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The Colorado Ongoing Basin Emission (COBE)-2
Interim Report

Prepared for: Colorado Department of Public Health and Environment

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Executive Summary

In 2024, the Colorado Ongoing Basin Emissions (COBE) project partnered with three aerial measurement companies to estimate methane emissions from upstream oil and gas facilities across Colorado. More than 30,000 scans were taken of over 10,000 facilities, and 2,102 methane emissions were detected.

Two independent emission models — a mechanistic discrete-event simulator (MAES) and a data-driven statistical model — applied the same aerial measurement data to develop measurement-informed methane emission inventories for the state. Despite using the same underlying aerial data, the model estimates differed by a factor of 2.5. The data-driven model relied solely on aerial measurements and estimated emissions at the facility level, whereas the mechanistic model began with an existing inventory (ONGAEIR), classified emissions as normal or abnormal, and modeled emissions at the equipment level. The goal of COBE-2 was to investigate the discrepancy between the two models and help inform the 2027 default intensity verification factor for CDPHE.

The results of the two models initially were 38.7 Gg CH_4/y from MAES, and 97.7 Gg CH_4/y from the statistical model, resulting in factors of 1.47 and 3.7 compared to ONGAEIR 2024. After pulling a revised version of ONGAEIR and updating modeling methods, the current factors estimated by MAES and the statistical model are 2.06 and 4.0, respectively. Consequently, the ratio between the two models decreased from 2.5 to 1.94.

1 Project Overview

Colorado Ongoing Basin Emissions (COBE) project assisted the Colorado Department of Public Health and Environment (CDPHE) and its Air Pollution Control Division (APCD) to develop recommended 2026 default intensity verification factors for methane emissions from upstream oil and gas facilities for the implementation of the GHG Intensity Verification Rule. During the COBE project, three aerial methane detection companies (Bridger Photonics, GHGSat and Insight M) performed approximately 30,000 scans of over 10,000 upstream facilities, detecting 2,102 methane emissions. With this data, two models were developed to create methane emission estimates that could be compared to the state's Oil and Natural Gas Annual Emissions Inventory Report (ONGAEIR). Colorado State University's (CSU) Methane Emissions Technology Evaluation Center (METEC) team used a mechanistic discrete-event simulator (MAES) to combine the inventory and aerial data to create a measurement-informed inventory. Colorado School of Mines (Mines) developed a statistical model to create a measurement-based inventory. The final emissions estimates of 38.7 Gg CH_4/y from MAES and 97.7 Gg CH_4/y from the statistical model resulted in factors of 1.47 and 3.7 when compared to ONGAEIR 2024. The final report from COBE is available online[1] and updated results have been released in a preprint[2].

The primary objective of COBE-2, which is funded by the Mark Martinez and Joey Irwin Memorial Public Projects Fund through Colorado's Energy & Carbon Management Commission (ECMC), is to investigate the two models' discrepancies and provide updated estimates to help inform the 2027 default intensity factor. To achieve this, the team updated the MAES model, incorporated sensitivity studies in the statistical model, and reran the models using an updated version of ONAGEIR 2024.

2 Model Updates

The MAES model relies directly on the state inventory database, ONGAEIR. ONGAEIR 2024 is continually updated with corrections from operators; the version used in this report was pulled from CDPHE in May 2026. Of the 11,727 upstream facilities that were operating or partially operating, 10,152 were able to be modeled — slightly more than the previous 10,110. The (Mines) statistical model uses only the number of facilities, which is matched to the facilities that can be modeled by MAES. Updates to the ONGAEIR dataset included revised emission estimates, which caused total reported methane emissions for the modeled facilities to rise slightly from 24.08 Gg CH_4/y to 24.44 Gg CH_4/y.

2.1 MAES model

Multiple updates were made to the MAES codebase in COBE-2. Because MAES relies on an input probability of a leak for a given class of emitters, p_{Leak}, we tested whether simulated emissions reflected this probability. This revealed that the portion of time emitters were active did not always agree with the input p_{Leak}; the issue was fixed by correcting the random selection of event durations.

