Carbon Mapper and RMI comments on EPA Supplemental Proposal to Reduce Methane and Other Harmful Pollution from Oil and Natural Gas Operations

Submitted to the Environmental Protection Agency
Docket ID No. EPA-HQ-OAR-2021-0317
FRL-8510-04-OAR
February 2023

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Acknowledgement: The authors would like to acknowledge and thank staff at Highwood Emissions Management, MiQ, RMI, and Carbon Mapper for taking part in helpful discussions and providing technical input that informed the comments here.

Executive Summary

We focus the majority of our comments here on two aspects of the proposed supplemental notice of rulemaking for the oil and gas (O&G) methane rule: (1) the matrix approach for alternative screening by operators; and (2) the Super-Emitter Response Program (SERP) that enables third-party detection and notification of large emission events. The SERP in particular represents a powerful backstop to multiple EPA and other federal agency programs. Carbon Mapper and RMI strongly support the proposed matrix approach for screening with recommended modification as well as the establishment of the SERP and plan to actively contribute to both programs to the extent possible as NGOs.

Secondarily, we support and suggest considerations for the: (3) new emissions monitoring requirements for all well sites; (4) aspects of the rule related to flaring reduction; and (5) aspects of the rule related to documenting change of ownership.

We recommend that the EPA:

I. Regarding the matrix approach to alternative screening by operators:

- Amend Tables 20 and 21 (screening matrix for facilities required to conduct optical gas imaging [OGI] ground-based monitoring) to include a minimum screening frequency of “Weekly + Annual OGI” with a minimum detection threshold of 100 kilograms per hour (kg/hr). This will enable the inclusion of satellites and high-altitude remote-sensing aircraft that offer equivalent or better methane mitigation performance compared to other options in the matrix for many regions while providing maximum flexibility and affordability. Without this modification, the higher frequency monitoring of intermittent higher-emission sources offered by available remote-sensing technologies will be excluded as approved alternative screening methods, resulting in lost mitigation opportunities.
- Review and consider revising assumptions used in Fugitive Emissions Abatement Simulation Toolkit (FEAST) modeling for the Supplemental Proposal for purposes of evaluating equivalency in the screening matrix. In particular, EPA should carefully consider the impacts of a) not accounting for spatial and temporal coverage, b) overly optimistic detection limits for optical gas imaging (OGI) and audio-visual-olfactory (AVO), and c) under-estimated leak generation rates for large emitters.

II. Regarding the Super-Emitter Response Program (SERP):

- Source geolocation and operator identification: In order to minimize the likelihood of identification errors, EPA should require third-party reporters to geolocate methane sources within 100 meters, provide the date and time of each observation, and to make every feasible effort to identify the nearest operator based on available asset ownership information. EPA can help expedite responses and minimize errors by developing a list of operator points of contact and a national geographic information system (GIS) database of O&G infrastructure to be made available to approved third-party reporters.
- Emissions quantification: To help track the amount of methane mitigated by repair actions and support assessment of the overall impact of the SERP program, EPA should require third-party reporters to make every feasible effort to report quantitative emission rate estimates and uncertainties for every source reported to operators. EPA should

consider conducting an annual review of SERP reports to help assess and improve the Greenhouse Gas Reporting Program (GHGRP)'s treatment of super-emitters.

- Notification and publication: EPA should encourage third-party reporters to expedite operator notification of super-emitter detection following robust quality control review and require that reporting is conducted in a transparent and non-proprietary manner. We also suggest that EPA publish reported super-emitter events as well as operator mitigation reports on an annual basis.
- Reporter certification: EPA should provide flexibility on the types of organizations that can serve as qualified third-party reporters. EPA should also clarify definitions of "demonstrable errors", "owner/operator" and "site" and specify the evaluation interval with regards to reviewing a third-party reporter in the event of persistent misreporting.
- Funding: EPA should provide competitive grants and other funding opportunities to ensure the establishment and continuity of third-party observing systems and frameworks for robust identification and notification of facility operators, which otherwise would likely remain limited to philanthropic funding.

III. Regarding emissions reduction at all sites:

- Ensure monitoring of all small well sites and monitoring within 90 days of startup or modification of well sites and compressor stations.
- Require that monitoring should cover the entire life-cycle including proper well closure to prevent the prevalence of abandoned wells.

IV. Regarding the proposed flaring reduction rules:

- Require that, for requested exceptions to the proposed requirements for associated gas flaring and flame monitors, any demonstrations should be subject to a time- and/or volume-based limitation and should require resubmittals to ensure that original conditions granting such an exception persist.
- Ensure that EPA remains abreast of studies and data available that would indicate improvements in flare performance based on requirements.

V. Regarding change of ownership notifications:

- Ensure that reports include information about owners, operators if different, and certification of notification to relevant state authorities for record keeping and consistency between state and federal agencies.
- Include changes in ownership in the SERP public database, in order to highlight if ownership has changed since notice of a super-emitter event.

Please do not hesitate to reach out with any questions about these comments. You can reach out via email to:

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Carbon Mapper and RMI comments on EPA Supplemental Proposal to Reduce Methane and Other Harmful Pollution from Oil and Natural Gas Operations

1. Amendments to the Matrix of Advanced Methane Detection Technologies

The EPA has proposed a matrix approach for alternative protocols for fugitive emissions monitoring and repair for affected well sites and compressor stations (Table 1A). The proposal, which allows operators to choose alternatives to quarterly Optical Gas Imaging (OGI) by trading screening frequency with detection limits, was developed based on results obtained from EPA modeling with the Fugitive Emissions Abatement Simulation Toolkit (FEAST). The EPA specifically requests comment on the proposed matrices as well as assumptions used in FEAST modeling.

While we appreciate and support the EPA's draft framework, which reflects improvement upon previous protocols and rapid advancements in detection technologies, we believe the current proposal contains critical holes rooted in flawed assumptions in the FEAST modeling that underpins it. To address these concerns, we provide evidence-based recommendations supported by empirical studies and a report conducted by Highwood Emissions Management commissioned by the authors (Appendix A). If accepted by EPA, these recommendations would significantly strengthen the rulemaking and further encourage greater, more cost-effective methane emissions reductions from the oil and natural gas sector. Specifically, we urge an expansion of the screening alternatives to leverage all technologies available to reduce emissions -- including satellites and high altitude remote-sensing aircraft -- and to offer practical approaches with equivalent or better methane mitigation performance compared to other options in the current proposal (Table 1B). Our comments are consistent with many of the recommendations we included in a joint comment on the November 2021 Proposal.

Recommendation 1: Expand proposed matrix to include a Minimum Screening Frequency of "Weekly + Annual OGI" with a Minimum Detection Threshold of 100 kilograms per hour (kg/hr).

Recommendation 2: Review and consider revising assumptions used in FEAST modeling for the Supplemental Proposal, including the assumed detection limits for OGI and audio-visual-olfactory (AVO) surveys, parameterization of spatial and temporal coverage, and leak generation rates, all of which can impact simulation results - particularly regarding intermittent high emission events.

Table 1A. EPA alternative screening matrices, as currently drafted.

TABLE 20—SURVEY MATRIX FOR ALTERNATIVE PERIODIC SCREENING APPROACH FOR AFFECTED FACILITIES SUBJECT TO QUARTERLY OGI MONITORING [a]

Minimum screening frequency	Minimum detection threshold of screening technology [b]
Quarterly + Annual OGI	≤1 kg/hr
Bimonthly	≤2 kg/hr
Monthly	≤4 kg/hr
Bimonthly + Annual OGI	≤10 kg/hr
Monthly + Annual OGI	≤30 kg/hr

[a] Well sites with major production and processing equipment, controlled storage vessels, natural gas-driven pneumatic controllers, associated covers and closed vent systems, and control devices, centralized production facilities, and compressor stations.
[b] Based on a probability of detection of 90 percent.

TABLE 21—SURVEY MATRIX FOR ALTERNATIVE PERIODIC SCREENING APPROACH FOR SINGLE AND MULTI-WELLHEAD ONLY SITES AND SMALL WELL SITES

Minimum screening frequency	Minimum detection threshold of screening technology [a]
Semiannual	≤1 kg/hr
Triannual	≤2 kg/hr
Triannual + Annual OGI	≤5 kg/hr
Quarterly + Annual OGI	≤15 kg/hr
Monthly + Annual OGI	≤30 kg/hr

[a] Based on a probability of detection of 90 percent.

Table 1B. EPA alternative screen matrix, with proposed amendments.

Minimum screening frequency	Minimum detection threshold of screening technology
Above rows as written in Table 20 and 21	*Above rows as written in Table 20 and 21*
Weekly + Annual OGI	<= 100 kg/hr

The EPA proposal states that "*technologies with a minimum detection threshold above 30 kg/hr could not be deemed equivalent to the proposed fugitive emissions monitoring and repair program in NSPS OOOOb and EG OOOOc at any screening survey frequency.*" The implications for this proposal, as written, are such that satellite technologies and some aircraft remote-sensing technologies will not be available as approved alternative screening methods. To our knowledge, no satellites currently operational nor those expected for launch in the next few years and only a few currently operating airborne systems are capable of meeting a 30 kg/hr minimum detection threshold of screening at 90 percent probability of detection.

Despite not meeting the currently proposed maximum detection threshold, many satellite and high-altitude aircraft remote-sensing technologies are uniquely capable of spotting intermittent super-emitters thanks to a combination of broader spatial coverage and higher frequency sampling. This means that, in practice, these technologies can provide operators across many U.S. oil and gas production regions maximum flexibility and affordability as part of leak detection and repair (LDAR) regimes. In some instances, these technologies are already being deployed voluntarily by operators seeking to go 'above and beyond' required practices.

