MiQ Equivalency Table Methodology

Purpose

MiQ has developed and maintains the MiQ Equivalency Table to serve as a guidance document for operators interested in certification that choose to elect the application of a tiered monitoring approach outside the performance scoring criteria stipulated in the Monitoring Technology Deployment (MTD) pillar of the MiQ Standard (shown in Table 1). The following document provides a summary of results of the most current iteration of the MiQ Equivalency Table as well as details of the methodology used, modeling inputs, and caveats of the results shown here.

Operators are always encouraged to employ bespoke modeling of their unique Facility through the application of public models such as LDAR-Sim, the Fugitive Emissions Abatement and Simulation Tool (FEAST), and Aro-FEMP. However, operators without easy access to such modeling capabilities are encouraged to use the results of the MiQ Equivalency Table to gain clarity on how different combinations of MTD are evaluated under the MiQ Standard, streamline their evidence-gathering efforts for certification, and ultimately spend more resources mitigating and monitoring for methane emissions.

Table 1. Performance Scoring of the MTD Pillar of the MiQ Onshore Production Standard

Points	**Facility-scale inspection** (MDL of 25 kg hr^{-1} at 90% PoD)	**Source-level inspection**	
12	4x @ 100% sites	1x @ 100% sites	3x @ 50% sites
8	2x @ 100% sites	1x @ 100% sites	2x @ 50% sites
4	1x @ 100% sites	1x @ 100% sites	1x @ 50% sites
0	0x	1x @ 100% sites	N/A

Modeling Results

Figures 1-7 below show the summarized modeling results of the 88 Alt-LDAR Programs evaluated in the current iteration of the MiQ Equivalency Table, across three Facility designations:

1. Generic "oil" basins (GOR[1] ≤ 100 mcf bbl^{-1})
2. Generic "gas" basins (GOR[1] > 100 mcf bbl^{-1})
3. Potential high-emitter basins (see Table 2)

Table 2 below lists the basins currently categorized as "potential high-emitters" with justification. In future iterations of the MiQ Equivalency Table, this list may change as additional studies are published on regions, especially those outside of North America. Figures 1-7 also show the major parameters for Facility Scale inspections (modeled as Aerial surveys), Source Level inspections (modeled as OGI surveys), and continuous emissions monitoring deployment tested. These parameters are summarized in Table 3. Across all subcategories and Facility designations, programs are determined to be equivalent to the 0-, 4-, 8-, or 12-point program specified in Table 1 above. Table 4 below shows a count of the equivalent ratings by Facility designation across all 88 Alt-LDAR Programs. It should be noted that these ratings represent only the Monitoring Technology Deployment pillar of the MiQ Standard and to achieve a particular overall MiQ grade, an operator must also meet the required performance metrics in the Methane Intensity and Company Practices pillars as well (see Section 6.2 of the MiQ Onshore Production Standard).

Table 2. List of Potential High-emitter Basins

Basin	Justification
Bakken	See Plant et al. (2022)
Eagle Ford	See Plant et al. (2022)
Permian	See Chen et al. (2022) and Sherwin et al. (2023)
Onshore basins outside of US & Canada	Basins outside of any national regulation regarding methane emissions abatement assumed to have a higher likelihood of super-emitting events; See Yu et al. (2023) for discussion of global methane hotspots

[1] "Gas-to-oil ratio," with cutoff established by the EPA to classify production wells as either gas wells or oil wells. Used here to differentiate production basins.

Table 3. Key Parameters Varied Across Alt-LDAR Programs

Detection Method	MDL / Alarm Threshold	Spatial Coverage	Deployment Frequency	Facility Coverage
OGI/FU	Zimmerle Curve Parameters	0.7	1x, 2x, 3x, 4x, 6x yr^{-1}	33%, 50%, 75%, 100% of sites (based on minimum Source Level inspection requirements)
Aerial	5, 10, 25 kg hr^{-1}	0.9	0x, 1x, 2x, 3x, 4x yr^{-1}	100% of sites
CMS	10, 25 kg hr^{-1}	0.75, 0.9	365x yr^{-1}	25%, 33%, 50%, 66% of sites

Table 4. Count of Equivalent Program Ratings by Facility Designation

Equivalent Program Rating	Facilities with GOR ≤ 100 mcf bbl^{-1}	Facilities with GOR > 100 mcf bbl^{-1}	Potential High Emitter
12	37	43	48
8	13	15	14
4	25	26	22
0	13	4	4

Table 5. Alt-LDAR Program Subcategories

Sub-category	Program Summary	# Programs
1	Varying Facility Scale *w/ alarm @ 5, 10, or 25 kg* hr^{-1} + Varying Source Level + No CMS	8
2	Varying Facility Scale *w/ alarm @ 10 or 25 kg* hr^{-1} + 1-1.5x yr^{-1} Source Level + No CMS	18
3	2x yr^{-1} Facility Scale *w/ alarm @ 10 kg* hr^{-1} + 1-2x yr^{-1} Source Level + 50% CMS: *Passive Fence-Line Network w/ alarm @ 10 or 25 kg* hr^{-1}	10
4	1x yr^{-1} Facility Scale *w/ alarm @ 10 or 25 kg/hr* + 1x or 2x yr^{-1} Source Level + Varying CMS: *Passive Fence-Line Network w/ alarm @ 25 kg* hr^{-1}	16
5	1x yr^{-1} Facility Scale *w/ alarm @ 10 or 25 kg/hr* + 1x or 2x yr^{-1} Source Level + Varying CMS: *Active Scanning System w/ alarm @ 10 kg* hr^{-1}	16
6	0x or 1x yr^{-1} Facility Scale *w/ alarm @ 10 or 25 kg* hr^{-1} + 3x yr^{-1} Source Level + Varying CMS: *Passive Fence-Line Network w/ alarm @ kg* hr^{-1}	12
7	No Facility Scale + 1x yr^{-1} Source Level + Varying CMS: *Passive Fence-Line Network w/ alarm @ 25 kg* hr^{-1} or *Active Scanning System w/ alarm @ 10 kg* hr^{-1}	8

Program	Facility scoring			Facility Scale monitoring		Source Level monitoring		Continuous Monitoring		
	Generic oil basin (GOR ≤ 100 mcf bbl^{-1})	Generic gas basin (GOR > 100 mcf bbl^{-1})	Potential High-Emitter	Frequency [surveys yr^{-1}]	Alarm Threshold [kg hr^{-1}]	Frequency [surveys yr^{-1}]	Add'l Monitoring [Facility %]	Sensor Type	Alarm Threshold [kg hr^{-1}]	% of Facility deployed
1.1	12	12	12	2	5	4				
1.2	12	12	12	4	5	2				
1.3	12	12	12	2	10	4				
1.4	12	12	12	4	10	2				
1.5	12	12	12	1	25	6				
1.6	12	12	12	1	25	4				
1.7	12	12	12	1	10	6				
1.8	12	12	12	1	10	4				

Figure 1. Subcategory 1 results: 2x, 4x, or 6x yr^{-1} OGI across 100% of sites coupled with various Facility Scale inspection frequencies (1x, 2x, 4x yr^{-1}) and alert thresholds (5, 10, 25 kg hr^{-1}).

