant that occurs naturally in oil and natural gas. Acute and chronic exposure impacts the central nervous system (US EPA, 2016).
Xylenes	Hazardous air pollutant that occurs naturally in oil and natural gas. Acute exposure causes gastrointestinal and neurological effects, and irritation of the eyes, nose, and throat. Chronic exposure results in central nervous system effects (US EPA, 2016).

Web Tool Overview

The Methane Risk Map has two primary views: 'All Events View' and 'Event View.'

All Events View

The All Events View shows a map of all of the events currently available on the MRM. On the bottom, a graph shows the distribution of methane emissions rates across all of the events on the map. While extensive, these events only represent a subset of all methane emissions events from the oil and gas sector. For more information, see Inclusion/Exclusion Criteria in the Version Notes.



On the left-hand sidebar, you can find a list of all the modeled events on the site. Methane emissions events can be filtered by location (basin, state, and county), infrastructure, emissions rate, and date. To select a specific event, you can choose from the left side bar or zoom in on the map to select a pin. When you hover over a pin, the unique event ID, date, and emissions rate will be visible.

As you zoom in using +/- or scrolling, methane events will uncluster on the map. Clicking the circle underneath the +/- will revert the map back to its default view.

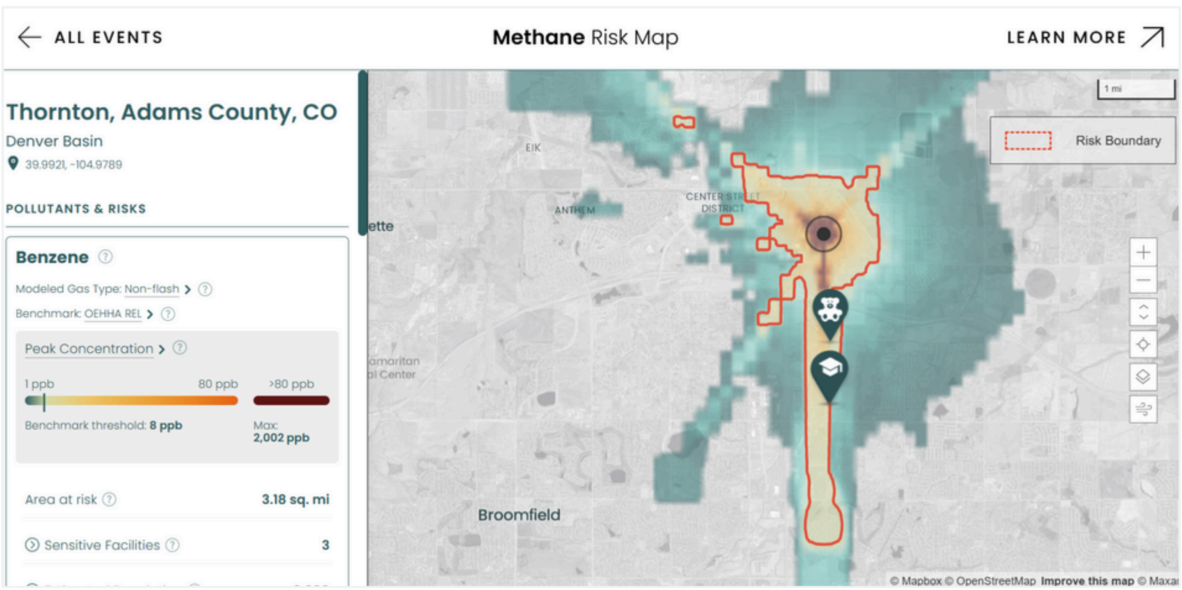
Event View

The Event View shows the results of a single methane emissions event. On the left-hand side, you can see the city, county, and basin where the event happened, as well as the latitude and longitude coordinates of the event. Clicking on the coordinates launches a new Google Maps tab redirected to the exact location of the event.

The left side bar is organized into two main sections: ***Pollutants & Risks*** and ***Event Details***. For more information on any of the variables shown, hover over the tooltip, indicated by a question mark.