We generally support the use of equivalency modeling such as FEAST and other rigorous models to determine the matrices. However, as acknowledged by EPA, the inputs and assumptions used in any model are critical in determining equivalency between alternative screening and the standard fugitive emissions detection and repair program. In this case, the exclusion of an entire class of monitoring instruments capable of higher frequency monitoring is of primary concern and is a direct result of suboptimal assumptions in EPA's FEAST modeling. Specifically, there are concerns with the EPA's intermittency assumptions for super-emitters, inability to properly parameterize temporal and spatial coverage of conventional methods in FEAST, and unrealistic assumptions about AVO screening performance.

To address these concerns, the authors partnered with Highwood Emissions Management to conduct modeling with Leak Detection and Repair Simulation (LDAR-Sim) to test the sensitivity of EPA's FEAST modeling to key input assumptions and explore screening scenarios not explored by EPA. The Highwood analysis used LDAR-Sim to evaluate the relative mitigation performance of different screening scenarios for monitoring 2,000 sites in a virtual world over the course of one year. These simulations used the same emissions distribution EPA derived from the Cusworth *et al* 2021 Permian study and other common assumptions in an attempt to replicate EPA's FEAST modeling while also evaluating different assumptions[1]. The Highwood analysis is most sensitive to the following parameters: leak production rate, leak rate distribution, minimum detection limit, spatial coverage, and sample frequency (temporal coverage). The full report, including inputs and results of the Highwood analysis, is provided in Appendix A.

Key result 1: Impact of Model Input Assumptions
Industry, technology providers, and experts in LDAR simulation repeatedly bring into question key assumptions about AVO and OGI performance used in EPA's FEAST modeling. Overly optimistic parameterization of these two technologies has important ramifications for equivalency – when these parameters are adjusted, conventional screening programs display more modest mitigation potential (Figure 1). Additionally, we have concerns with other assumptions used in EPA's FEAST modeling.

We highlight five significant issues in EPA's FEAST modeling assumptions:

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[1] Cusworth, D., et al., "Intermittency of Large Methane Emitters in the Permian Basin," *Environ. Sci. Technol. Lett.* 2021, 8, 7, 567–573, https://doi.org/10.1021/acs.estlett.1c00173

1. **Spatial coverage is not parameterized in EPA FEAST modeling**. Spatial coverage represents the average proportion of a facility the method can effectively survey. For example, a value of 0.7 indicates that the method will find a leak 100% of the time in 70% of the site. In practice, every time a method goes to survey a new leak, a weighted coin is flipped representing spatial coverage. If the method "loses" the weighted coin flip, it will not detect the emission and it will also not be able to detect it on ensuing survey visits. In the Highwood LDAR-Sim modeling an average spatial coverage of 0.8 was assumed. This value is understood to be more accurate and realistic based on information provided by technology vendors.

2. **Temporal Coverage is not parameterized in EPA's FEAST modeling**. Temporal coverage represents the probability that the method will detect a leak in a single survey - an important consideration given the prevalence of intermittent emissions observed in field studies (e.g., Cusworth *et al* 2021). This parameter can be used to ***approximate*** intermittency (when represented this way, intermittency only concerns detection but baseline emissions for these emissions are still considered constant; updating this behavior is a work in progress). For example, if the value is set to 0.80, it represents an intermittent emission that has a 20% chance of not emitting when a survey is conducted. In practice, every time a method goes to survey a leak, a weighted coin is flipped representing temporal coverage. If the method "loses" the weighted coin flip, it will not detect the emission. However, unlike spatial coverage, this coin is re-flipped the next time the method comes to the site with the emission in question. As such, this parameter has a much larger negative effect on methods with less frequent surveys as the temporal coverage "weighted coin" is flipped less frequently. So, if a method with a high survey frequency fails to detect an emission due to temporal coverage, it will have a "re-try" sooner than a method with a lower survey frequency that missed the same emission due to temporal coverage. In the Highwood LDAR-Sim modeling an average temporal coverage of 0.75 was assumed.

   The impact of the spatial and temporal coverage parameters can be seen in Figure 1 when comparing "P_OGI4x_FEAST" and "P_OGI4x_Highwood."

3. **AVO MDL assumed in EPA's FEAST modeling is likely unrealistically low.** AVO surveys have a noticeable impact on simulation results (compare programs with and without AVO surveys parameterized with the "FEAST" and "Highwood" scenarios shown in Figure 1). The FEAST parameterization with an MDL of 0.0678 g/s (.244 kg/hr) and no coverage parameters assumes AVO inspections will find *all* leaks below the MDL. There is ample anecdotal evidence to suggest this does not happen in practice. It is difficult to accurately model due to the lack of empirical evidence on its performance AVO remains the largest unknown in the simulations run up to this point. While Highwood believes the FEAST AVO parameterization is overly optimistic in terms of performance, it is hard to know how to re-parameterize this parameter and investigate it further. We urge EPA to consider this factor when attempting to compare the performance of AVO with other screening methods.

4. **OGI MDL assumed in EPA's FEAST modeling is likely unrealistically low.** In Highwood simulations, MDL for various methods can be parameterized using a single emission rate (like that used for AVO) or a probability of detection (PoD). In the latter, emission rates are applied to a curve and a "weighted coin" is flipped weighted to dictate if the method can detect the emission. EPA parameterized OGI MDL in FEAST using a single emission rate of 0.02 g/s. However, experts frequently bring this into question and peer-reviewed studies demonstrate operator experience should be considered. Highwood OGI is parameterized using a PoD curve that has a 95% PoD at an emissions rate of 0.182 g/s. This was informed by Zimmerle *et al.* 2020 which accounts for operator experience[2]. The impact of the OGI MDL input can be seen in Figure 1 when comparing "FEAST" and "Highwood" scenarios.

5. **Leak generation rate assumptions in EPA FEAST modeling may be too low.** EPA assumes leak generation rates of 0.5 to 1% for various classes of sites. However, a recent analysis of one million aerial observations of six oil and gas basins revealed leak generation rates are considerably higher for large sources above 10 kg/hr - about 2.5% on average and as high as 8.4%[3]. This indicates that airborne and satellite remote sensing systems with higher detection limits will be disadvantaged in EPA's FEAST modeling relative to other screening methods.

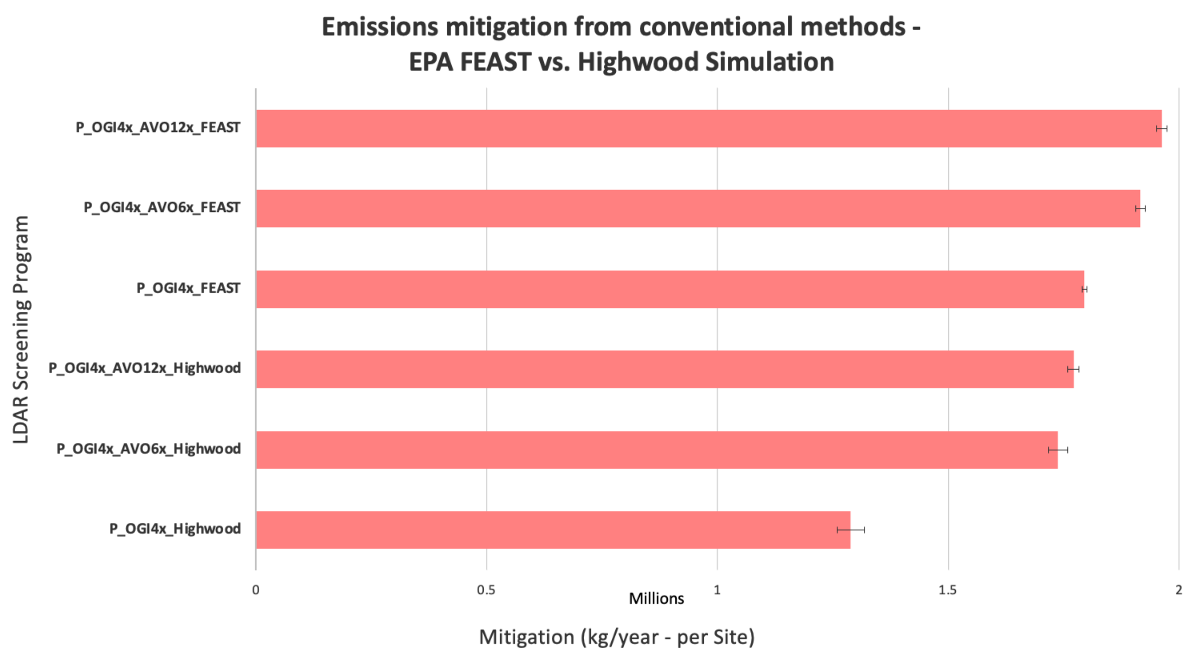

Figure 1. Select results from Highwood report, comparing emissions mitigation for several conventional LDAR screening programs using OGI and/or AVO methods using Highwood

[2] Zimmerle, D., Vaughn, T., Bell, C., Bennett, K., Deshmukh, P. and Thoma, E. (2020). Detection Limits of Optical Gas Imaging for Natural Gas Leak Detection in Realistic Controlled Conditions. Environmental Science & Technology, 54(18), pp.11506–11514

[3] Sherwin, E., et al., 2023, "Quantifying oil and natural gas system emissions using one million aerial site measurements," Figure 3, in review *Nature*, preprint: https://doi.org/10.21203/rs.3.rs-2406848/v1

assumptions and EPA FEAST modeling. Each row label refers to the measurement method(s), number of samples per year and the model used (e.g., P_OGI4x_AVO12x_FEAST refers to EPA's FEAST model results for a quarterly OGI + monthly AVO surveys). See Appendix A for full definition for each screening program.