Program	Facility scoring			Facility Scale monitoring		Source Level monitoring		Continuous Monitoring		
	Generic oil basin (GOR ≤ 100 mcf bbl^{-1})	Generic gas basin (GOR > 100 mcf bbl^{-1})	Potential High-Emitter	Frequency [surveys yr^{-1}]	Alarm Threshold [kg hr^{-1}]	Frequency [surveys yr^{-1}]	Add'l Monitoring [Facility %]	Sensor Type	Alarm Threshold [kg hr^{-1}]	% of Facility deployed
2.1	0	4	4	2	25	1				
2.2	0	4	4	3						
2.3	4	4	4	4						
2.4	4	4	4	2	10					
2.5	4	4	4	3						
2.6	4	4	8	4						
2.7	4	4	4	2	25		33%			
2.8	4	4	4	3						
2.9	4	4	8	4						
2.10	4	4	4	2	10					
2.11	8	4	8	3						
2.12	8	8	8	4						
2.13	4	4	4	2	25		50%			
2.14	4	4	4	3						
2.15	4	8	8	4						
2.16	4	4	4	2	10					
2.17	8	4	8	3						
2.18	8	8	8	4						

Figure 2. Subcategory 2 program results: 1x yr^{-1} OGI across 100% of sites and 1 additional OGI at 0%, 33%, or 50% Facility coverage coupled with various Facility Scale inspection frequencies (2-4x yr^{-1}) and alert thresholds (10, 25 kg hr^{-1}).

<table>
<tr><th rowspan="2">Program</th><th colspan="3">Facility scoring</th><th colspan="2">Facility Scale monitoring</th><th colspan="2">Source Level monitoring</th><th colspan="3">Continuous Monitoring</th></tr>
<tr><th>Generic oil basin (GOR ≤ 100 mcf bbl^{-1})</th><th>Generic gas basin (GOR > 100 mcf bbl^{-1})</th><th>Potential High-Emitter</th><th>Frequency [surveys yr^{-1}]</th><th>Alarm Threshold [kg hr^{-1}]</th><th>Frequency [surveys yr^{-1}]</th><th>Add'l Monitoring [Facility %]</th><th>Sensor Type</th><th>Alarm Threshold [kg hr^{-1}]</th><th>% of Facility deployed</th></tr>
<tr><td>3.1</td><td>4</td><td>8</td><td>12</td><td rowspan="10">2</td><td rowspan="10">10</td><td>1</td><td>0%</td><td rowspan="10">Passive fence-line network</td><td rowspan="5">25</td><td rowspan="10">50%</td></tr>
<tr><td>3.2</td><td>8</td><td>8</td><td>12</td><td>1</td><td>25%</td></tr>
<tr><td>3.3</td><td>8</td><td>12</td><td>12</td><td>1</td><td>50%</td></tr>
<tr><td>3.4</td><td>8</td><td>12</td><td>12</td><td>1</td><td>75%</td></tr>
<tr><td>3.5</td><td>12</td><td>12</td><td>12</td><td>2</td><td>0%</td></tr>
<tr><td>3.6</td><td>8</td><td>8</td><td>12</td><td>1</td><td>0%</td><td rowspan="5">10</td></tr>
<tr><td>3.7</td><td>8</td><td>8</td><td>12</td><td>1</td><td>25%</td></tr>
<tr><td>3.8</td><td>8</td><td>12</td><td>12</td><td>1</td><td>50%</td></tr>
<tr><td>3.9</td><td>12</td><td>12</td><td>12</td><td>1</td><td>75%</td></tr>
<tr><td>3.10</td><td>12</td><td>12</td><td>12</td><td>2</td><td>0%</td></tr>
</table>

Figure 3. Subcategory 3 program results: 1x yr^{-1} OGI across 100% of sites and 1 additional OGI between 0-100% Facility coverage coupled with 2x yr^{-1} aerial surveys at 10 kg hr^{-1} alert threshold and CMS at 50% Facility coverage with either a 10 or 25 kg hr^{-1} alert threshold. CMS modeled to resemble passive, stationary fence-line sensors.

<table>
<tr><th rowspan="2">Program</th><th colspan="3">Facility scoring</th><th colspan="2">Facility Scale monitoring</th><th colspan="2">Source Level monitoring</th><th colspan="3">Continuous Monitoring</th></tr>
<tr><th>Generic oil basin (GOR ≤ 100 mcf bbl^{-1})</th><th>Generic gas basin (GOR > 100 mcf bbl^{-1})</th><th>Potential High-Emitter</th><th>Frequency [surveys yr^{-1}]</th><th>Alarm Threshold [kg hr^{-1}]</th><th>Frequency [surveys yr^{-1}]</th><th>Add'l Monitoring [Facility %]</th><th>Sensor Type</th><th>Alarm Threshold [kg hr^{-1}]</th><th>% of Facility deployed</th></tr>
<tr><td>4.1</td><td>0</td><td>4</td><td>4</td><td rowspan="16">1</td><td rowspan="8">25</td><td rowspan="4">1</td><td rowspan="16"></td><td rowspan="16">Passive fence-line network</td><td rowspan="16">25</td><td>25%</td></tr>
<tr><td>4.2</td><td>0</td><td>4</td><td>4</td><td>33%</td></tr>
<tr><td>4.3</td><td>0</td><td>8</td><td>8</td><td>50%</td></tr>
<tr><td>4.4</td><td>4</td><td>8</td><td>8</td><td>66%</td></tr>
<tr><td>4.5</td><td>8</td><td>12</td><td>12</td><td rowspan="4">2</td><td>25%</td></tr>
<tr><td>4.6</td><td>8</td><td>12</td><td>12</td><td>33%</td></tr>
<tr><td>4.7</td><td>12</td><td>12</td><td>12</td><td>50%</td></tr>
<tr><td>4.8</td><td>12</td><td>12</td><td>12</td><td>66%</td></tr>
<tr><td>4.9</td><td>0</td><td>4</td><td>4</td><td rowspan="8">10</td><td rowspan="4">1</td><td>25%</td></tr>
<tr><td>4.10</td><td>4</td><td>8</td><td>4</td><td>33%</td></tr>
<tr><td>4.11</td><td>4</td><td>8</td><td>8</td><td>50%</td></tr>
<tr><td>4.12</td><td>4</td><td>12</td><td>12</td><td>66%</td></tr>
<tr><td>4.13</td><td>12</td><td>12</td><td>12</td><td rowspan="4">2</td><td>25%</td></tr>
<tr><td>4.14</td><td>12</td><td>12</td><td>12</td><td>33%</td></tr>
<tr><td>4.15</td><td>12</td><td>12</td><td>12</td><td>50%</td></tr>
<tr><td>4.16</td><td>12</td><td>12</td><td>12</td><td>66%</td></tr>
</table>

Figure 4. Subcategory 4 program results: 1x yr^{-1} OGI across 100% of sites and 1 additional OGI at 100% Facility coverage for half of the programs coupled with 1x yr^{-1} aerial surveys at either 10 or 25 kg hr^{-1} alert threshold and CMS at 25 kg hr^{-1} alert threshold with varying Facility coverages (25-66%). CMS modeled to resemble passive, stationary fence-line sensors.