In COBE, tanks were modeled using an emission factor times an activity factor, which likely underrepresented uncontrolled tanks. We developed a mechanistic model for uncontrolled tanks that uses fluid flows and gas composition to estimate flashing emissions directly. This represents a significant improvement over the prior factor-based approach; under the updated model, emissions from uncontrolled tanks are 4.4 times higher than previously estimated.

[1] Brown, J. A. et al., "Colorado Ongoing Basin Emissions (COBE) Updated Final Report." November 20, 2025. https://hdl.handle.net/10217/242813.

[2] Brown, J. A. et al., "Measurement-Informed Methane Inventories for Colorado's Upstream Oil and Gas Sector: Two Independent Modeling Approaches." *ChemRxiv* 2026, no. 0831 (n.d.). https://doi.org/10.26434/chemrxiv.15008067/v1.

The heater and flare models were also updated. We discovered that the initial simulated conditions disagreed with steady state behavior in MAES for these models, introducing a "spin-up" period at the beginning of a simulation that disagreed with later behavior. The initial states for these models were updated to agree with the simulated Markov transitions and event durations, and the behavior at the beginning of the simulation now matches the steady state. Previously, heater fuel consumption was calculated based on rated heater power and lower heating value; it is now pulled directly from ONGAEIR's required annual fuel consumption input and converted into a rate using operator-provided average run times.

As MAES simulates flows and emissions in multiple gases, methane measurements must be scaled to estimate whole gas emissions. Emission factors created from aerial data were adjusted to more accurately match the composition of the emitted gas in MAES simulations, which varies by equipment. The most noticeable effect was in fugitive emissions, as this category had the largest change in the methane fraction. This adjustment, along with the other updates to p_{Leak} above, led to fugitive emissions in the MAES updated model to increase by 66% compared to the previous estimate for fugitives. This addresses some of the discrepancy previously observed between MAES simulations and aerial data at medium to large emission rates.

Additional sensitivity studies were run on the MAES model. This included modeling pneumatics mechanistically — given the number of pneumatics statewide, this significantly increased computational cost. Another test used site-specific gas composition, however, due to lack of representative data for the entire state, this was only run on selective sites. Tested on 29 sites, methane emissions decreased by 4% when using the site-specific gas composition.

Finally, using MAES to individually estimate emissions from each production facility in Colorado requires significant computational overhead and relies on detailed statewide reporting data. To assess the feasibility of simulating a subset of representative sites, extrapolation error was evaluated across randomly sampled subsets of differing site counts. The total estimate of randomly sampled subsets of about 1,000 sites extrapolated to MAES' state-wide estimate within a few percent. Spread (variation between repeated draws of the same size) dropped from 45% at 50 sites to 2% at 1,000 sites.

2.2 Statistical model

The Mines statistical model now uses solely the Williams[3] distribution to inform emission rates below 5 kg/hr (the lowest DMC across aerial vendors). Previous analyses using the Williams and Sherwin[4] distributions produced very similar inventory estimates, with differences well within the bootstrapped uncertainties. The Williams distributions were chosen over the Sherwin distribution because the Williams distributions' reliance on empirical facility-level measurement data aligns better with the assumptions of the statistical model and the interpretation of aerial observations as short-duration snapshots of facility emissions. The estimates in Sherwin et al., on the other hand, rely more on equipment-level simulations and emission factors. While the choice between these two distributions had little effect on the results, a sensitivity analysis revealed substantial sensitivity to the probability of a facility emitting above 5 kg/hr. This probability is currently calculated empirically using the data from the aerial vendor with the lowest DMC. The estimated mean emission rate is essentially a weighted average of the means above and below this threshold, so if these means are held fixed, the total emissions estimate increases linearly with the

[3] Williams, J. P. et al., "Small Emission Sources in Aggregate Disproportionately Account for a Large Majority of Total Methane Emissions from the US Oil and Gas Sector," *Atmospheric Chemistry and Physics* 2025, 25, 1513–1532.
[4] Sherwin, E. D. et al., "US oil and gas system emissions from nearly one million aerial site measurements," *Nature*, vol. 627, pp. 328–334, Mar. 2024.

probability assigned to the higher-emitting group. In our analysis, increasing this probability by one percentage point (e.g. from the current estimate of about 4% to 5%) increased estimated statewide emissions by approximately 12.5 Gg CH_4/y. These results show that estimation of this probability, and an assessment of how well the observed proportion represents the state-wide facility population, are priorities for further model development.