Key result 2: Satellites can offer equivalent performance to other screening methods. The methane mitigation performance of all evaluated satellite programs, most importantly with detection threshold 100 kg/hr and weekly screening, is equivalent to or exceeds the performance of options currently allowed in EPA proposal.

The Highwood simulations evaluated the performance of an annual OGI inspection plus three hypothetical LDAR screening programs compatible with MDL and sample frequencies of representative satellite and airborne remote-sensing systems: 30 kg/hr, monthly; 50 kg/hr, biweekly (14 day); and 100 kg/hr, weekly. All three programs achieve greater emissions mitigation than quarterly OGI parameterized using Highwood assumptions (Figure 2, P_OGI4x_Highwood) under the Cusworth distribution. This is due primarily to the impact of the improved spatial and temporal coverage capabilities of remote sensing satellites and aircraft.

We note that while some existing and planned satellites and aircraft are capable of achieving methane MDLs at or below 30 kg/hr, that typically only occurs under a narrow range of environmental conditions and hence we recommend a 100 kg/hr threshold, which is likely more achievable for more technology providers.

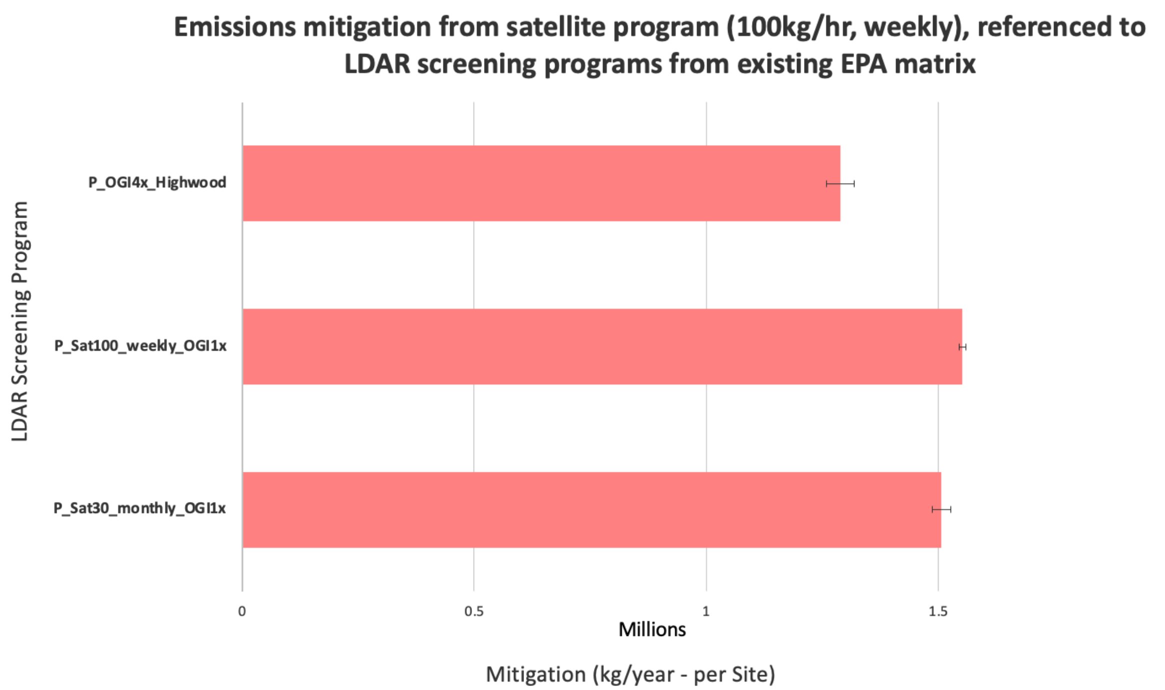

Figure 2. Select results from Highwood report, comparing emissions mitigation for a satellite-inclusive (100 kg/hr weekly) LDAR screening program with existing screening matrix options 30 kg/hr monthly and quarterly OGI-only (using Highwood assumptions). Each row label refers

to the measurement method(s), number of samples per year and for the satellite cases, detection limit (e.g., P_Sat100_weekly_OGI1x refers to weekly satellite observations with 100 kg/hr MDL + annual OGI). See Appendix A for full definition for each program.

The Highwood simulation results lead us to strongly encourage *Recommendation #1* and *Recommendation #2* as described above and envisioned in Table 1B. **Unless EPA expands the matrices to include the 100 kg/hr threshold, most satellites and many airborne systems will be excluded as alternative methods and dramatically limit the potential for emissions mitigation.** For example, a recent review paper by Jacob *et al* 2022 noted most current and planned methane-capable satellites have detection limits well above 30 kg/hr but only a few report the ability to achieve detection limits as low as 100 kg/hr[4]. We note that while EPA's and Highwood's modeling both use the same Cusworth *et al.* emissions distribution from surveys of the high emission Permian Basin, recent studies combining field measurements and simulation such as that from Sherwin *et al.* 2023 indicate that other major oil and gas basins exhibit similar emissions distribution characteristics[5]. Specifically, the Sherwin *et al.* study indicates 40%-80% of total point-source emissions from the oil and gas sector exceed 100 kg/hr in the Permian, Barnett, Marcellus and San Joaquin basins. Additionally, cumulative distribution functions for point source emissions in those basins as well as the lower-emission Uinta and Denver-Julesburg basins do not display a large drop between 100 kg/hr and 30 kg/hr. Therefore, our recommended additions to the screening program would be equally effective in achieving similar methane reduction across most U.S. oil and gas producing basins.

Additionally, we urge EPA to consider the influence that the design of its rulemaking will exert on a rapidly changing landscape: specifications in the final matrix will affect technology development for years to come. Moreover, the US approach to and inclusion of advanced technologies, namely satellites with global, high-frequency monitoring capabilities, have the chance to spur positive domestic impact beyond the sectoral scope of this rule (focused on onshore oil and gas production) and beyond our national borders. At this pivotal moment in time for climate mitigation, expanding the matrix per our recommendations would ensure that all technologies available for methane reduction remain eligible while not requiring operators to opt into these high-frequency screening programs. Finally, given that emissions data will continue to rapidly improve, we encourage EPA to recognize the importance of having a regulatory process and expectation to update the screening protocols periodically over time.

2. Super-Emitter Response Program

We encourage EPA to take all steps necessary to ensure successful implementation of the proposed Super-Emitter Response Program (SERP). This innovative, first-of-a-kind initiative will combine third-party observations and direct operator notification of super-emitter events

[4] See Table 3 in Jacob et al., Atmos. Chem. Phys., 22, 9617–9646, 2022 https://doi.org/10.5194/acp-22-9617-2022

[5] Sherwin, E., et al., 2023, "Quantifying oil and natural gas system emissions using one million aerial site measurements," Figure 3, in review *Nature*, preprint: https://doi.org/10.21203/rs.3.rs-2406848/v1

with requirements for operators to conduct follow-up assessment and repair action. As NGOs, Carbon Mapper and RMI strongly support the establishment of the SERP program.

If implemented in a sufficiently robust, widespread, and sustained fashion, the SERP can offer many benefits. The SERP provides a critical backstop to the operator LDAR screening program by filling potential gaps in spatial and temporal coverage. The SERP can also identify potential issues with self-reported methane leakage with implications for EPA's Methane Emission Reduction Program introduced in the Inflation Reduction Act. Similarly, the SERP will have the ability to flag gaps in EPA's Greenhouse Gas Reporting Program (GHGRP), particularly for intermittent super-emitters that often go undetected by traditional site-level monitoring, enabling improvements in overall methane accounting. While the SERP as proposed is limited to the onshore oil and gas production equipment included in the scope of this rule, it establishes a framework that encourages the use of persistent wide-area, high-resolution methane monitoring by satellites and other remote methods. One benefit of such systems is the ability to precisely geolocate methane point source emissions at adjacent infrastructure such as gathering pipelines, downstream natural gas operations, landfills etc, thus reducing the potential for mis-attribution to oil and gas producers. Another benefit, particularly for satellites capable of detecting methane over the ocean, is the ability to detect leaks and malfunctioning equipment at coastal processing and export facilities and offshore oil and gas platforms - thus offering more complete methane intensity verification of the US natural gas value chain with implications on US competitiveness in global markets. SERP-enabled precise location, quantification and transparent reporting of methane super-emitters will offer significant climate benefits and additional co-benefits, such as enabling improved assessment and communication of local impacts (both for operators and nearby communities) resulting from potential co-emitted pollutants such as VOCs and other health-harming air pollutants. Finally, the SERP will contribute to improved public confidence in mitigation progress by industry and government.

The success of the SERP program can be maximized through the following actions. These are intended to reduce the probability of misidentification, to improve the utility of third-party data for operators and the EPA, to maximize transparency and public trust, and to ensure the program is sufficiently resourced to achieve maximum impact.

1) SOURCE GEOLOCATION & OPERATOR IDENTIFICATION
    a) EPA should require third-party reporters to use remote methods (not requiring on-site access) to geolocate the origin of methane super-emitter plumes to within 100 meters with 90% circular error probability. Precise geolocation can help reduce the likelihood of misidentifying facilities and can aid follow-up analysis by operators.
    b) EPA should require third-party reporters to make every economically feasible effort to identify the nearest potential facility operator based on available asset ownership information.
    c) EPA should require third-party reporters to provide the date and time (to within the nearest second) of each super-emitter detection at a given facility with a goal of providing operators with an estimate of the source persistence following multiple observations where possible. Precise timing information can help minimize the chance of false alarms and aid in follow-up analysis by operators.

d) EPA should establish and make available to all approved third-party reporters a list of operator-provided points of contact with contact information to facilitate timely and accurate notification.
e) EPA should consider establishing a publicly available national geographic information system (GIS) database of all oil and gas production infrastructure covered under this rule to facilitate accurate and timely identification of facilities and/or individual equipment by third-party reporters. The database should include a provision for updating records based on operator feedback (e.g., correcting ownership information in the event of a misidentification).