Program	Facility scoring			Facility Scale monitoring		Source Level monitoring		Continuous Monitoring		
	Generic oil basin (GOR ≤ 100 mcf bbl^{-1})	Generic gas basin (GOR > 100 mcf bbl^{-1})	Potential High-Emitter	Frequency [surveys yr^{-1}]	Alarm Threshold [kg hr^{-1}]	Frequency [surveys yr^{-1}]	Add'l Monitoring [Facility %]	Sensor Type	Alarm Threshold [kg hr^{-1}]	% of Facility deployed
5.1	0	4	4	1	25	1		Active scanning system	10	25%
5.2	0	4	4							33%
5.3	4	8	8							50%
5.4	8	12	12							66%
5.5	12	8	12			2				25%
5.6	12	12	12							33%
5.7	12	12	12							50%
5.8	12	12	12							66%
5.9	4	4	4		10	1				25%
5.10	4	4	8							33%
5.11	4	12	8							50%
5.12	4	12	12							66%
5.13	12	12	12			2				25%
5.14	12	12	12							33%
5.15	12	12	12							50%
5.16	12	12	12							66%

Figure 5. Subcategory 5 program results – 1x yr^{-1} OGI across 100% of sites and 1 additional OGI at 100% Facility coverage for half of the programs coupled with 1x yr^{-1} aerial surveys at either 10 or 25 kg hr^{-1} alert threshold and CMS at 10 kg hr^{-1} alert threshold with varying Facility coverages (25-66%). CMS modeled to resemble active, scanning systems able to cover entire sites.

Program	Facility scoring			Facility Scale monitoring		Source Level monitoring		Continuous Monitoring		
	Generic oil basin (GOR ≤ 100 mcf bbl^{-1})	Generic gas basin (GOR > 100 mcf bbl^{-1})	Potential High-Emitter	Frequency [surveys yr^{-1}]	Alarm Threshold [kg hr^{-1}]	Frequency [surveys yr^{-1}]	Add'l Monitoring [Facility %]	Sensor Type	Alarm Threshold [kg hr^{-1}]	% of Facility deployed
6.1	12	8	8			3		Passive fence-line network	25	25%
6.2	12	8	12							33%
6.3	12	12	12							50%
6.4	12	12	12							66%
6.5	12	12	12	1	25					25%
6.6	12	12	12							33%
6.7	12	12	12							50%
6.8	12	12	12							66%
6.9	12	12	12		10					25%
6.10	12	12	12							33%
6.11	12	12	12							50%
6.12	12	12	12							66%

Figure 6. Subcategory 6 program results – 3x yr^{-1} OGI across 100% of sites coupled with either 0x or 1x yr^{-1} aerial surveys at either 10 or 25 kg hr^{-1} alert threshold and CMS at 25 kg hr^{-1} alert threshold with varying Facility coverages (25-66%). CMS modeled to resemble passive, stationary fence-line sensors.

<table>
<tr><th rowspan="2">Program</th><th colspan="3">Facility scoring</th><th colspan="2">Facility Scale monitoring</th><th colspan="2">Source Level monitoring</th><th colspan="3">Continuous Monitoring</th></tr>
<tr><th>Generic oil basin (GOR ≤ 100 mcf bbl^{-1})</th><th>Generic gas basin (GOR > 100 mcf bbl^{-1})</th><th>Potential High-Emitter</th><th>Frequency [surveys yr^{-1}]</th><th>Alarm Threshold [kg hr^{-1}]</th><th>Frequency [surveys yr^{-1}]</th><th>Add'l Monitoring [Facility %]</th><th>Sensor Type</th><th>Alarm Threshold [kg hr^{-1}]</th><th>% of Facility deployed</th></tr>
<tr><td>7.1</td><td>0</td><td>0</td><td>0</td><td rowspan="8"></td><td rowspan="8"></td><td rowspan="8">1</td><td rowspan="8"></td><td rowspan="4">Passive fence-line network</td><td rowspan="4">25</td><td>25%</td></tr>
<tr><td>7.2</td><td>0</td><td>0</td><td>0</td><td>33%</td></tr>
<tr><td>7.3</td><td>0</td><td>4</td><td>4</td><td>50%</td></tr>
<tr><td>7.4</td><td>4</td><td>4</td><td>4</td><td>66%</td></tr>
<tr><td>7.5</td><td>0</td><td>0</td><td>0</td><td rowspan="4">Active scanning system</td><td rowspan="4">10</td><td>25%</td></tr>
<tr><td>7.6</td><td>0</td><td>0</td><td>0</td><td>33%</td></tr>
<tr><td>7.7</td><td>4</td><td>4</td><td>4</td><td>50%</td></tr>
<tr><td>7.8</td><td>4</td><td>4</td><td>4</td><td>66%</td></tr>
</table>

Figure 7. Subcategory 7 program results – 1x yr^{-1} OGI across 100% of sites coupled with CMS at varying alert thresholds (10 or 25 kg hr^{-1}) and Facility coverages (25-66%). CMS modeled to resemble passive, stationary fence-line sensors and active scanning systems.

Key Terms for Modeling Methodology

Work Practice: A description of how a methane detection technology is used to collect information about emissions, including operating procedures (e.g. distance from source, measurement time, environmental envelopes, production segments).

Leak Detection and Repair Program (LDAR Program): The systematic implementation of one or more methane detection technologies across a collection of assets (i.e. sites) in a Facility. In LDAR-Sim, an LDAR Program is modeled as a combination of one or more Methods to be used for each site in the Virtual World.

Alternative Leak Detection and Repair Program (Alt-LDAR Program): An LDAR Program which incorporates an alternative, non-OGI methane detection technology such as Aerial flyovers or Continuous emissions Monitoring Systems. Alt-LDAR Programs typically include an OGI Method. Occasionally, "program" is used to indicate both LDAR and Alt-LDAR Programs.

Optical Gas Imaging (OGI): A common leak detection approach that uses thermal infrared cameras to visualize methane and various other organic gases. Common OGI cameras create images of a narrow range of the mid-IR spectrum (3.2– 3.4 µm wavelength) which methane and other light hydrocarbons actively absorb.

Aerial survey/Method: In general, a common leak detection approach that uses methane-sensing technology on manned/unmanned aircraft or drones to detect, track, repair, and report fugitive emissions. In this work, Aerial Methods are modelled as periodic surveys deployed across 100% of the Facility that screens for emissions at the site-level and can trigger OGI follow-up Methods.

Continuous Monitoring Systems (CMS): In general, a group of methane-sensing technologies that autonomously collects, records, and reports methane emissions data on a small timescale (minutes to hours). In this work, CMS Methods are modelled as daily surveys deployed at a user-specified number of sites within a Facility.

Flagging: In LDAR-Sim, identifying that a particular site is the source of an emission which must be followed up on by an OGI Method. The *reporting_delay* parameter specifies the time between a Method detecting a leak and flagging a leak for follow-up (see Table 6).

Tagging: In LDAR-Sim, physically tagging the emission source component for repair. Typically done by follow-up inspection personnel. The *repair_delay* parameter specifies the time between a Method tagging a leak and the leak actually being repaired (see Table 6).

Virtual World: In LDAR-Sim, the virtual environment defined by a set of parameters informing characteristics of chosen sites and leaks that arise at those sites. This includes characteristics such as site locations, site weather, how frequently leaks occur at sites and how large leaks that occur will be.

Program(s): In LDAR-Sim, the deployment of a combination of one or more Methods that detect, Flag, Tag, and ultimately repair leaks in the Virtual World.