Pollutants & Risks

Below the event location details is the ***Pollutants & Risks*** section. In addition to modeling methane, we model five hazardous air pollutants: benzene, toluene, ethylbenzene, xylenes, and hexane. The Event View defaults to visualizing benzene as it is the most toxic of these pollutants. Benzene is proven to cause acute and chronic health effects and has been classified as a Group 1 carcinogen by the International Agency for Research on Cancer, meaning there is sufficient evidence of carcinogenicity in humans.[7,8] However, the user has the option to select any of the other pollutants and the map will automatically update.



The user can visualize the modeled air quality impacts by two metrics: peak pollutant concentration and persistence. The first option is the ***Peak Concentration*** view, which shows the spatial extent of the modeled risk posed by the event. This view shows the peak modeled concentrations of the selected pollutant over the modeled time period, illustrated by the color gradient. These concentrations are compared to the selected safety or health benchmark to identify the area at risk, represented by the red line ('***Risk Boundary***'). On the color scale, lighter green and yellow colors indicate lower concentrations, while the darker colors indicate higher concentrations, and grey areas either had an estimated peak concentration of zero or were outside of the modeled area. The colors to the right of the vertical line on the color scale indicate concentrations that exceed the selected safety or health benchmark. Color scales for each pollutant are the same size and range across all events, making it easier to compare events. The maximum peak concentration within the risk area for an event is provided below the color scale (‘***Max***’).

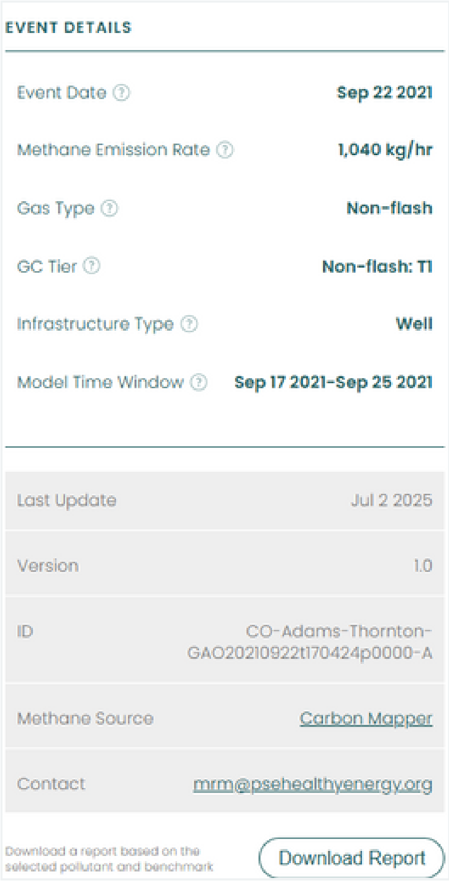
The second option is the ***Persistence*** view, which shows the persistence of the modeled risk posed by the event. This view calculates the percentage of modeled hours where concentrations at each location exceeded the selected risk benchmark. The color scale shows five ranges of percentages, ranging from light red to dark red, where light red indicates less persistence and dark red indicates more persistence.

For each event, the user has the option to select one of the pre-loaded benchmarks or input a custom benchmark. Benzene and the other modeled hazardous air pollutants come pre-loaded with two health benchmarks, from California’s Office of Environmental Health Hazards Assessment or Texas’ Commission on Environmental Quality, where applicable. Methane comes pre-loaded with one safety benchmark from the National Institute of Occupational Safety and Health. The custom benchmark allows users to explore different risk tolerance levels for each pollutant.

Based on the selected benchmark, the ***Area at Risk*** calculates the square miles within the risk boundary. Since different pollutants are emitted at different rates, the area at risk changes depending on the selected pollutant, gas type, and/or benchmark. We also provide the number of sensitive facilities, the estimated population, and the demographic breakdown of the population that falls within that area. Sensitive facilities represent facilities whose occupants are more susceptible to the adverse effects of exposure to air pollution, such as childcare centers, schools, hospitals, nursing homes, and prisons. On the map, these are shown as green icons. Users can hover over the icon to see information about the facility, including the type of facility, the name, and the distance from the source. The estimated population and demographic breakdown is calculated by finding the geometric centroids of every census block within the area at risk. If no intersections are found, the estimated population is set to zero and the demographic breakdown is set to zero. If the total estimated population is under 100 people, the population is set to “<100 people” and the demographic breakdown is set to “Unknown.”