2) EMISSIONS QUANTIFICATION
   a) EPA should require third-party reporters to make every technical and economically feasible effort to report quantitative emission rate estimates and uncertainties for each source reported to operators. This can help track the amount of methane mitigated by repair actions and support assessment of the overall impact of the SERP program.
   b) EPA should consider implementing an annual review of the GHGRP to evaluate consistency with SERP reports towards improving treatment of super-emitter activity in the former.
   c) EPA should consider leveraging quantitative emission estimates from SERP reports to support local air-quality and environmental justice assessments for front-line communities in the proximity of super-emitter events.
3) NOTIFICATION AND PUBLICATION
   a) EPA should encourage third-party reporters to expedite operator notification of super-emitter detection. Notification timelines should account for robust quality control review that minimizes false alarms. EPA should be flexible on notification timelines in the interest of maximizing SERP participation from qualified non-profit or research organizations whose quality control (QC) processes may be constrained by available workforce.
   b) EPA should require that all super-emitter reporting is conducted in a transparent and non-proprietary manner.
   c) EPA should maintain a public database of all super-emitter notifications by certified third-party reporters with updates on an annual basis including mitigation reports by operators where available.
4) REPORTER CERTIFICATION
   a) EPA should provide flexibility in certifying reporting organizations under the SERP including allowing both data providers and reporting organizations meeting the agency criteria to be considered “third parties”.
   b) EPA should carefully review and elaborate on proposed criteria for removing approval of a third-party reporter for participation in the SERP program, particularly regarding the definition of “demonstrable errors”. For example, if an owner/operator claims that a third-party reported super-emitter did not exceed the 100 kg/hr threshold, EPA should require counterevidence with equivalent or better measurement technology based on simultaneous observations (since EPA recognizes that source intermittency is not grounds for error).
   c) EPA should clarify the definition of “owner/operator” and “site” and specify the interval for evaluation when reviewing claims that “more than three notifications

were made in error". In one instance the proposed rule applies to "the same site" and in another "to that same owner or operator". While more than three verifiable errors at a single production site in one month might be reasonable grounds for review, three errors across a population of hundreds of facilities over the course of a year would not be excessive considering statistical fluctuations inherent in a large number of samples.

5) FUNDING
    a) EPA should provide competitive grants and other funding opportunities to ensure the establishment and continuity of third-party observing systems and frameworks for robust identification and notification of facility operators, which otherwise would likely remain limited to philanthropic funding. Potential SERP funding sources include provisions for methane monitoring in the Methane Emissions Reduction Program (see Docket ID No. EPA-HQ-OAR-2022-087).

3. Updates to emissions monitoring requirements for all sites

An update from the November 2021 proposal includes routine fugitive emission monitoring requirements for small well sites, which were exempt in the previous draft. We support the monitoring of small well sites and monitoring within 90 days of startup or modification of well sites and compressor stations, as long standing and/or undiscovered leaks may generate considerable emissions over time. This is particularly true of remote sites not frequently visited by operators otherwise. Furthermore, we support carrying monitoring requirements through the entire life of well sites inclusive of proper well closure to prevent the prevalence of abandoned wells, a currently unmitigated emission source.

4. Flaring Reduction

Under this supplemental proposal, EPA is proposing to require operators and owners to prioritize alternative beneficial reuse options for associated gas from oil wells utilizing a hierarchy of standard control options, and all options must be exhausted prior to resorting to flaring at a site via requesting a variance. The first demonstration and request for variance would require certification by a professional engineer or approved equivalent, and subsequent reports would require simply reporting whether circumstances have changed regarding the need to flare. EPA seeks comment on details and triggers required to continue and/or re-analyze granted variances.

As the impetus for this rule is prevention of the indefinite use of flaring, we support that flaring variances last for a finite period and/or volume (whichever is reached first). New usable sales pipelines or other infrastructure, feasible delivery points for compressed gas, technology, or discoveries in additional beneficial uses may present themselves as available later in the asset's life. As proposed in this rule, we also support that such triggers (variance age, volume flared, or new developments/innovations) should trigger a new, full and certified review similar to original variance requests.

We support EPA in requiring operators to attempt to access an existing sales line, the preferred standard control option, and facilitate alternative off-site transport and use of associated gas. Furthermore, since sites operate for decades and sales lines are typically not under the control of the well owners and operators, we recommend that operators include an attempt to collaborate with gathering system owners regarding both upcoming or proposed sales line projects and production projects, as this may inform and optimize sales lines route engineering. If enough operators collaborate with gathering system owners, gathering system owners may respond to the demonstrated need of sales pipelines in unserved/underserved areas. Otherwise, pipelines may not be developed due to a lack of discussion and identification of opportunity.

This supplemental proposal and existing regulations does not contain provisions to directly validate or verify destruction efficiency, unless a flare is detected as part of the Super-Emitter Response Program. We recommend that EPA remain abreast of studies and data available that would indicate improvements in flare performance based on requirements. Furthermore, this supplemental proposal requires use and performance monitoring of a pilot flame used for flaring at all times, "unless a demonstration has been made that the NHV of the inlet gas to the flare consistently exceeds the operating limit established in the rule." We believe, similar to the above discussion regarding flaring variances, that this demonstration should be subject to a time- and/or volume-based limitation and should require re-submittals to ensure that original conditions granting such an exception persist.

5. Identification of Owners/Operators of Facilities - Change of Ownership

In this supplemental proposal, the EPA noted that states, NGOs, and other stakeholders are concerned with the prevalence of orphaned wells and unplugged idled wells, as such wells are generally unmanned and often in disrepair. Given orphaned wells often have no defined legal and responsible owners, improperly closed and orphaned wells are at risk of indefinitely producing emissions. To address this, the EPA is proposing to require owners and operators to communicate all changes of ownership of individual well sites through annual reports to increase visibility and reinforce each new owner's responsibilities.

We support the inclusion of this disclosure in annual reports, as clear documentation, consolidated within the EPA's repository, should decrease confusion regarding ownership and associated obligations. Annual reports should include information about owners, operators if different, and certification of notification to relevant state authorities (departments of environmental quality, counties, oil and gas authorities, etc.) for record keeping and consistency between state and federal agencies. Many state authorities already require such notifications, and checking that such steps are processed in federal annual reports would greatly increase participation and improve the accuracy of state-wide databases. Similarly, other relevant information such as state customer numbers, authorized signatories, site contact information, and corporate/administrative contact information could be included to further synchronize state and federal databases. If state-wide databases are up-to-date and in sync with federal databases, state authorities may be able better assist the EPA in preventing orphaned wells and ensuring proper well closure.

Furthermore, change in ownership may affect sites included within the SERP. As the EPA is seeking comment on all aspects of this proposed program, we recommend also sharing information regarding changes in ownership with the SERP public database, in order to highlight if ownership has changed since notice of the event.

Appendix A: Carbon Mapper LDAR-Sim Simulation Modeling: Proposed EPA Ruling Investigation, prepared by Highwood Emissions Management

January 2023

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Executive Summary

The EPA has proposed supplemental rules around methane leak detection and repair. Part of these supplemental rules define a "matrix" of criteria which alternative technologies (drones, satellites, etc.) must meet in order to achieve equivalency with the conventional LDAR methods and work practises, optical gas imaging cameras (OGIs) and audio visual olfactory (AVO) surveys performed at predefined frequency depending on the site type. These matrixes of criteria were established using the Fugitive Emissions Abatement Simulation Testbed (FEAST) model. Some concerns have been raised over the FEAST modeling including the leak rate distributions used and the parameterization of the conventional methods.

To investigate alternative modeling approaches, Highwood Emissions Management on behalf of Carbon Mapper and MiQ ran simulation models using LDAR-Sim designed to approximate the modeling carried out by FEAST as well as present alternative approaches through new LDAR-Sim parameters and parameterization of conventional LDAR methods.

LDAR-Sim modeling indicates that when a leak rate distribution based on an augmented version of the emissions distribution from Cusworth 2021[1] is used, Satellite based LDAR programs can achieve emissions reduction equivalency with a quarterly OGI based program assuming Highwood parameterization assumptions. With the satellite-based programs achieving 68.5% - 72.1% emissions reduction and the quarterly OGI program achieving 58.9% emissions reductions. However, satellite-based programs cannot achieve emissions reduction equivalency when compared against a program which makes use of AVO surveys as parameterized by the FEAST modeling.

Finally, we found that the LDAR-Sim specific spatial and temporal coverage parameters have a large impact on simulation results. When we assume "perfect" coverage vs. values typically assumed in LDAR-Sim modeling we see a drop in emissions reduction by up to 23.1%.

Next steps are to investigate how to more accurately represent AVO inspections in simulation modeling.

Glossary

The following key definitions are applied throughout this report. Further details on the framework which informed these definitions can be found in Fox, TA, et al. 2019[2]:

- **Technology**: A gas sensing instrument, optionally configured with a deployment platform and/or ancillary instruments (e.g., anemometers, positioning), that can be used to gather data on emissions.
- **Work practice**: A description of how a technology is used to collect information about emissions, including operating procedures (e.g., distance from source, measurement time, environmental envelopes for sure, production segments)
- **Method**: The combination of a technology, a work practice, and analytics for use in an LDAR Program. An LDAR Program has at least one method (in cases where only one method is used, method and LDAR Program are synonymous).
- **Leak Detection and Repair Program (LDAR Program)**: An LDAR Program is the systematic implementation of one or more methods across a collection of assets. The program describes the method, or combination of methods, to be used for each facility, along with survey frequency, repair response, and reporting standards. Ultimately, it is the LDAR Program that results in emissions mitigation, not the technologies or methods in isolation.