Before the updated MAES results presented in this report were available, we investigated a hybrid approach that used the previous MAES-estimated emissions to fill in the below 5 kg/hr rates within the statistical model framework. As expected, this analysis showed alignment between the hybrid and MAES approaches in the small emission rate regime, but discrepancies in total emissions persisted due to emissions from rates above 5 kg/hr. Thus, for the model versions evaluated, the below-threshold distribution was not the only driver of disagreement. Repeating this analysis with the updated MAES results would establish whether this is still the case.

Comparisons between continuous monitoring system (CMS) inference and MAES on specific facilities are pending; we are in contact with operators about obtaining historical CMS data. The five facilities that we had done detailed comparisons at the equipment-level are unfortunately not well suited for MAES modeling given the type of equipment on these facilities. While waiting for access to new CMS data, the Mines team has focused on improvement details to the CMS inference specifically targeting equipment-level inference. By now, we have identified facility setups and wind regimes under which equipment-level CMS inference results are most reliable, and hence most useful for detailed comparisons to MAES.

2.3 Aerial emissions distributions

We examined the possible influence of measurement error on the aerial data, finding notable effects for large emission rates. Error models for the various aerial technologies were updated from those used in the first COBE project based on a recent study[5]. Additional errors due to aerial vendors' use of wind reanalysis tools were included in a sensitivity study, as there is limited existing work estimating these errors. For a rough illustration of scale, once the windspeed errors are incorporated, 95% of emission rate measurements are expected to be within about a factor of 3 from the true rate. Random measurement errors widen the true distribution and exaggerate the long tail, and failing to account for this effect can result in overestimating the frequency of large emission rates. A sensitivity analysis with a range of realistic error models showed this may result in up to a 30% overestimate of the contribution of rates over 5 kg/hr and up to a 55% overestimate of the contribution of rates over 100 kg/hr, with the amount of overestimation highly dependent on the characteristics of the measurement errors.

The lognormal distributions fit in the statistical model have not yet been adjusted to account for this effect, which may contribute to its larger estimate of emissions at rates over 5 kg/hr. A new nonparametric method for estimating the underlying distribution of true emission rates, removing the distortion caused by measurement error, was used to create the distributions for failure conditions (compressors, tanks, and fugitives) used in the MAES model. Bootstrapping suggests large uncertainties in the frequencies of large emission rates, in addition to the risk of overestimation described here, so the effect of large emissions on regional estimates remains an important topic of study.

3 Updated comparison of models and ONGAEIR

After the updates were made to the MAES and statistical models, the updated emissions were compared to ONGAEIR (see Figure 1). The total methane emissions are broken out by contribution of emission

[5] Dudiak, C. D., et al. "Quantification Error Model for Aerial LiDAR Methane Emission Rate Estimates." *ACS ES&T Air* 3.7 (2026): 1704-1716.

rates: small (<5 kg/hr), medium (5-100 kg/hr) and large (>100 kg/hr). Due to adjustments in the MAES model, the updated MAES results attribute a greater percentage of emissions to the medium range and a smaller percentage of emissions to the large range compared to the original results. While the two models still have discrepancies, they are proportionally closer than the original results, and the two models for the DJ basin are aligned to within the bootstrapped confidence intervals. It should be noted that the updated ONGAEIR estimate for the Piceance basin decreased by 26%, which led to higher factors for this basin.