For some events, the user has the option to view two different modeled gas types, flash or non-flash. A key finding in our research is that the type of gas emitted makes a substantial difference in the concentration of hazardous air pollutants produced. Flash gas (upstream gas emissions originating from liquid storage tanks) contains much higher levels of hazardous air pollutants than non-flash gas (upstream natural gas from the wellhead). This is because when stored liquid experiences a big change in temperature or pressure, such as when a valve opens, some of the liquid “flashes” into a gas, taking with it high levels of the hazardous air pollutants that were present in the hydrocarbon liquid. For many events, we can estimate what type of gas was emitted based on what equipment exists in the area of the event and thus model one gas type. However, for some events, we are not able to assume whether either flash or non-flash gas is emitted. For these events, we model both and allow the user to toggle between both results.

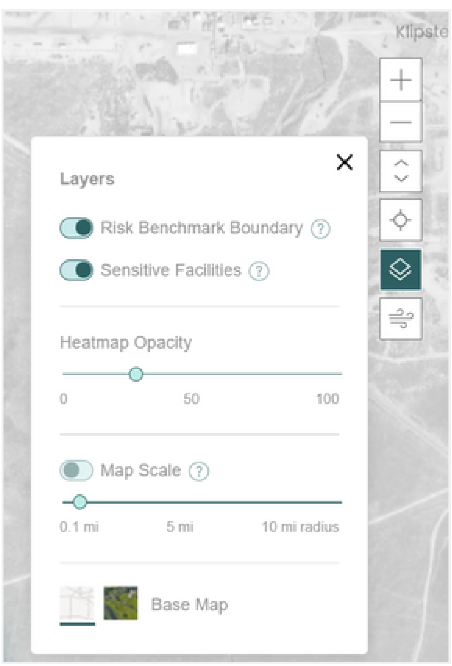
Event Details



Specifics of the methane emissions event are found in the Event Details section. The date of the event and emissions rate are pulled directly from the data source. The infrastructure type is determined via assessment of nearby infrastructure (see more in ***Source Attribution***). The modeled time window represents the dates used in the simulation. Because the observations only provide a snapshot and event durations are not regularly reported with emissions data, for most events we model a 7-day period centered on the date of detection (three days before and ends three days after). For a small subset of events with a known duration, we modeled that period. This range is used to assess the variability of the modeled 1-hour concentrations due to the variability in hourly meteorological data.

The bottom of the side bar provides additional details about the event, including the date the tool was last updated, the version of the tool, the event ID, and the link to the methane data source for the event. Additionally, the Download Report button allows users to download a report on the event based on the selected pollutant and benchmark. Each event also has a unique URL for ease of sharing. The MRM contact information is also provided for any questions that may arise regarding the tool.

Navigation



By scrolling or clicking +/- on the right, the user can zoom in and out to see the full risk area. The map orientation can be adjusted by clicking and holding the arrows while moving the mouse around. To reset the map to the default view, click the target icon.

Clicking on the layers icon will open up a submenu, which provides the user with options for customization. The user can toggle on/off the risk benchmark boundary and the sensitive facilities layer, switch between the greyscale basemap and a satellite basemap, increase/decrease the heatmap opacity, and add a customizable map scale, which draws a circle around the source, based on a user-inputted radius.

Clicking the wind icon will open up a windrose, which shows the direction and speed of wind at the source over the modeled time window. The average wind speed and direction is represented in the center of the windrose.

Methods Overview

Methane Emissions Data Acquisition

Methane emissions originate from various sources, including but not limited to oil and gas operations, solid waste, livestock, and wastewater. The MRM focuses specifically on methane emissions from the oil and gas supply chain, which encompasses three primary sectors: upstream (production), midstream (transmission), and downstream (distribution). These sectors can be further categorized into segments, which are described in the following ***Source Attribution*** section.