Method(s): In LDAR-Sim, a representation of a leak detection technology and the Work Practice it follows. Method parameters inform key technology characteristics such as detection capabilities and operating envelopes and key Work Practice characteristics such as survey/screening frequency, reporting delay and triaging behavior for follow-up (where applicable).

Spatial Coverage: In LDAR-Sim, a parameter that represents the inability of a measurement technology to detect certain sources of methane emissions. This is due to certain emission sources being by their nature "inaccessible" to certain technologies, regardless of emission rate. Functionally, this is a user-specified value between 0-1 attached to each Method that gets applied *once* to each generated leak to determine if said Method will *ever* detect said leak. For example, a Method with Spatial Coverage of 0.9 has a 10% chance of never finding a given leak.

Temporal Coverage: In LDAR-Sim, a parameter that represents the inability of a measurement technology to detect any given methane emission on a given day due to external factors such as operator error. Functionally, this is a user-specified value between 0-1 attached to each Method that gets applied *each time* a Method attempts to detect an emission. For example, a Method with Temporal Coverage of 0.9 has a 10% chance of not detecting an emission that it otherwise would have on a given survey or screening.

Natural Repair Delay (NRD): In LDAR-Sim, a parameter determining the total number of days a leak is allowed to exist in simulation. This user-specified integer value represents unintentional leak repairs due to routine maintenance, refits, retrofits, and other causes. In simulation, once a leak has existed for a number of days equal to the NRD it will be "naturally" repaired.

Leak Production Rate (LPR): In LDAR-Sim, a parameter specifying the probability of a new leak occurring each day for each site in the Virtual World. This is a user-specified decimal value (see Table 6).

Leak Rate Source: In LDAR-Sim, the source(s) of data informing the emission rates of leaks generated in a simulation. This can be provided in the form of user-specified shape parameters to create a statistical distribution or as a set of known user-specified leak rates to sample from. Leak Rate Sources can be set uniformly across all sites or specified separately for user-defined site types using LDAR-Sim subtyping functionality (see "Subtyping").

Minimum Detection Limit (MDL): In LDAR-Sim, a parameter dictating the smallest emission rate a given Method can detect. The MDL can be input as a single user-specified value or as a curve with user-specified shape parameters. In practice, this value or curve is ideally determined through blinded control release testing and reported at a 90% probability of detection. In this work, the MDL of Aerial and CMS Methods are set as single value alarm thresholds (e.g. 10 or 25 kg hr^{-1}). For OGI Methods, the MDL is set as a curve with shape parameters (see "MDL Representation").

MiQ MTD Grade Band Programs: The MiQ Standard for Onshore Production specifies four LDAR Programs which an operator may choose to follow to be rated 0, 4, 8, or 12 points, contributing towards the Facility's overall MiQ grade (see Table 1 and a more detailed version in Table 7). These four MiQ MTD Grade Band Programs are modelled in LDAR-Sim as Programs and used as thresholds to determine equivalency of the 88 Alt-LDAR Programs tested.

Facility: All contiguous onshore natural gas production sites and equipment located in a single geologic basin, field, or subfield.

Facility Scale: Inspections undertaken by an operator at the Facility Level use a leak detection technology that covers the entire Facility's emission sources in three-dimensional space and must be capable of detecting and pinpointing the source of emissions to the site level at a minimum. One example of such a technology is an aerial flyover.

Source Level: Inspections undertaken by an operator at the Source Level use a leak detection technology that can identify the source of a leak. One example of such a technology is an OGI camera.

Survey Period: In LDAR-Sim, a quantity used to determine *scheduling* parameters that dictate what months a certain Method can be deployed (*deployment_months*) and how long a certain Method has to perform follow-up inspections (*min_followup_days_to_end*), if applicable (see Table 7). Quantitatively, this value is equal to the total number of required surveys (*RS*) of all Methods deployed at 100% of sites in a Program (e.g. a Program with an annual OGI survey at 100% of sites, annual flyover at 100% of sites, and an additional OGI follow-up requirement at 50% of sites has 2 Survey Periods). This is done to minimize redundant (i.e. overlapping) Method deployments (see "Scheduling" for discussion).

Modeling Methodology

The MiQ Equivalency Table applies the use of an open-source modeling program to assess a multitude of likely cases of tiered Facility Scale and Source Level monitoring. While these various equivalency models or techniques have unique characteristics, they all have the same basic functionality mind: to simulate the effectiveness of leak detection and repair (LDAR) programs against a virtual environment that is populated with relevant emissions information to most accurately model a specific operating environment.

In addition to the MiQ MTD Grade Bands, 88 Alt-LDAR Programs are evaluated and compared across three Facility designations differentiated by the use of three separate emissions distributions (i.e. Leak Rate Sources; see "Use of representative emission distributions" for further discussion). These programs were created to resemble feasible multi-method deployments that many operators are already close to following due to their regulatory requirements and advanced technology and emissions monitoring strategies. Comparing these programs to MiQ's current MTD requirements and grade thresholds clarifies how different monitoring schemes map to the MiQ Standard.

Creating a Consistent Virtual Environment

To ensure the comparability of simulation results, each LDAR Program is evaluated in a consistent Virtual World. This is done by keeping several parameters (shown in Table 6) constant across all simulations. Thus, these parameters are not evaluated in this work. However, in practice many of these parameters can vary considerably and may be studied in future iterations of equivalency determination program development.

Table 6. Consistent LDAR-Sim Parameters Across All Programs Evaluated in the MiQ Equivalency Table

Parameter	Parameter Level	Value	Justification
Number of simulations (LDAR-Sim User Manual)	All Programs	10	Multiple simulations run to balance the effect of outlier simulations (see "Additional simulation" for discussion)
Program start date	All Programs	[2024, 1, 1]	5-year simulation length used to obtain representative LDAR Program performance across time
Program end date	All Programs	[2028, 12, 31]	See above
LDAR-Sim version	All Programs	2.0	Most current version available at the beginning of the modeling effort
Infrastructure file (LDAR-Sim User Manual)	All Programs	*facilities_permian_MiQ-Tables_v1.csv*	Default LDAR-Sim infrastructure file for the Permian basin, modified only to specify what proportion of sites have CMS systems for various programs (see "Subtyping" for further discussion)
Site Samples	All Programs	1000	Total number of sites included in Permian infrastructure file, all included in modeling to better evaluate detection technologies
Natural Repair Delay (NRD) (LDAR-Sim User Manual)	All Programs	365	Default LDAR-Sim input, assume leaks not repaired through monitoring surveys are removed after 1 year (see "Use of