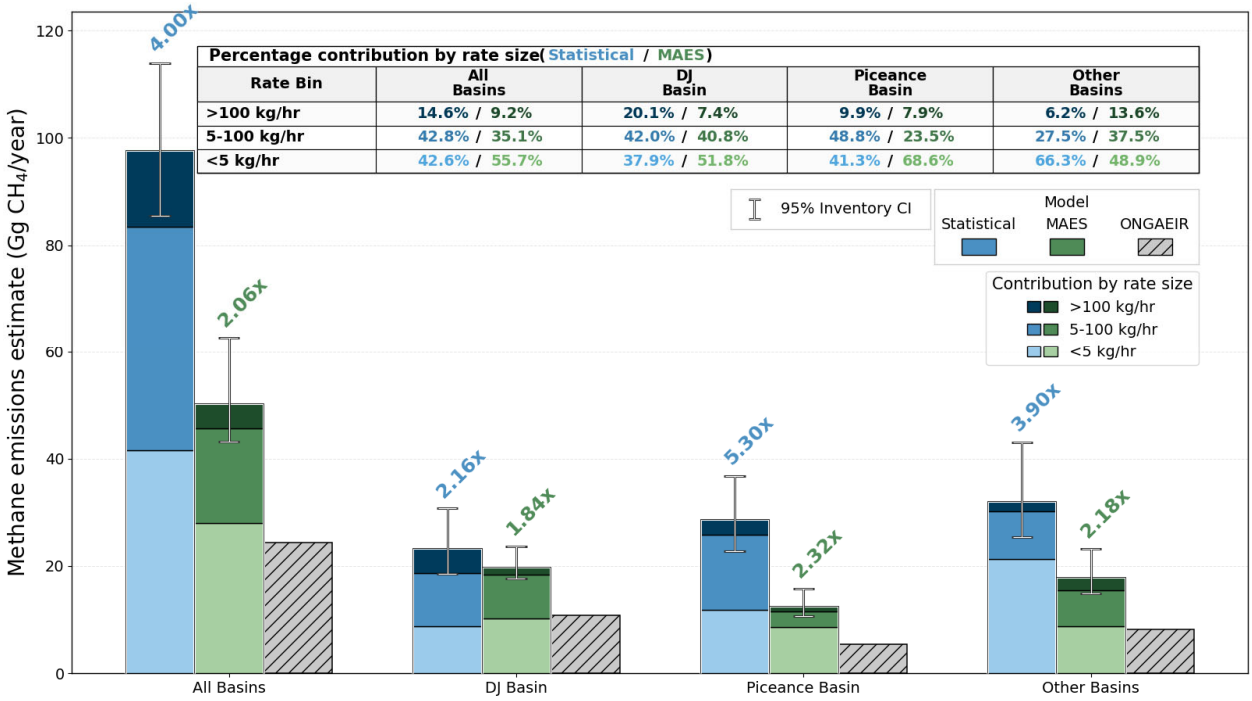


Figure 1: Statistical (Mines) and MAES MII results are compared to ONGAEIR reported emissions, both state-wide and split into basins. Both results are broken up by the contribution of small (<5 kg/hr), medium (5-100 kg/hr) and large (>100 kg/hr) emission rates. The factor of model results divided by ONGAEIR is shown above the corresponding bar.

Table 1: Total methane emissions in Gg/year are broken out by contribution of methane emission rates for the statistical, MAES MII and ONGAEIR.

Total methane estimates by rate size (**Statistical**/**MAES**/**ONGAEIR**)												
Gg CH_4/year	All Basins			DJ Basin			Piceance Basin			Other Basin		
>100 kg/h	14.25	4.62		4.69	1.46		2.83	1.00		1.99	2.44	
5-100 kg/h	41.84	17.66		9.80	8.10		14.00	2.95		8.83	6.72	
<5 kg/h	41.56	28.04		8.83	10.28		11.86	8.61		21.30	5.31	
Total	**97.66**	**50.32**	**24.44**	**23.32**	**19.84**	**10.79**	**28.70**	**12.56**	**5.42**	**32.12**	**17.92**	**8.23**
Lower 95% CI	85.42	43.15		18.60	17.63		22.75	10.67		25.42	14.86	
Upper 95% CI	113.97	62.71		30.72	23.67		36.82	15.82		43.07	23.22	