The methane emissions data used in the MRM webtool is sourced from third-party observation platforms, such as Carbon Mapper[9]. These emissions are measured by airborne and satellite imaging spectrometry. The methane emission events are initially attributed to oil and gas facilities by the third-party data provider. We then build on this attribution by applying additional filtering criteria developed by PSE to identify and retain only those methane emission events that originate specifically from upstream oil and gas operations. Details on this attribution process can be found in the next section.

Source Attribution

Attribution Overview

Four key variables are identified and attributed to assign an accurate gas composition profile to each methane emissions event: Sector, Segment, Infrastructure, and Gas Type. Sector and segment classifications can typically be determined at the facility level, while infrastructure type and gas type require a separate attribution process. All events were attributed using the same protocol except for the case studies from Bisogno et al. 2025[10], which were attributed from in-depth review of event descriptions from news, government agencies, and companies.

Sector-Level Attribution

We spatially referenced each emission source with Rextag[11], a proprietary energy infrastructure database, using the event-specific geographic coordinates from the methane data provider. For each event, we identified potentially associated infrastructure and facilities and assigned a sector if all associated infrastructure and facilities belonged to the same sector. For facilities, we used the coordinates of each facility, provided by Rextag, as the location. For individual infrastructure and most facility types, we applied a 150 meter buffer; to account for the large footprint of gas processing plants and gas storage facilities, we utilized larger 500-meter and 3,000-meter buffers, respectively. These differing buffer sizes were used to balance capturing as much information about each event's potential sector while accounting for variations in facility footprints. For example, an emissions event with a gas well (upstream) and a natural gas transmission pipeline (midstream) within 150-meter would be assigned an "ambiguous" sector and therefore would not be included among the cases. ***It is important to note that the current version of the MRM webtool only includes emissions events from the upstream oil and gas sector.***

Segment-Level Attribution

After sector attribution, we further categorized all upstream emissions events into four segments based on the 150-meter buffer. We assigned the industry segment only if all infrastructure belonged to a single segment. When the segment could not be definitively identified following this approach, we categorized the segment as “ambiguous,” though for some high-priority events we manually determined sector and segment through in-depth review of satellite imagery. ***The following segments are included in the MRM:***

- **Onshore Production**
- **Gathering and Boosting**
- **Gas Processing**
- **Ambiguous**

Infrastructure-Level Attribution

We manually reviewed current and historical satellite imagery alongside energy infrastructure datasets (e.g., oil and gas well locations) to likely-associated infrastructure for each event. Here, “infrastructure” encompasses oil and gas equipment with the potential to release methane emissions, including, but not limited to, wells, storage tanks and pipelines. For events detected by aircraft-based spectrometer instruments, all visible infrastructure within a 10-meter radius of the emissions source was identified. For satellite-detected events, which have less precision and lower resolution than aircraft measurements, we applied a wider 50-meter radius. When several infrastructure types were detected within the buffer, the infrastructure type was categorized as “Multiple Equipment;” if no infrastructure was visible or none could be positively identified, the infrastructure type was categorized as “Unknown.” The following list represents the possible infrastructure options:

- **Storage Tank**
- **Pipeline**
- **Well**
- **Compressor**
- **Flare Stack**
- **Separator**
- **Multiple Equipment**
- **Unknown**

Gas-Type Attribution

Once infrastructure was identified, a corresponding gas type was assigned to the methane emissions event, which is displayed in the “Event Details” tab for each event in the webtool. The following list represents the infrastructure identified and gas type associated with each:

- **Storage Tank (Flash Gas)**
- **Pipeline (Non-Flash Gas)**
- **Well (Non-Flash Gas)**
- **Compressor (Non-Flash Gas)**
- **Flare Stack (Flash and Non-Flash Gas)**
- **Separator** (Flash and Non-Flash Gas)
- **Multiple Equipment** (Gas type follows the infrastructure identified)
- **Unknown** (Gas type follows the rules below)

If multiple pieces of infrastructure were present, the gas type was classified as either flash or non-flash when all infrastructure shared the same associated gas type. For example, an emissions event was classified as non-flash if both a pipeline and well were present. If the infrastructure indicated a mix of gas types, both flash and non-flash were assigned. In cases where no visible natural gas infrastructure was present within the buffer radius, the infrastructure type was categorized as “Unknown,” and the gas type was assigned as non-flash. This default assignment of non-flash when no visible infrastructure was present reflects our observation that common sources of flash gas typically have a visible above-ground signature. When visible infrastructure was present but could not be positively identified, the gas type was assigned as both flash and non-flash.