			representative emission distributions”)
Leak Production Rate (LPR) (LDAR-Sim User Manual)	All Programs	0.0065 leaks site^{-1} day^{-1} (~2.4 leaks site^{-1} yr^{-1})	Default LDAR-Sim input (see “Use of representative emission distributions” and Fox et al, 2021)
Consider venting (LDAR-Sim User Manual)	All Programs	FALSE	All generated leaks considered repairable (see “Intentional vs Unintentional Emissions”)
Pre-generate leaks (LDAR-Sim User Manual)	All Programs	TRUE	All Programs evaluated across the same set of generated leaks in a simulation to fairly evaluate and compare Program performance
Weather file (LDAR-Sim User Manual)	All Programs	*weather_permian.nc*	Default Permian weather file in LDAR-Sim containing precipitation, temperature, and wind data
Max workday (LDAR-Sim User Manual)	Aerial and OGI Methods	8 hours	Assumed 8-hour workday for mobile crews
	CMS Methods	24 hours	Assumed to be actively monitoring for 24 hours
Required Surveys (LDAR-Sim User Manual)	CMS Methods	365 yr^{-1}	Assumed to be monitoring 365 days yr^{-1} with daily site-level reading at the specified % of sites
Survey duration (LDAR-Sim User Manual)	OGI Methods	120 min site^{-1}	Assumed longer consistent survey duration for handheld OGI and OGI follow-up inspection
	Aerial and CMS Methods	1 min site^{-1}	Consistent shorter survey duration
Time between sites (LDAR-Sim User Manual)	OGI Methods	30 min site^{-1}	Consistent time between sites for a handheld OGI crew; assumed to be longer than other mobile methods
	Aerial and CMS Methods	1 min site^{-1}	Consistent shorter time between sites
Temporal Coverage (LDAR-Sim User Manual)	All Methods	1.0	Default LDAR-Sim input
Spatial Coverage (LDAR-Sim User Manual)	Aerial Methods	0.9	Used as a proxy for 90% probability of detection
	OGI Methods	0.7	See “MDL Representation” for discussion
Weather *Precipitation* *Temperature* *Wind* (LDAR-Sim User Manual)	Aerial and OGI Methods	0 – 0.5 mm/hr -40.0 – 40.0 °C 0 – 10 m/s @ 10m	Default LDAR-Sim inputs; Consistent operating envelope
	CMS Methods	0 – 10 mm/hr -30.0 – 40.0 °C 0 – 15 m/s @ 10m	Consistent operating envelope for CMS technologies (see Longpath CO Alt-AIMM)

	Aerial Methods	None	Consistent operating environment for Aerial Methods
Reporting Delay (LDAR-Sim User Manual)	CMS Methods	0 days	Assume real-time reporting alert to operations
	OGI Methods	2 days	Assume small reporting delay for leak to be entered into system
	Aerial Methods	21 days	Based on aggregated operator and client feedback
Repair Delay (LDAR-Sim User Manual)	All Programs	28 days	Assume consistent repair schedule

Program Modelling Approach

Individual Programs are evaluated in the consistent modeling environment summarized in Table 6 above along with particular parameters of interest summarized in Table 3. Each LDAR Program is made up of some combination of Aerial, Continuous Monitoring System (CMS), OGI, or OGI Follow-up (FU) Methods. The minimum detection limit (MDL) parameter for OGI Methods is set as a curve to resemble experienced handheld OGI technicians (see "MDL Representation" for further discussion). OGI and OGI FU are component-level detection Methods that can Tag a leak for repair whereas Aerial and CMS Methods "screen" for emissions at an aggregated site level and can only Flag a site for an OGI FU survey. Thus, although Aerial and CMS Methods benefit from shorter survey duration and time between surveys than OGI Methods (see Table 6), there is still an additional time delay since they require an OGI FU Method to be deployed before a leak is Tagged for repair (see "Modeling of follow-up Source Level surveys" for additional discussion).

All Programs are simulated for five years, each year beginning with an OGI survey across 100% of sites. Only after the initial annual OGI survey are Aerial Methods able to be deployed. This is done to minimize redundant monitoring surveys (see "Scheduling" for additional discussion). For any Program with partial Source Level survey coverage (i.e. OGI at < 100% of sites), these Source Level inspections are modelled as OGI FU surveys attached to Aerial surveys (see "Modeling of follow-up Source Level surveys" for additional discussion). Thus, follow-up OGI surveys are modelled exactly the same as OGI surveys, though they have separate Method parameter files.

MiQ Monitoring Technology Deployment (MTD) Grade Band Programs

Equivalency ratings are determined for 88 Alt-LDAR Programs using 4 MiQ MTD Grade Band Programs as scoring thresholds (see Table 1). The detailed parameterization of the MiQ MTD Grade Band Programs is shown in Table 7 below. The 12-, 8-, and 4-pt Programs have partial Source Level survey requirements modelled as described above, with a requirement that 50% of total sites receive an OGI follow-up after each aerial survey, regardless of the number of detections made by Aerial Methods. In the case that Aerial Methods flag < 50% of sites for follow-up, sites are randomly flagged for follow-up until the 50% requirement is met. To maintain consistency in this deployment pattern, the 12-pt program is modelled as a special case where the first three aerial screening surveys have the 50% FU requirement but the last does not. For the fourth aerial survey, follow-up OGI surveys are solely deployed in response to aerial detections.

Table 7. MiQ MTD Grade Band Program Parametrization

Program	Parameter Name(s)	0-pt	4-pt	8-pt	12-pt
Facility Level frequency	*M_RS* for Aerial Methods	4x yr^{-1} @ 100% of sites	2x yr^{-1} @ 100% of sites	1x yr^{-1} @ 100% of sites	-
Facility Level alert threshold (Spatial Coverage)	*M_sensor.MDL* *M_coverage.spatial* for Aerial Methods	25 kg hr^{-1} (0.9)	25 kg hr^{-1} (0.9)	25 kg hr^{-1} (0.9)	-
Source Level frequency	*M_RS* for OGI Methods with full survey coverage **and** *M_follow_up* parameters for Aerial Methods with partial follow-up requirements	4x yr^{-1} @ 100%, 50%, 50% and 50% of sites	3x yr^{-1} @ 100%, 50%, and 50% of sites	2x yr^{-1} @ 100% and 50% of sites	1x yr^{-1} @ 100% of sites
Source Level MDL (Spatial Coverage)	*M_sensor.MDL* *M_coverage.spatial* for OGI and FU methods	Zimmerle curve (0.7) See “MDL Representation”			
Survey Periods (SP)	-	5	3	2	1
Source Level survey coverage requirement	*M_follow_up. Min_followups* for aerial methods	[0.5, 0.5, 0.5, 0]	[0.5, 0.5]	[0.5]	-
Survey Period length	*M_follow_up. Min_followup_days _to_end* = 365 days / SP / 2 for aerial methods	36 days	60 days	90 days	-
Scheduling delay [deployment months]	*M_scheduling. deployment_months* = 12 months / SP	2 mo. [3-12]	4 mo. [5-12]	6 mo. [7-12]	-

Alternative LDAR Programs

Alt-LDAR Programs are separated into seven subcategories, as summarized in Table 5. Subcategories are arranged according to relevancy across types of operators, regions and regulatory environments. OGI survey frequency is varied to model current or proposed regulatory requirements across Canada and the USA. Aerial survey frequency is varied based on informal understanding of how frequently operators currently use aerial technologies to comply with various voluntary initiatives such as MiQ or OGMP 2.0 and burgeoning regulatory frameworks such as Alberta Alt-FEMP, Colorado AIMM and the upcoming Colorado intensity verification rule. Unlike OGI Methods, the minimum detection limit (MDL) parameter for Aerial and CMS Methods is set as a single-value alert threshold (see “MDL Representation” for further discussion). Alert thresholds of advanced technologies including both aerial surveys and CMS are varied to simulate common Work Practices that have been observed from operators in efforts to balance understanding causes of the bulk of identified emissions while not inundating operations and engineering staff with alerts, particularly with CMS. Total deployment of CMS deployment is varied to simulate the impact of installing CMS at scale in phased approaches. Operators with higher levels of CMS deployment are also recognized in this work as certain scenarios reach as high as 66% CMS deployment. Finally, CMS Methods are differentiated between “passive” and “active” systems using the Spatial Coverage parameter. See “MDL Representation” for discussion about the pairing of MDL and Spatial Coverage parameters employed in this work.