Introduction

Highwood Emissions Management (Highwood) on behalf of MiQ and Carbon Mapper have undertaken a modeling exercise using LDAR-Sim to investigate how the Carbon Mapper satellite platform will perform against the proposed supplemental EPA methane rule work practices. Simulation modeling was designed to represent the EPA defined performance of conventional LDAR methods (OGI and AVO) as well as a Highwood defined performance of these methods.

Methodology

LDAR-Sim has over 100 parameters which allow for the fine tuning of the facilities in the virtual world (the size and frequency of emissions they generate) and the performance/behaviour of the LDAR and Alt-LDAR Programs and methods (Minimum detection limit, travel speed, survey speed, operational weather envelopes, etc.). The body of this report will, at a high level, describe the LDAR-Sim parameterization hierarchy and operation, and touch on the most relevant parameters to the Carbon Mapper simulation modeling. More extensive parameterization details will be detailed in an appendix.

LDAR-Sim Parameter Hierarchy

Figure A1 Illustrates the hierarchy/nomenclature of parameterization in LDAR-Sim

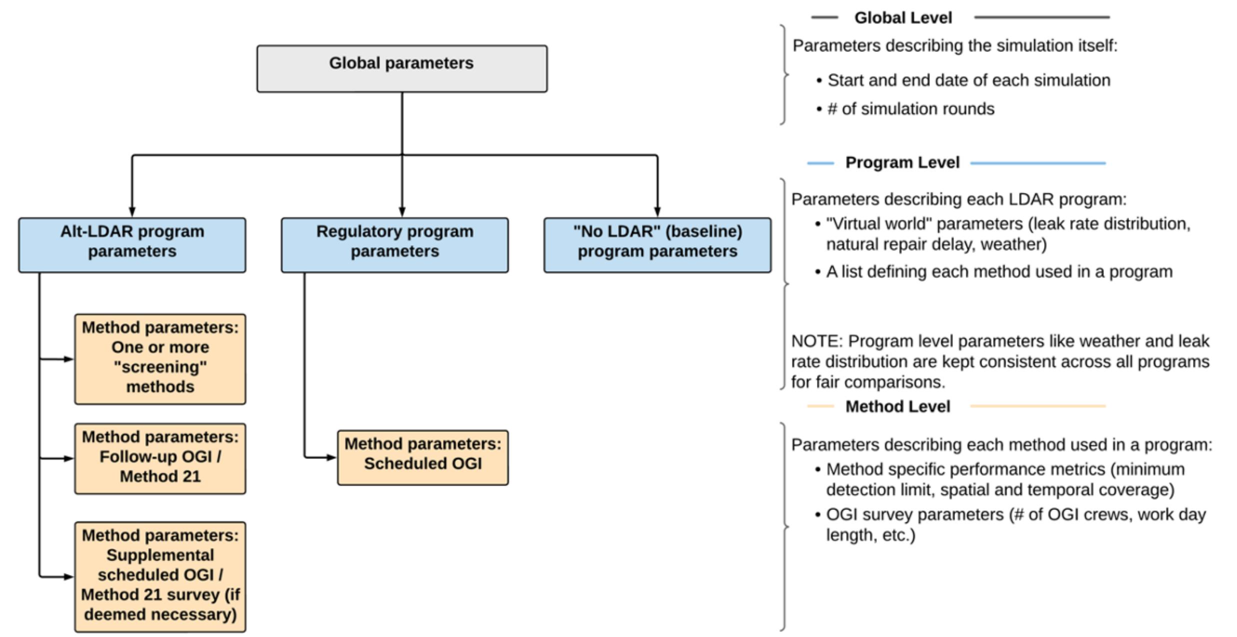

Figure A1 LDAR-Sim Parameterization Hierarchy

LDAR-Sim Simulation Flow

Figure A2 Presents a high-level overview of the processes which occur during each day of the simulation. Some additional functionality has been added to LDAR-Sim since the creation of this figure. Furthermore, some functionality is simplified (thresholds and minimum detection limits are synonymous in the simulations described in this report).

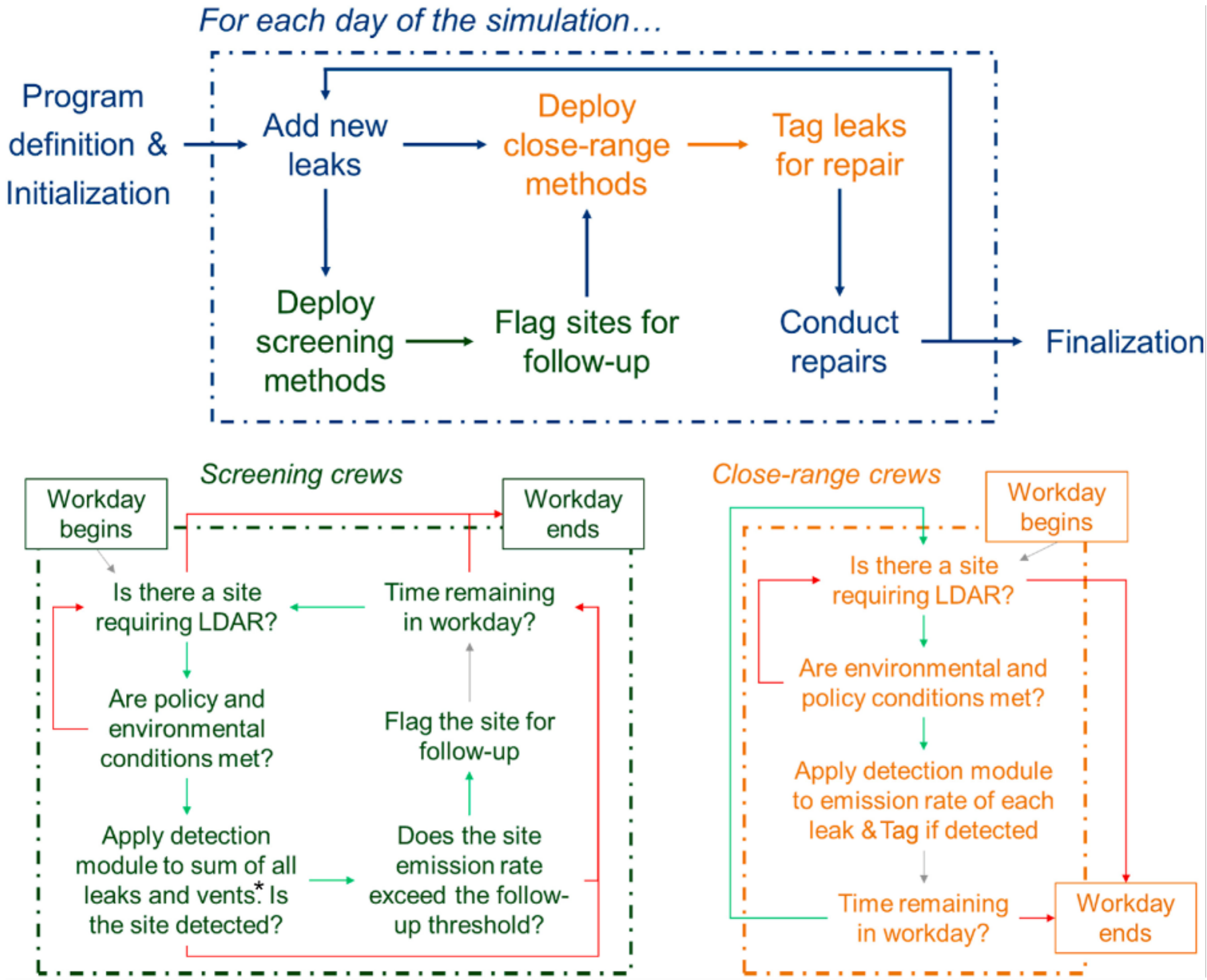

Figure A2. A detailed overview of some of the processes with occur in LDAR-Sim simulations each day of simulated time, modified from Fox et al. 2020. In this report, screening methods (green text and arrows) are Satellite screenings while close-range Methods (orange text and arrows) are land based OGI crews. Red arrows represent 'no', green arrows are 'yes', and grey arrows are mandatory. While this flowchart provides a good overview of some processes it is based on a previous version of LDAR-Sim and does not include travel time considerations used in the modeling detailed in this report.

LDAR-Sim and FEAST Differences

While an attempt was made to replicate how the supplemental EPA rule FEAST modeling considered conventional LDAR programs (described in more detail here, starting on PDF page 223) there are some key differences between how FEAST and LDAR-Sim considers simulated infrastructure. FEAST approaches simulations from a bottom up approach, providing parameterization of leak frequency and leak size to different component/equipment types at a given facility type and representing these equipment and component types proportionally at each site. For example, in the FEAST modeling done for the supplemental EPA ruling, 4 different "Model Plants" were considered. In Model Plant 4, designed to represent a complex site with controlled tanks (tank emissions are considered fugitives) there are 612 "fugitive equipment components" (representing things like loose valves, etc.), 4 "tanks" (representing fugitive tank-based emissions) and 2 "Large emitters" (representing super-emitters from various sources). Each of these 3 equipment types will have a predefined leak frequency and leak rate distribution.

LDAR-Sim considers facilities from a top-down approach with leak size and leak frequency operating at site-level. Emissions characteristics are assigned to given site subtypes (well production facilities, compressor stations, etc.). Both LDAR-Sim and FEAST do not consider venting/allowable emissions for the purpose of this investigation.