Gas Composition Estimation

We estimate gas composition of emission events using three tiers of approaches, where Tier 1 estimates represent the highest degree of confidence and estimates from higher tiers are prioritized over lower tiers. Our approaches are based on our nationwide upstream gas composition database. Our peer-reviewed manuscript published in *Environmental Research Communications* (Rowland et al. 2025)[12], provides a comprehensive description of our data collection, database, and analyses. We obtained upstream gas composition data from analytical laboratory reports in air permit applications and a regulatory gas composition database traceable to individual laboratory reports. We requested permit applications through Freedom of Information Act (FOIA) requests or downloaded them through state regulatory agency websites. Our gas composition database is composed of 8,012 samples. The dataset contained 3,487 flash gas (i.e. upstream gas emissions from liquid storage tanks or from liquid sources due to a decrease in pressure or increase in temperature) and 4,525 non-flash gas (i.e. upstream natural gas from the wellhead and post-liquid separation) samples. The included samples were from 11 states and 19 oil and gas basins, with 70% of our samples from the Permian, Gulf Coast, and Uinta Basins. Separators and wells were the most commonly labeled equipment types among all samples. Nine US EPA HAPs were present in our data, with BTEX and hexane reported in the majority of samples. Benzene was detected in 97% of non-flash gas samples and >99% of flash gas samples. BTEX and hexane concentrations tended to be higher in flash gas than in non-flash gas.

Tier 1 - Exact Match with Speciated Samples

Tier 1 estimates use a representative speciated gas analysis from the same facility as the emission event to determine gas composition. This tier most closely resembles regulatory methods from state agencies that require a gas analysis when estimating emissions from oil and gas infrastructure. We determine if an emissions event and a speciated gas sample are from the same facility through manual review of their locations, maps and satellite imagery of facility boundaries, a proprietary geodatabase of U.S. energy infrastructure, and facility maps and names from associated air permit documents. We prioritize gas analyses from the same equipment type as the emissions event when multiple analyses are available for a facility. At a minimum, the site-specific gas analysis must be of the same gas type as the emissions event. Due to the specificity of the required data and coverage of our gas composition database, we are only able to provide a limited number of Tier 1 gas composition estimations.

Tier 2 - Localized Modeled Composition

Tier 2 estimates use an average of a subset of speciated gas analyses, based on information about the source and local gas composition samples. Currently, all Tier 2 approaches average by gas type and county or county-infrastructure combinations. For each methane emissions event, we selected the most accurate and available approach. We ranked averaging approaches by accuracy via cross-validation, a model evaluation technique from machine learning. For example, we found that averaging analyses within a county was significantly more precise than averaging all the samples from the same equipment type and basin. For each event, our approach is limited by available source information; for example, if we cannot determine the equipment of an event, we cannot average by equipment type. Additionally, approaches are constrained by the number of samples in our dataset with the same characteristics as the event; we set a minimum of 10 samples. For example, if a non-flash event occurred in a county from which our database only includes five samples, we would not have a sufficient sample size to accurately characterize the average gas from that county. Due to the sample size minimum and limited geographic coverage of the database, we were not able to provide Tier 2 estimates for some events.

Tier 3 - Broad Modeled Composition and Speciation Profiles

Tier 3 estimates use either a basin average of speciated gas analyses or broad speciation profiles used by regulatory agencies to estimate emissions from oil and gas production operations for permitting purposes. We only utilize these broad speciation profiles for regions where we have no Tier 1 or 2 estimates due to their lack of specificity and, for the case of regulatory profiles, uncertainty in methodology. Currently, all non-flash emission events in California use Tier 3 estimates - a statewide natural gas fugitives regulatory profile[13].