Limitations and Future Work

The current iteration of the MiQ Equivalency Table evaluates 88 multi-tiered Alt-LDAR Programs across three emissions distributions against the MiQ Standard’s scoring criteria for Monitoring Technology Deployment. Discussed below are various areas of uncertainty in the modeling approach used in this work as well as areas of improvement for future iterations of the MiQ Equivalency Table. These include the use of comprehensive regional emissions information, improved technology performance characteristics, basin-specific infrastructure information, and additional tuneability in newer versions of LDAR-Sim.

It is Important to note that the advanced technologies included in this work have co-benefits that are not reflected in the modeling results that are extremely valuable to other aspects of the MiQ Standard such as emissions reconciliation. Non-quantitative Source Level technologies can be used to perform causal analysis and assist in time-bounding detected emissions events. Data from Continuous Monitoring Systems allows operators to better understand intermittency and characterize emissions behavior at a granular level. Top-down aerial technologies efficiently survey 100% of a Facility’s emission sources, capture process-related emissions that are typically missed with Source Level technologies and provide quantitative site-level emissions data that can be used to credibly assess additionality against an operator’s emissions inventory. For this reason, no Alt-LDAR Program utilizes a singular detection Method. Furthermore, MiQ strongly encourages the use of technologies that directly measure emissions within a tiered technology approach, a trait of nearly every MiQ-certified operator’s monitoring technology deployment program.

Use of representative emissions distributions and other leak source parameters
The parameters that inform emissions behavior in LDAR-Sim are the main drivers of uncertainty in both modeling and determining the emissions reduction performance of Alt-LDAR Programs. These include the emissions distribution(s) used in sampling emission rates as well as the Leak Production Rate (LPR) and Natural Repair Delay (NRD).

Academic research has thoroughly demonstrated that different operating regions exhibit different emissions profiles (see Sherwin et al, 2023). This is due to a variety of reasons including reservoir characteristics, necessary operating equipment, age of infrastructure, and economic factors. The downhole pressure of a reservoir may affect the steady state operation of a producing well, especially during periods of very high production. High downhole pressures may also lead to less required compression throughout the supply chain leading to fewer compression- and combustion-related emissions. In areas of dry gas production, well pads and even downstream treatment facilities are very simple sites with few sources of constant venting besides gas-driven pneumatics, chemical pumps and produced water tanks. Conversely, areas that produce large amounts of oil or condensate have more complex setups (e.g. more separation equipment, oil and water tank batteries, vapor recovery and flare gas systems) that lead to additional sources of methane emissions. These differences account for some of the reasons why emission profiles can vary widely across region and form the basis for evaluating LDAR Programs across different emissions distributions. In this work, LDAR Programs are evaluated against three emissions distributions to represent three distinct Facility designations:

1. Zavala-Araiza et al., 2015 ("ZA") to represent generic oil basins (GOR ≤ 100 mcf bbl^{-1})
2. Carbon Mapper's 2021 Pennsylvania survey ("Penn"; reported in Sherwin et al., 2023 preprint) to represent generic gas basins (GOR > 100 mcf bbl^{-1})
3. Carbon Mapper's 2019 Permian survey ("Permian"; reported in Sherwin et al., 2023 preprint) to represent potential high-emitter basins (see Table 2)

The ZA distribution is commonly referenced as a distribution that incorporates large-emitting events that would be more common to an oil-producing basin. The Penn distribution is the most comprehensive public dataset of methane emissions measurements from a prominent dry gas basin. The Permian distribution is chosen to represent basins shown to have a higher potential for super-emitting events (see Table 2 for list and justification), due to factors like absence of methane-specific regulation or operations of higher complexity as described above. Emissions distributions are largely a function of the detection capabilities of the technologies used. The three used in this work combine top-down measurements with simulated bottom-up emissions data. Thus, the quality of the distribution relies on the methods used to stitch the two types of data together. The ZA distribution is fit to a lognormal curve using parameters as inputs in LDAR-Sim whereas the Penn and Permian distributions are leak files that LDAR-Sim samples from directly.

Sampling from combined datasets of raw emission rates in LDAR-Sim introduces the possibility of high variance in emissions reductions performance between Programs as simulations suffer from extreme variability due to the heavy-tailed nature of the distributions used. Leaks are commonly generated as either large emission rates from the top-down data or small (in some cases 10-100x smaller) emission rates from the bottom-up data. Top-down measurement technologies also typically have limited ability to distinguish between fugitive and vented emissions and inevitably create distributions that include rates from both, causing fugitive emissions to be artificially inflated in LDAR-Sim (see "Unintended vs. intended emissions" below). Thus, when sampling from distributions with high emission rate variance, program performance can be dictated by only a handful of the largest leaks – if they are detected by the random chance-based methods deployed and how quickly they are repaired. This can result in non-intuitive results (e.g. 8-pt program outperforming 12-pt program) which occurred for one set of simulations sampling from the Sherwin Pennsylvania distribution and was re-run with 30 simulations instead of 10. This points to the general recommendation of conducting a large number of simulations (i.e. 50-100+) to allow for overall results to "average out" across all simulations (see "Additional simulation capacity" below and Zhang et al, 2023 for discussion).

Fitting combined emissions datasets to lognormal curves reduces the variance issue described above, but academic evidence suggests that emissions distributions, particularly those captured aerially or via remote sensing, do not fit well to lognormal curves as even the lognormal shape will underrepresent the "heavy tail" of super emitters (see Section S2 of Sherwin et al, 2023 SI for an extensive discussion). In this work, the fitted lognormal Zavala Araiza distribution used to represent generic oil basins produced an emissions baseline that is much smaller in magnitude than those used to represent generic gas basins and the potential high-emitter basins (see Figure 8 below). An alternative would be to compare results using an additional emissions distribution from an oil basin such as the Denver Julesburg or San Joaquin basin, which have both been comprehensively surveyed and are presented in the Sherwin et al. pre-print.