Key Parameterizations

The following parameters have the most marked impact on simulation results.

- **Leak Production Rate**: (LPR) The probability that a fugitive emission will arise at a given site on a given day. A Highwood assumed default value of 0.0065 which leads to, on average, 2.4 leaks per site per year is used across all programs. FEAST employs specific LPR's for the various equipment types, but since LDAR-Sim operates on a site level this is simplified.
- **Leak Rate Distribution**: The distribution which dictates the simulated emission "size" as a rate. As per initial conversations with Carbon Mapper, two LDAR-Sim simulations were run. One used a leak rate distribution informed by Zavala-Araiza, 2015[3] "Production" distribution (a "compressor" distribution is also present in this study) and one used an augmented version of the Cusworth, 2021[4] distribution. Augmentation of the Cusworth distribution was carried out by the group conducting FEAST modeling for the EPA rule and is discussed in the technical memo. At a high level, augmentation was carried out to account for the relatively large minimum detection limit (MDL) of the aircraft used in gathering emission rates in the Cusworth study – the distribution was adjusted to allow for the possibility of leaks smaller than the aerial MDL.
- **Method MDL**: Can be a single emission rate (the method cannot detect and flag any emission smaller than this rate) or a probability of detection (PoD) curve (emission rates are applied to the curve, a "weighted coin" is flipped weighted by the resultant probability which dictates if the method can detect the emission). The "Highwood OGI" is parameterized with a PoD curve informed by Zimmerle, 2020[5] which accounts for operator experience. **The Highwood OGI PoD curve has a 95% PoD at an emission rate of 0.182 g/s**. All other methods MDL is parameterized by single values:
    - FEAST informed OGI MDL: 0.02 g/s (informed by FEAST EPA modeling Memo)
    - FEAST informed AVO MDL: 0.0678 g/s (informed by FEAST EPA modeling Memo)
    - Satellite MDL: 100 kg/hr (27.8 g/s), 50 kg/hr (13.9 g/s), 30 kg/hr (8.33 g/s) (informed by Carbon Mapper guidance)
- **Spatial coverage**: A representation of the average proportion of a facility the method can effectively survey. For example, a value of 0.7 indicates that the method will find a leak 100% of the time in 70% of the site. In practice, every time a method goes to survey a

new leak, a weighted coin is flipped representing spatial coverage. If the method "loses" the weighted coin flip, it will not detect the emission and it will also not be able to detect it on ensuing survey visits.

- **Temporal Coverage**: The probability the method will detect a leak in a single survey. This parameter can be used to ***approximate*** intermittency (the current gap is that intermittency when represented this way only concerns **detection**, baseline emissions for these emissions are still considered constant, updating this behaviour is a work in progress). For example, if the value is set to 0.80, it represents an intermittent emission that has a 20% chance of not emitting when a survey is conducted. In practise, every time a method goes to survey a leak, a weighted coin is flipped representing temporal coverage. If the method "loses" the weighted coin flip, it will not detect the emission, however, unlike spatial coverage, this coin is re-flipped the next time the method comes to the site with the emission in question. As such, this parameter has a much larger negative effect on methods with less frequent surveys as the temporal coverage "weighted coin" is flipped less frequently. So, if a method with a high survey frequency fails to detect an emission due to temporal coverage, it will have a "re-try" sooner than a method with a lower survey frequency which missed the same emission due to temporal coverage. Note that FEAST does not consider either of the coverage parameters.
- **Coverage parameterization**: In "Highwood" programs a spatial coverage of 0.8 and a temporal coverage of 0.75 are used. While these parameters are difficult to define, Highwood believes they are important to consider and as such chose conservative values based on conversations with vendors.

Program and method nomenclature

The following will describe the programs run in simulation, their parameterization and why there were used / what they are designed to represent. Often, programs are designed to replicate elements of the supplemental EPA rules (Figure A3, Figure A4):

Table: Fugitive Emissions monitoring requirements by source category.

Source Category	Monitoring Requirements
Single wellhead-only sites and small well sites	Quarterly AVO inspections
Multi-wellhead-only sites with two or more wellheads	Semiannual OGI (or EPA Method 21) monitoring and quarterly AVO inspections.
Well sites and centralized production facilities with major production and processing equipment	Quarterly OGI (or EPA Method 21) monitoring and bimonthly AVO inspections.
Compressor Stations	Quarterly OGI or EPA Method 21 monitoring and monthly AVO inspections[1]

[1]EPA commented that even though small company compressor stations are not human-crewed 24 hours a day, they are visited weekly, if not daily. Therefore, monthly AVO requirements would not increase monitoring costs.

Figure A3. Conventional LDAR survey requirements for various site types as per the supplemental EPA rules. Matrix defined by FEAST modeling. Source: https://highwoodemissions.com/new-epa-methane-emissions-regulations-proposal/

Table: Survey matrix for alternative periodic screening (facilities subject to quarterly OGI monitoring).

Minimum Screening Frequency	Minimum Detection Threshold of Screening Technology[1]
Quarterly + Annual OGI	≤1 kg/hr
Bimonthly	≤2 kg/hr
Monthly	≤4 kg/hr
Bimonthly + Annual OGI	≤10 kg/hr
Monthly + Annual OGI	≤30 kg/hr

[1] Based on a probability of detection of 90 percent.

Figure A4. Equivalency requirements for alternative LDAR technologies as per the supplemental EPA rules. Equivalency "tiers" are defined by FEAST modeling. Source: https://highwoodemissions.com/new-epa-methane-emissions-regulations-proposal/

Programs used in LDAR-Sim, their high-level parameterization and what they are designed to represent follow:

- **P_OGI4x_AVO12x_FEAST**
  - Methods and Frequencies
    - Quarterly OGI surveys
    - Monthly AVO surveys
  - Use / representation:
    - This program is designed to represent the proposed regulatory requirement of monitoring compressor stations (Figure A3).
  - Parameterization:
    - Methods are parameterized based on EPA FEAST modeling. Single cut-off MDL values are used, and no coverages are applied.
- **P_OGI4x_AVO6x_FEAST**
  - Methods and Frequencies:
    - Quarterly OGI surveys
    - Bi-monthly AVO surveys
  - Use / representation:

        - This program is designed to represent the proposed regulatory requirement of monitoring "Well sites and centralized production facilities with major production and processing equipment" (Figure A3).
    - Parameterization:
        - Methods are parameterized based on EPA FEAST modeling. Single cut-off MDL values are used, and no coverages are applied.
- **P_OGI4x_FEAST**
    - Methods and Frequencies:
        - Quarterly OGI surveys
    - Use / representation:
        - This program was used to allow a 1-to-1 comparison of FEAST and Highwood OGI parameterization. Highwood does not currently have an empirically defined means of parameterizing AVO, so, this program has it completely removed.
    - Parameterization:
        - Methods are parameterized based on EPA FEAST modeling. Single cut-off MDL values are used, and no spatial coverages are applied.
- **P_OGI4x_AVO12x_Highwood**
    - Methods and Frequencies:
        - Quarterly OGI surveys
        - Monthly AVO surveys
    - Use / representation:
        - This program is designed to represent the proposed regulatory requirement of monitoring compressor stations (Figure 3), only, with OGI and AVO parameterized as Highwood typically would.
    - Parameterization:
        - Methods are parameterized based on Highwood assumptions. A PoD curve is used for OGI detection and spatial and temporal coverage parameters of 0.8 and 0.75 are applied respectively to all methods.
- **P_OGI4x_AVO6x_Highwood**
    - Methods and Frequencies:
        - Quarterly OGI surveys
        - Bi-monthly AVO surveys
    - Use / representation:
        - This program is designed to represent the proposed regulatory requirement of monitoring "Well sites and centralized production facilities with major production and processing equipment" (Figure A3), only, with OGI and AVO parameterized as Highwood typically would.
    - Parameterization:

        - Methods are parameterized based on Highwood assumptions. A PoD curve is used for OGI detection and spatial and temporal coverage parameters of 0.8 and 0.75 are applied respectively to all methods.
- **P_OGI4x_Highwood**
    - Methods and Frequencies:
        - Quarterly OGI surveys
    - Use / representation:
        - This program was used to allow a 1-to-1 comparison of FEAST and Highwood OGI parameterization. Highwood does not currently have an empirically defined means of parameterizing AVO, so, this program has it completely removed.
    - Parameterization:
        - The OGI method is parameterized based on Highwood assumptions. A PoD curve is used for OGI detection and temporal and spatial coverage parameters of 0.8 and 0.75 are applied respectively to all methods.
- **Satellite programs**
    - Methods and Frequencies and parameterization:
        - Weekly monitoring = 100 kg/hr MDL, bi-weekly monitoring = 50 kg/hr MDL, monthly monitoring = 30 kg/hr MDL
        - Satellite methods have been modeled with spatial and temporal coverage parameters of 0.9 and 0.75 respectively.
        - Each program has an annual supplemental OGI method that is parameterized using Highwood assumptions (PoD curve and coverage parameters applied).
    - Use / representation:
        - Designed to represent the potential various satellite performance. The monthly frequency satellite program is designed to represent the equivalent alternative modeling tier of Figure A4.
- **P_none**
    - A program devoid of LDAR programs. The only way in which an emission is repaired in this program is through the “Natural Repair Delay” parameter. This parameter represents the duration a leak exists until it is “organically” repaired (retrofits, random operator inspections, etc.). This parameter is set to 365 days and is present for all programs.