When both basin averages of speciated gas analyses and regulatory profiles are available, we prioritize estimates based on our speciated gas composition database due to uncertainty in regulatory profile development. When multiple regulatory profiles are available, we prioritize profiles based on the following criteria: availability of both benzene and methane values, more specific geographic match, and more specific infrastructure match.

Air Quality Modeling

This section provides a brief overview of the models and methods used to produce the peak concentration and persistence maps displayed on the MRM. Our peer-reviewed manuscript, published in *Environmental Research Letters* (Bisogno et al. 2025)[14], provides a comprehensive description of our methodology.

Dispersion Modeling

We use the American Meteorological Society/Environmental Protection Agency Regulatory Model (AERMOD)[15] to model the concentrations of methane and HAPS in the air. We run the Weather Research and Forecasting Model (WRF)[16] to generate the wind, temperature, and atmospheric stability information needed for AERMOD's dispersion modeling. Besides meteorology, AERMOD requires three additional primary inputs for dispersion modeling: an emissions rate, a source description, and a receptor grid.

The emissions rate for each event is derived from available satellite and aircraft measurements (the specific data source is cited in the '***Event View'*** for each event). Because these observations only provide a snapshot and event durations are not typically reported, for most cases we model a 7-day period centered on the time of measurement. For the small subset of events with a known duration, we modeled that period.

This allows us to estimate the range of possible outcomes given the known emissions rate and weather variability. We also only model 1-hour average concentrations for this same reason, as longer averaging periods (for example, 8-hour) would require more information about the duration of the event. Thus, the final product displayed on the MRM is an estimate of regions where acute health risks may have occurred (see the ***Threshold/Impact Assessment*** section).

For the source description, each was modeled as a 10-by-10 meter ground-level volume source, allowing us to use the same approach for every emissions event. Our internal sensitivity tests (Bisogno et al. 2025) revealed close agreement between the volume source and the point source type (which is typically used for oil and gas releases), yielding an average difference of 2.7% across all modeled receptors.

For the receptor grid, we placed ground-level AERMOD receptors following a slightly modified version of the Texas Commission on Environmental Quality (TCEQ) guidance[17]:

- 50-meter buffer around the source
- 50 to 300 meter: 25 m spacing
- 300 m to 1 km: 100 m spacing
- 1 km to 5 km: 250 m spacing
- 5 km to 20 km: 1 km spacing

TCEQ recommendations were used due to their high density of receptors close to the source and wide spatial extent compared to other guidelines. Based on our previous findings[18], the recommended spacing was adjusted to increase the density of the receptor grid between 1 and 5 km from the source.

Estimating Non-Methane Pollutant Concentrations

AERMOD, as a steady-state Gaussian model, simulates dispersion independent of the molecular properties of the pollutant being modeled. In other words, AERMOD assumes that different compounds will behave similarly in the atmosphere, and thus assumes that the molar ratio of methane to each HAP will be the same at the emissions source and at ground-level concentrations away from the source. Therefore, we multiply the modeled methane concentrations by the molar ratios described in the Gas Composition Estimation section to estimate the concentrations of other harmful pollutants (see Equations 1–3 in Bisogno et al. 2025).

Risk Assessment

Safety benchmarks define the level at which short-term surface-level air concentrations may pose risk through fire, explosion, or asphyxiation. Modeled methane concentrations were compared to the National Institute of Occupational Safety and Health's (NIOSH) Immediately Dangerous to Life or Health (IDLH) concentration, which is calculated as 10% of the lower explosive limit of methane, or 0.5% methane.

Health benchmarks define the level below which there is no significant risk of toxic health effects. Since acute health benchmarks for hazardous air pollutants are not determined at the federal level, it is up to the states to determine what concentrations pose risks; however, many states don't report a health benchmark for these contaminants. We show two benchmarks from California and Texas to get a range of the risks posed; (a) California's Office of Environmental Health Hazards Assessment's (OEHHA) acute Reference Exposure Level (aREL)[19], and (b) Texas' Commission on Environmental Quality's (TCEQ) Effects Screening Level (ESL)[20].