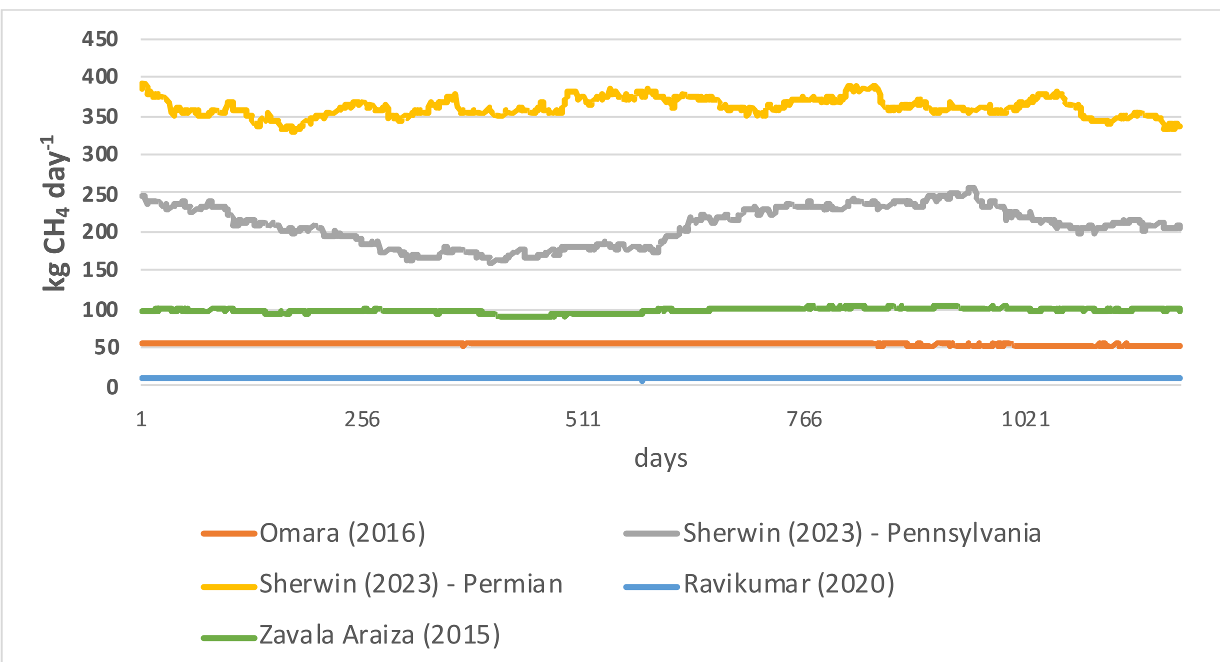

Figure 8. Comparison of baseline emissions (P_{none}) from five different emissions distributions. Only the ZA (green line), Penn (gray line), and Permian (yellow line) distributions are used in the current iteration of the MiQ Equivalency Table. Similar to the ZA distribution, the Omara (red line) and Ravikumar (blue line) distributions are fitted to a lognormal curve and included for comparison.

Future emission distributions used for modeling purposes will ideally be attributed to different equipment groups, emission sources and event types. This will help the modeling exercise tie the performance of a single Method or tiered LDAR Program more closely to the types of emissions that the technology is adept at detecting. Presently, the use of emission distributions that include intended emissions such as flaring emissions, tank battery venting, or known process events such as an equipment blowdown or a downhole liquids unloading event may overstate the effectiveness of Source Level inspection technologies simply because most Source Level inspections are not designed to inspect for non-fugitive emissions events.

As newer data is published that better characterizes emission behavior from specific sources, additional granularity can be added to leak behavior in LDAR-Sim (see sections below) to improve the practical use of chosen distributions. Regardless, the following prioritization ranking is loosely followed in this work and recommended for use in future iterations of equivalency determination program development.

1. Prioritize emissions distributions generated from measurements of similar infrastructure to those being modeled. For example, modelling exclusively single well pads but assuming emissions measurements measured at gas processing plants or compressor stations would be inaccurate.
2. Prioritize emissions distributions with a region matching the regions selected for modelling.
3. Prioritize emissions distributions generated from a combination of top-down and bottom-up emissions measurements. Using top-down or bottom-up emissions in isolation can lead to the introduction of significant survivorship bias.
4. Prioritize emissions distributions gathered from larger, comprehensive studies covering large percentages of a study area or over multiple years of study. The more representative data that has been collected, the higher the chance of it being representative of emissions in the region.
5. Prioritize newer studies. Newer studies are more likely to apply the most up to date measurement technology for more accurate results.

Ideally, the same leak source data informs both the emissions distribution and other critical leak parameters in LDAR-Sim like the Leak Production Rate (LPR) and Natural Repair Delay (NRD). Like emissions distributions, these values are likely region- and operator-specific but are notoriously difficult to characterize and require large, representative amounts of data to determine, which up to this point has not been done. In this work, we use the default LDAR-Sim values for LPR and NRD (see Table 6). Sensitivity analysis around the LPR and NRD values used can better constrain uncertainty in the results presented here. Additionally, as new data is published from various monitoring campaigns to obtain regional methane emissions estimates it is possible that basin-specific values become available for use in future iterations of equivalency modeling.

Intentional vs. Unintentional Emissions

LDAR-Sim provides the functionality to categorize the emissions in a distribution as either vented or fugitive, which can be thought of as intentional or unintentional. This allows the program to ignore detections of any emissions that are known to the operator, due to maintenance or normal operations, and unable to be mitigated by monitoring. Due to a lack of published data, this functionality is not used because the emissions distributions used in this work do not differentiate emissions to a high degree of confidence between intentional and unintentional releases. This may influence the modeling results, particularly on monitoring methods with high action thresholds if the amount of intentional emissions unable to be mitigated is heavily skewed towards the high emission rates in the distribution. The use of higher-sensitivity technologies in future survey work will allow emissions to be more accurately attributed and improve distributions for use in modeling.

MDL representation
The pairing of the Spatial Coverage and Minimum Detection Limit (MDL) parameters in this work differ in important ways between Aerial, Continuous Monitoring, and OGI detection Methods. In this modeling approach, a Spatial Coverage < 1.0 represents the imperfection of monitoring technologies in detecting every single leak within the emission rate distribution that its Method is rated for.

For OGI and OGI Follow-up (FU) Methods, a curve fitted with parameters is used for the MDL. This curve is derived from Zimmerle et al, 2020 and is meant to represent an experienced OGI camera operator. As a conservative assumption, a Spatial Coverage of 0.7 is applied to all OGI and OGI FU methods, meaning that an OGI survey will be able to detect emissions for 70% of sources in 3-dimensional space at a given site (in addition to meeting the MDL requirements). This assumption is backed by several studies that conclude there are several emission sources that will be difficult for an OGI camera to detect such as flare stacks, combustion units, elevated sources, and other sources inaccessible to LDAR technicians (see discussion in EPA Subpart W proposed rulemaking).

Aerial and CMS Methods have MDLs set at single-value alarm thresholds where all detections trigger an OGI FU. This is done both to be inclusive of technologies that vary in MDL and reflect common Work Practice of operators deploying Aerial and CMS technology. However, this means the true emission detection capabilities of these technologies are not fully captured in this work. Furthermore, the alarm thresholds used for CMS Methods are not entirely representative of reality where operators typically set an alarm or multiple alarms at x kg hr^{-1} above some baseline emissions rate, calculated as a rolling average. This is currently not possible to model as CMS Methods take site-level measurements once per day. Nevertheless, these Methods employ a Spatial Coverage of 0.9 to represent a 90% probability of detection, which is the level of certainty that a technology's MDL would be determined at through controlled release testing.

An additional categorization is added to CMS Methods to differentiate performance of "active" and "passive" (i.e. stationary) systems, the latter having been shown to capture emissions generally occurring around the elevation of the system in optimal wind conditions more reliably than elevated emission sources (e.g. tank batteries, flares and engine exhaust). This is represented by reducing Spatial Coverage to 0.75 for "passive" systems with a lower alarm threshold (i.e. 10 kg hr^{-1}), compared to an "active" scanning CMS that retains a Spatial Coverage of 0.9.