A note on EPA OGI and AVO survey frequency: The cadence of OGI and AVO surveys is provided in the EPA supplemental rule and there are potential overlapping surveys. LDAR-Sim modeling was true to the EPA FEAST modeling technical memo survey frequencies. Figure A5 describes the survey frequencies:

Month	Quarterly OGI	Bi-monthly AVO	Monthly AVO
1			AVO
2		AVO	AVO
3	OGI		AVO
4		AVO	AVO
5			AVO
6	OGI	AVO	AVO
7			AVO
8		AVO	AVO
9	OGI		AVO
10		AVO	AVO
11			AVO
12	OGI	AVO	AVO

Figure A5. OGI and AVO survey frequencies as defined by EPA and FEAST modeling

Results

Results are presented for the simulation drawing from Zavala-Araiza, 2015 and Augmented Cusworth, 2021. The horizontal bar graphs show **emissions mitigation** in kg of methane per year per site (there are 2000 sites per simulation) for each program (larger bar = better mitigation) whereas the time series shows emissions per site ("higher" time series = more emissions).

"FEAST Programs" and "Highwood Programs" are assigned the same color in the timeseries to aid in interpretability. This can be modified if required.

Using the Zavala-Araiza "Production" distribution

Emissions Mitigation

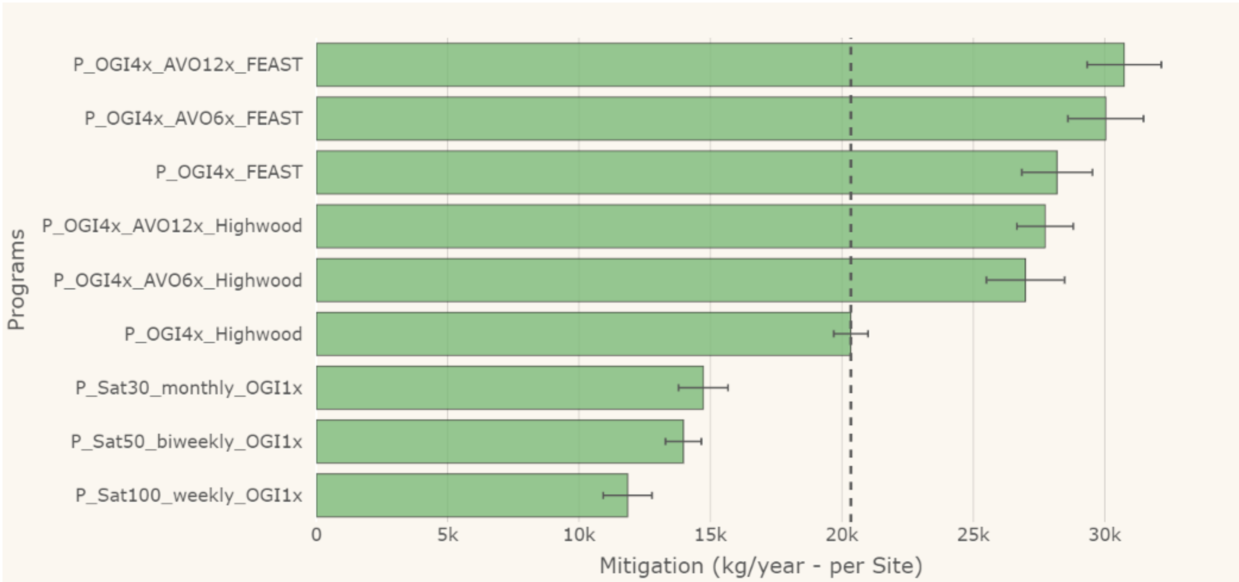

Figure A6. Emissions mitigation in kg of methane per site per year. Programs listed in the Y-axis are applied to a virtual world of 2000 sites where leak rates are informed by the Zavala-Araiza 2015 "Production" emission rate distribution.

Emissions Time Series

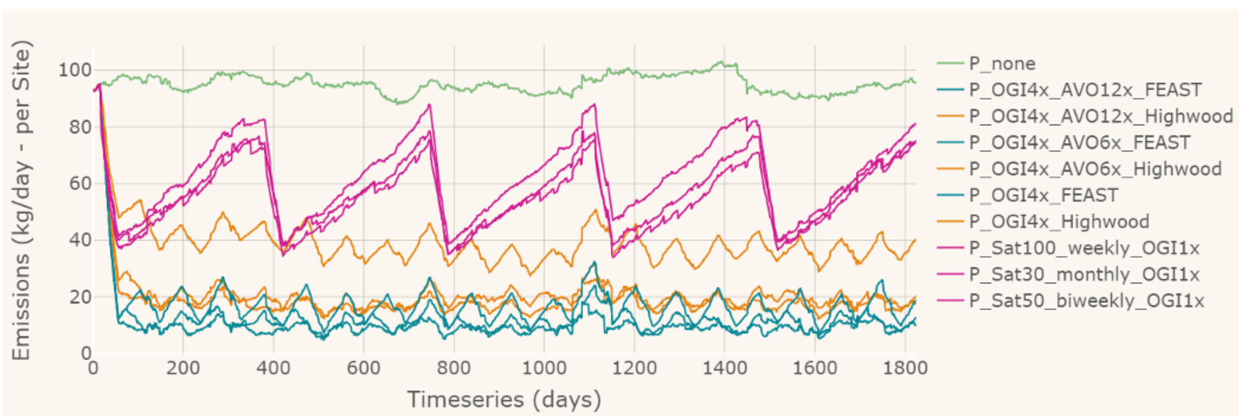

Figure A7. Emissions time series of various satellite and conventional LDAR programs applied to a virtual world of 2000 sites where leak rates are informed by the Zavala-Araiza 2015 "Production" emission rate distribution.

Using the "Augmented" Cusworth distribution

Emissions Mitigation

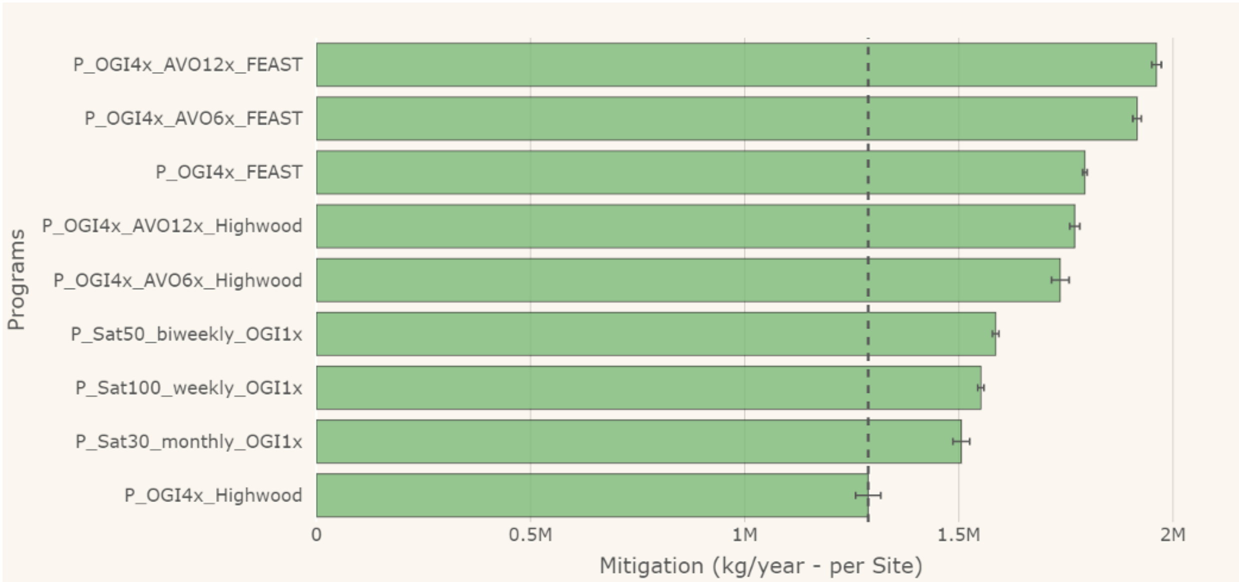

Figure A8. Emissions mitigation in kg of methane per site per year. Programs listed in the Y-axis are applied to a virtual world of 2000 sites where leak rates are informed by the augmented Cusworth 2021 emission rate distribution.

Emissions Time Series

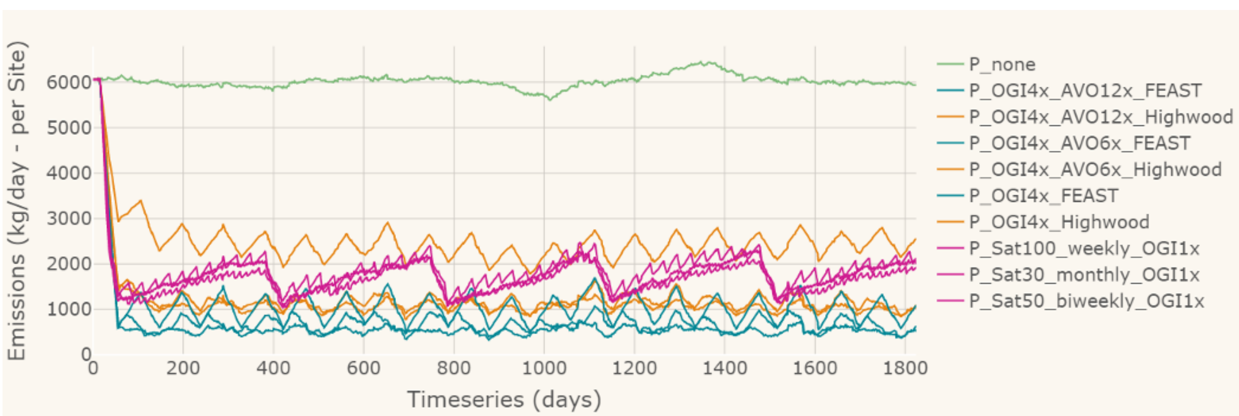

Figure A9. Emissions time series of various satellite and conventional LDAR programs applied to a virtual world of 2000 sites where leak rates are informed by the augmented Cusworth 2021 emission rate distribution.