We also provide the option to input a Custom Benchmark for Peak Concentrations, which will automatically update the MRM to compare concentrations of methane and hazardous air pollutants against a user-inputted safety or health benchmark.

We use these benchmarks to answer two questions for each event: (a) where might the event have posed an acute risk (***Peak Concentration***) and (b) how often risk may have been posed, based on variations in weather (***Persistence***)? At each receptor we calculate the 98th percentile hourly concentration across all modeled hours, representing the Peak Concentration. The risk boundary outlines the area where the model suggests risk could be posed, based on where the concentration exceeds the benchmark. Note that the risk boundary may show a non-continuous shape due to the effects of meteorology and terrain on the modeled concentrations. The ***Persistence*** view calculates at each receptor the percent of the modeled hours where concentrations for the chosen pollutant exceeded the chosen benchmark. When comparing modeled concentrations to these benchmarks, we exclude the top 2% of results (e.g., use the 98th percentile to compute peak concentration) to exclude potential model outliers, thereby making our results more robust[21]. To map these results, these metrics are interpolated to a uniform grid with approximately 50-meter spacing.

Population Characterization

This section provides an overview of the methods used to characterize the populations at risk of exposure to methane emissions events.

Data Description

We compiled demographic indicators from the 2020 Census and the 2019-2023 American Community Survey (ACS) and sensitive facility data from the Homeland Infrastructure Foundation-Level Data (HIFLD)[22,23]. Demographic indicators included total population, older adults (people >65 years of age), children (people <5 years of age), and race/ethnicity breakdowns (Non-Hispanic White, Non-Hispanic Black, Non-Hispanic Asian, Hispanic, Non-Hispanic American Indian or Non-Hispanic Alaska Native, and Native Hawaiian and Other Pacific Islander). Total population and the race/ethnicity and age breakdowns were downloaded at the census block level. We also compiled sensitive facilities locations for childcare centers, schools, hospitals, nursing homes, and prisons. We also identified the geometric center of each census block from the 2020 Census, as there were no centers of population at the block level available for download.

Methods for Event View

For each emissions event's risk exceedance area, we estimated total population, race/ethnicity breakdown, percentage of children and older adults, and number of sensitive facilities. For the total population and the race/ethnicity and age breakdowns, we identified census blocks in the risk exceedance area based on whether the block's geometric center was located within the area, following the approach of EJScreen[24].

We summed the total and subpopulation population counts for each included census block and subsequently calculated the percentages out of the total population (for the race/ethnicity and age percentage breakdowns). If the total population was under 100 people, we labeled the population as "<100 people" and did not estimate the demographic breakdowns. If no geometric centers of population were within the risk area, demographic values were set to zero.

Methods for Landing Page

We estimated the total population and number of sensitive facilities within two miles of at least one of the methane emissions events included in the MRM. We chose a two-mile buffer because the average maximum distance of a benzene OEHHA REL benchmark exceedance was two miles during the 2025.08.26 release. We drew a two-mile buffer around each methane emissions event and identified the census blocks that were within the buffer using the block's geometric center. We summed the population counts for each included census block to get the total population. We also identified the sensitive facilities within the two-mile buffer to get a total number of sensitive facilities and total number of each kind of sensitive facility. If the buffer areas for two or more events overlapped, we merged the buffers to avoid double-counting census blocks and sensitive facilities.

Limitations

The demographic indicators obtained using census block and should be considered estimates and not true values. In the event view and landing page statistics, we used the census block geometric center to estimate the demographics within the risk area and the two-mile buffer. Using geometric centers is less computationally expensive relative to using census block polygons and allows dynamic updates of population estimates as the user interacts with the tool. However, using the census block geometric center might underestimate the population within the risk exceedance area. It excludes census blocks whose geographic boundaries intersect the risk area but whose geometric centers fall outside it. It is possible that some residents of these partially intersecting blocks may still reside within the affected area even when the block's geometric center is outside the risk area. It is also possible that not all of the block population resides within the risk area, even when the geometric center is located within the risk area. In this case, our approach overestimates the population as demonstrated by a validation study of events in Texas. This limitation is particularly relevant to rural areas where census blocks tend to have larger areas.

Endnotes

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