Representation of a technology's MDL using the Spatial Coverage parameter has limitations. Spatial Coverage is unable to distinguish between the type of emission events that are modeled from an emissions distribution. For example, OGI Methods with Spatial Coverage of 0.7 means an OGI inspection has a 70% chance of catching a flange leak as well as methane slip from an engine, when in reality these values may be closer to 90% and 0%, respectively. In reality, a technology's ability to detect an emissions event is dependent on emission rate, emission source, and environmental constraints. As more source-specific emissions information becomes available, MDL and Spatial Coverage can be tuned to reflect a technology's detection performance more accurately (see "Use of representative emissions distributions" above). Additionally, the impact of Spatial Coverage on modeling results can be assessed through additional sensitivity analysis. Future iterations of modeling can further differentiate advanced technologies and include additional categories of monitoring such as satellite networks and remote sensing. Additional granularity can be added to the results of the modeling by specifying the MDL and alarm threshold separately for screening technologies.

Subtyping infrastructure files

All LDAR Programs evaluated in this work use the LDAR-Sim default Permian infrastructure file and associated weather file. This is chosen because of the large number of sites (*site_samples* = 1000) included compared to the other LDAR-Sim default infrastructure files which enables better comparison of technologies with partial Facility survey coverage (i.e. OGI and CMS @ ≤ 100% of sites). Though the infrastructure file and Leak Rate Source are mutually exclusive inputs in LDAR-Sim, the chosen emissions distribution will be representative of the infrastructure specific to the region being monitored. Thus, future modeling could be more representative by using locations and weather data of actual assets in the basin of interest (i.e. Marcellus or Appalachian) as well as subtype files to differentiate site-level emissions behavior.

Subtype files in LDAR-Sim allow for sites in an infrastructure file to be assigned a "subtype" that specifies equipment groups, emission rates, Leak Production Rates (LPR), Natural Repair Delay (NRD) and venting rates to be modelled per site type. Due to a lack of information needed to accurately represent the different regions of interest, no subtype files were used in this work. However, as more granular emission data is published (see "Use of representative emissions distributions" above), subtype files could be developed with additional specificity in type of sites included (i.e. simple wellpads, complex wellpads, and/or tank batteries) and their respective emission characteristics. Programs with Continuous Monitoring Systems and Aerial Methods may benefit the most from effective subtyping, where clearer justification could be made about how to most efficiently deploy CMS while providing additional assurance with Aerial and OGI Methods. Finally, the use more representative weather files will help improve the deployment characteristics and effectiveness of certain technologies in different, adverse weather conditions.

Additional simulation capacity
The bulk of equivalency models shown in this work were run with 10 simulations each, with 7 of the 264 total distribution-specific Programs requiring additional (30-50) simulations to constrain variability. Certain modeling runs produced counter-intuitive results (i.e. programs with higher monitoring frequency performing worse than those with lower frequency, "B" grade performing better than "A" grade), especially with the Penn-sampled distribution. Increasing simulations to 100 per Program and averaging the results would better constrain outlier events potentially caused by one or multiple very large emission events going undetected for a long period of time and comparing to a program that catches the events, without any change in the technology used. Running re-formatted simulation batches (less site samples and fewer programs) on newer versions of LDAR-Sim could allow for a greater number of simulations to be run with shorter run times.

Intermittency
Currently LDAR-Sim has no way of representing intermittency of emissions in simulations. This is primarily due to a lack of data in existing emission distribution datasets about the length of detected emissions, and lagging methods to determine intermittency without having to go to the operator for contextual and attributing detail on each detect. Currently in simulation, all emissions are assumed to be emitting at a set, non-fluctuating rate until either the emission is detected and repaired or until the emission reaches the model's rate of natural repair. Not capturing intermittency of emissions in the modeled environment will affect the modeled capabilities of certain technologies vs. the capabilities in the real world. For example, ignoring intermittency of leaks may overestimate the effectiveness of technologies that provide snapshot, point-in-time survey results. Likewise, the constant nature of emissions may also underestimate the effectiveness of continuous monitoring technologies to more reliably detect emission sources that come and go with changes in process conditions. However, since aerial surveys must cover 100% of the Facility, surveys would be modeled representatively with or without intermittency modeled.

Scheduling
The methodology used in this work assumes each year begins with a Source Level inspection across 100% of the Facility and then delays the deployment of the first Aerial survey based on the number of Survey Periods calculated. It is not guaranteed that surveys happening after the initial survey are optimally spaced out. However, the alternative would be to create explicit method files for each survey that occurs, which would quickly become too complicated and is not clear how much of an impact it would have on overall program performance. Furthermore, newer versions of LDAR-Sim have built-in scheduling improvements that may reduce the occurrence of redundant surveys in simulations.

Modeling of follow-up Source Level surveys and standalone Source Level surveys
This work models any partial deployment (i.e. deployment at < 100% of sites) of a Source Level inspection Method as minimum follow-up parameters of Aerial Methods. This is done in the MiQ MTD Grade Band Programs to accommodate the MiQ Standard's allowance of OGI follow-

up (FU) surveys to count toward Facility-wide Source Level monitoring requirements. The same methodology is followed for Alt-LDAR Programs for comparability but could be parameterized more explicitly. Modeling all OGI surveys independently of Aerial surveys will allow stand alone and follow up OGI surveys to be parameterized differently as well. For example, OGI FU surveys could be parameterized as having a slightly higher spatial coverage than “routine” OGI surveys to represent that OGI FU surveys are more targeted through the reporting of the screening method.

Overview

One of the 3 key performance criteria through which points are awarded in the MiQ Onshore Production standard (The MiQ Standard) is Monitoring Technology Deployment. The MiQ Standard provides 4 pre-defined leak detection and repair programs (LDAR Programs), each with a unique combination of facility-scale screening and close-range source-level follow-up surveys, the applicant can deploy to obtain a given score for the Monitoring Technology Deployment element of overall scoring. The frequency and performance characteristics of technology deployment in these pre-defined LDAR programs applies to generic facilities in varying geographies.

The MiQ Standard grants allowance for applicants to demonstrate the efficacy of other LDAR programs potential mitigation compared to the predefined MiQ Standard LDAR programs via simulation modelling. If the applicant can prove an LDAR program can achieve equal or greater mitigation than a given pre-defined MiQ Standard program, the applicant can receive the points the given MiQ Standard program would award.

MiQ has conducted an internal modelling investigation using LDAR-Sim to explore equivalency with the 4 pre-defined MiQ Standard LDAR programs across a range of different assumptions including program work practice and basin-specific emissions characteristics. Highwood Emissions Management (Highwood) has provided a review of the methodology MiQ used in their simulation modelling as well as the model results.

Highwood Review Methodology

MiQ provided Highwood 2 deliverables for review:

1. A summary sheet with inputs and results of each scenario.
2. A written report providing additional detail on modeling approach assumptions, limitations, and recommendations for future model improvements.

Highwood provided the following additional context during their review of the written report:

- Suggestions around a more complete glossary (“Key definitions”) in the report.
- Background information on “typical” LDAR programs deployed in various basins.
- A methodology for choosing modeled emissions rate distributions.
- Commentary on areas of improvement in the modelling methodology adopted by MiQ.

Highwood provided the following guidance when reviewing the summary sheet of model results:

- A review of all simulation results; results which struck the reviewers as abnormal were flagged.
- A recommendation on consistency of some model parameterization of compared programs.
- In one case where the cause of abnormal results was difficult to identify, MiQ provided Highwood with all input files. Highwood conducted an internal review and suggestion for MiQ. A model re-run with the suggestion applied led to expected results.

In summary, during their review Highwood found the MiQ modelling team has become extremely proficient with the use of LDAR-Sim and only minor methodology suggestions were made.