Discussion

When reviewing results often discussion will center around "P_OGI4x_FEAST" and "P_OGI4x_Highwood" – programs intentionally devoid of AVO inspections. Highwood believes the FEAST representation of AVO surveying is overly optimistic in terms of performance, however, does not have ample empirical data with which to adjust performance. As such, when comparing FEAST and Highwood parameterization more useful conclusions can be drawn by investigating programs without AVO.

The following key takeaways can be drawn from these results:

- ➢ The supplemental EPA ruling matrixes indicate equivalency can be achieved with quarterly OGI by a screening program with a minimum detection limit of 30 kg/hr and monthly survey frequency. This equivalency is not seen in the presented results (when comparing satellite programs with "FEAST" quarterly monitoring programs). This is because the alternative satellite-based programs are parameterized using Highwood assumptions of coverage and OGI MDL. In other words, for these results we have only parameterized the satellite-based programs around Highwood assumptions. Additional simulations were run in which satellite-based programs were parameterized with FEAST modeling assumptions (no coverage parameters, or, assumed "perfect" coverage) and each satellite program did achieve equivalency with quarterly OGI based programs parameterized with FEAST assumptions. These results are omitted here for clarity but can be circulated if desired.

- ➢ The augmented Cusworth distribution, on average, leads to much larger leaks in the system as evidenced by the y-axis of the timeseries and the x-axis of the horizontal bar charts. Note that more emissions in the system allow for greater potential mitigation as shown in the larger bar chart values.

- ➢ The cyclicity seen in the timeseries for the satellite programs reflects the impact of the annual OGI method (cyclicity is annual). This cyclicity is more pronounced in the Zavala-Araiza simulation, indicating that the annual OGI program is finding most of the emissions and therefore contributing the most to emissions reductions. This result is expected as the Zavala-Araiza distribution typically leads to "small" leaks, the average leak was 0.48 g/s (1.73 kg/hr), much smaller than the MDL's of the satellite methods. Conversely, the average leak size when using the Cusworth distribution is 29 g/s (104.4 kg/hr). This helps illustrate the importance of leak rate distribution, the Zavala-Araiza production distribution is likely too small to accurately represent super-emitters in a basin like the Permian.

- ➢ The importance of satellite MDL and survey frequency varies according to the distribution:
  - ○ In the Zavala-Araiza distribution, the lowest/best MDL but more irregular frequency leads to the best mitigation, this is likely caused by the, on average, small emissions. In the Cusworth distribution simulation, the satellite program with the "middle" MDL and survey frequency (50 kg/hr, biweekly) seems to represent a "sweet spot" and achieves the highest mitigation.
- ➢ The impact of the coverage parameters can be seen when comparing "P_OGI4x_FEAST" and "P_OGI4x_Highwood". While these simulations see OGI MDL parameterized differently (single cut-off vs. curve based approach), the Cusworth distribution is large enough that these differences are less noticeable (all leaks are sufficiently large when applied to the Highwood OGI PoD curve). As such, the difference is primarily due the presence of the coverage parameters.

- ➢ **All satellite programs achieve greater emissions mitigation than a quarterly OGI program parameterized using Highwood assumptions (P_OGI4x_Highwood) under the Cusworth distribution simulation**. This is due primarily to the impact of the coverage parameters. Keep in mind satellite methods have a slightly higher ("better") coverage parameterization than OGI methods.

- ➢ AVO surveys have a noticeable impact on simulation results (compare programs with and without AVO surveys parameterized with both "FEAST" and "Highwood" assumptions). The FEAST parameterization with an MDL of 0.0678 g/s and no coverage parameters assumes AVO inspections will find *all* leaks below the MDL. There is ample anecdotal evidence to suggest this is does not happen in practise. It is difficult to accurately model due to the lack of empirical evidence on its performance.

Next Steps

AVO remains the largest unknown in the simulations run up to this point. While Highwood believes the FEAST AVO parameterization is overly optimistic in terms of performance, it is hard to know how to re-parameterize this parameter and investigate it further. Investigations comparing satellite-based programs to less frequent OGI survey-based programs could also be undertaken to see if satellite programs could potentially fit into other tiers of the matrix.

Report Appendix: Further Parameterization

The programs described in the body of the report and their associated methods:

Programs:

- **P_none**
- **P_OGI4x_Highwood**
  - M_OGI4x_Highwood
- **P_OGI4x_FEAST**
  - M_OGI4x_FEAST
- **P_OGI4x_AVO6x_FEAST**
  - M_OGI4x_FEAST
  - M_AVO6x
- **P_OGI4x_AVO12x_FEAST**
  - M_OGI4x_FEAST
  - M_AVO12x
- **P_OGI4x_AVO6x_Highwood**
  - M_OGI4x_Highwood
  - M_AVO6x_HW

- **P_OGI4x_AVO12x_Highwood**
    - o M_OGI4x_Highwood
    - o M_AVO12x_HW
- **P_Sat100_weekly_OGI1x**
    - o M_Sat100_weekly
    - o M_OGI1x_Highwood
    - o M_OGI_FU_Highwood
- **P_Sat50_biweekly_OGI1x**
    - o M_Sat50_biweekly
    - o M_OGI1x_Highwood
    - o M_OGI_FU_Highwood
- **P_Sat30_monthly_OGI1x**
    - o M_Sat30_monthly
    - o M_OGI1x_Highwood
    - o M_OGI_FU_Highwood

More complete parameterization details follow. Note: weather envelope parameterization assumes LDAR-Sim defaults, this can be updated as required.

Global/Program Parameters (Parameters that are kept constant throughout)

Parameter	**Value**
Distributions [Mean, SD]	Augmented Cusworth (from EPA technical memo) [3.31, 1.64] ZA Production [-1.79, 2.17]
Leak Production Rate	0.0065
Simulation Duration	5 years {[2023, 1, 1] - [2027,12,31]}
Number of simulations	3
Sites	2000
Natural Repair Delay	365
Consider weather	True
Repair Delay	14 days

Method Parameters

M_OGI_HW

Parameter	**Value**
Survey Frequency	X1 X4 N/A(follow-up)
Survey Time	60 minutes
Time between sites	30 minutes
Spatial coverage	0.8
Temporal coverage	0.75
MDL	[0.24, 0.39] Based on Zimmerle et al. paper
Reporting Delay	2 days
Weather envelopes	Precip (hourly mm): [0.0, 0.5] Temp (°C): [-40.0, 40.0] Wind (avg hourly m/s): [0.0, 10.0]

M_OGI_FEAST (EPA)

Parameter	**Value**
Survey Frequency	X1 X4 N/A(follow-up)
Survey Time	60 minutes
Time between sites	30 minutes

Spatial coverage	1
Temporal coverage	1
MDL	0.02 g/s
Reporting Delay	2 days
Weather envelopes	Precip (hourly mm): [0.0, 0.5] Temp (°C): [-40.0, 40.0] Wind (avg hourly m/s): [0.0, 10.0]

M_AVO_HW

Parameter	**Value**
Survey Frequency	x6 x12
Survey Time	60 minutes
Time between sites	30 minutes
Spatial coverage	0.8
Temporal coverage	0.75
MDL	0.0678 g/s
Reporting Delay	2 days
Weather envelopes	Precip (hourly mm): [0.0, 0.5] Temp (°C): [-40.0, 40.0] Wind (avg hourly m/s): [0.0, 10.0]

M_AVO

Parameter	Value
Survey Frequency	x6 x12
Survey Time	60 minutes
Time between sites	30 minutes
Spatial coverage	1
Temporal coverage	1
MDL	0.0678 g/s (0.244 kg/hr)
Reporting Delay	2 days
Weather envelopes	Precip (hourly mm): [0.0, 0.5] Temp (°C): [-40.0, 40.0] Wind (avg hourly m/s): [0.0, 10.0]

M_Sat [100_weekly, 50_biweekly, 30_monthly]

Parameter	Value
Survey Frequency	x52 x26 x12
Survey Time	1 (instantly)
Time between sites	1 (instantly)
Spatial coverage	0.9
Temporal coverage	0.75

MDL	27.8 g/s (100kg/hr) 13.9 g/s (50kg/hr) 8.33 g/s (30kg/hr)
Reporting Delay	2 days
Weather envelopes	Precip (hourly mm): [0.0, 0.5] Temp (°C): [-40.0, 40.0] Wind (avg hourly m/s): [0.0, 10.0]

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[1] Cusworth, D.H., Duren, R.M., Thorpe, A.K., et al. (2021). Intermittency of Large Methane Emitters in the Permian Basin. Environmental. Sci. Technol. Lett. 8(7), 567-573. https://doi.org/10.1021/acs.estlett.1c00173
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[4] Cusworth, D.H., Duren, R.M., Thorpe, A.K., et al. (2021). Intermittency of Large Methane Emitters in the Permian Basin. Environmental. Sci. Technol. Lett. 8(7), 567-573. https://doi.org/10.1021/acs.estlett.1c00173
[5] Zimmerle, D., Vaughn, T., Bell, C., Bennett, K., Deshmukh, P. and Thoma, E. (2020). Detection Limits of Optical Gas Imaging for Natural Gas Leak Detection in Realistic Controlled Conditions. Environmental Science & Technology, 54(18), pp.11506–11514