KAIROS AEROSPACE

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Clerk of the Board
California Air Resources Board
1001 I Street
Sacramento, California 95814

Kairos Aerospace Comments on the Modified Text for the Proposed Regulation for Greenhouse Gas Emission Standards for Crude Oil and Natural Gas Facilities

We at Kairos Aerospace commend the ARB on its commitment to curb methane emissions from the oil and gas industry. The proposed regulation is one of the strongest, with the broadest applicability, in the nation. We would, however, respectfully recommend a modification to the rule that would achieve similar methane reductions at a lower cost to the regulated industry. We focus our comments on LDAR for fugitive methane emissions.

The fugitive methane emissions detection technology landscape is highly dynamic, with innovation happening in real time. Innovation in technology invariably leads to better outcomes at lower costs. However, the current draft is prescriptive in terms of LDAR technology, sacrificing the opportunity for commercialization of new technologies that could both improve overall environmental outcomes and lower costs. The inflexible nature of the LDAR regulation also impacts different operators differently, as significant variations can exist in operators' facilities, emissions, and costs of control.

<u>ARB should allow operators to seek approval to allow alternative compliance pathways, as long as the alternative is at least as effective in reducing methane emissions volume as quarterly OGI-based LDAR.</u> ARB should also establish clear criteria by which the equivalence of alternative programs will be judged, and ensure that the approval process is transparent and open to public participation. Only by allowing space for new and innovative technologies can ARB ensure that it is achieving its goal of maximum environmental impact at minimal cost.

Many Options Exist, and More Are in Development

As ARB knows, there is already a wide range of proven technologies and implementations on the market, with different detection limits, frequencies, and underlying science. ARB has undertaken projects with a variety of instruments – identifying methane hot-spots, implementing a tiered methane observation system, using aerial surveys for Aliso Canyon-related monitoring.[1,2] ARB recently posted a research report, "Enhanced Inspection & Maintenance for GHG and VOCs at Upstream Facilities,"[3] that evaluates the effectiveness of six different instruments and finds the three remote sensing instruments (RMLD, IR camera, and Picarro Surveyor) to be similar in their

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[1] "California Methane Monitoring for Climate Action and Public Safety," presented by Riley Duren. June 2016. https://www.arb.ca.gov/cc/oil-gas/Miller_2016-06-14%20-%20Duren_methane_hot_spots.pdf

[2] "Airborne Estimation of Surface Emissions," presented by Stephen Conley. June 2016. https://www.arb.ca.gov/cc/oil-gas/Conley_Presentation_ARB%20%281%29.pdf

[3] "Air Resources Board RFP No. 13-414: Enhanced Inspection & Maintenance for GHG & VOCs at Upstream Facilities – Final (Revised)," prepared by Sage ATC Environmental Consulting LLC for the California Air Resources Board. December 2016. https://www.arb.ca.gov/cc/oil-gas/sage_i&m_ghg_voc_dec2016.pdf

ability to detect emissions. ARB is also a part of the ITRC's Evaluation of Innovative Methane Detection Technologies team, which is working to evaluate and compare different technologies, and has participated in several workshops and conferences discussing ways to address fugitive methane emissions. These efforts indicate to us that ARB is aware of the plethora of options, and the ways they can be combined to yield better and more cost-effective results, yet the regulation itself does not reflect this understanding.

In addition to these existing options, there are several innovative technologies at different points along the spectrum from concept to commercialization. These options all have a different set of monitoring frequencies and technical capabilities. On one end of the spectrum there are technologies still in development, for example in ARPA-E's MONITOR program and EDF's Methane Detectors Challenge. On the other end, for example, there is Kairos Aerospace, which has patented and newly commercialized an aerial-based methane imaging system called LeakSurveyor that leads to greater methane reduction at a lower cost than the OGI required by the current draft regulation. Our system allows operators to conduct low-cost, high-frequency surveys of their fields to find and fix large emitters faster. We image methane in false color from fixed-wing aircraft, similar to NASA JPL's AVIRIS system, combined with simultaneous optical imagery, to produce georeferenced optical maps with methane plumes pinpointed and sized. Once we screen a large area and identify the emission sources, targeted ground crews follow up to identify and repair the specific component that is leaking. This approach results in a lower overall cost to operators, as compared to sending ground crews to every site. And more frequent surveys for large leaks result in a greater environmental impact than infrequent ground surveys.

It is, of course, critical that any alternative LDAR program achieves at least the same environmental impact as the LDAR program laid out in the regulation. Comparing different LDAR programs is possible through computer models, combined with real-world demonstrations.

Equivalent Environmental Impact is the Important Thing

<u>At a basic level, the emission control effectiveness of any LDAR program is a function of both the ability of the technology used to detect leaks and the frequency of monitoring.</u> An equivalent program may require more frequent monitoring, if its mass rate threshold for detecting leaks is higher, because higher mass emissions reductions from large leaks found earlier are offset to some degree by smaller leaks which go undetected. Indeed, this is reasoning put forth by the EPA in 2006 in a proposed amendment to allow OGI as an alternative work practice to Method 21,[4] and extends easily to a range of monitoring instruments. This reasoning is also used in a 2004 American Petroleum Institute report[5], which states:

> "Lower leak definitions for repair do not necessarily lead to better emissions control since, as the leak level is decreased, few additional leaking components are added to the repair group and these contribute very little to the overall mass emissions. The Smart LDAR

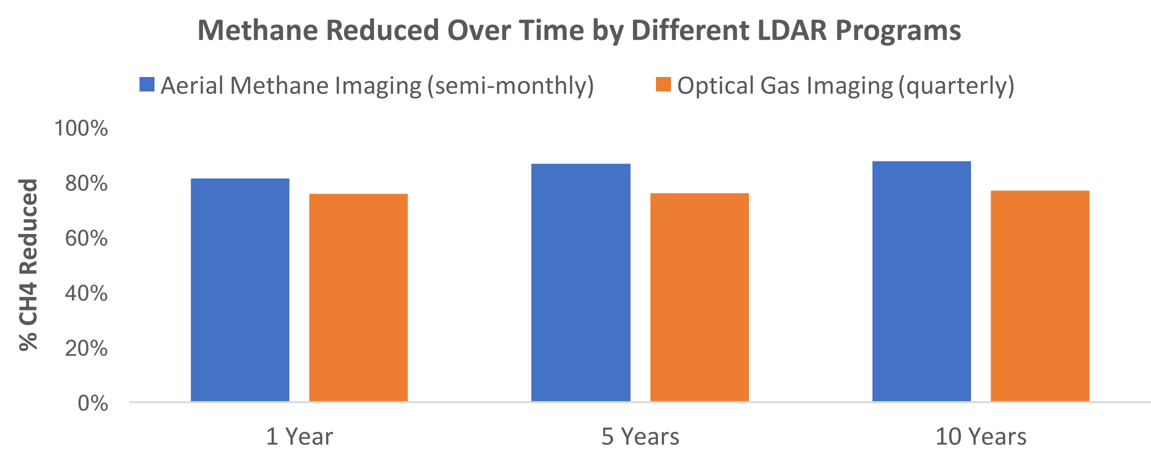
[4] EPA Alternative Work Practice to Detect Leaks from Equipment, 71 FR 17401 (April 6, 2006) (to be codified at 40 CFR 60).

[5] "Smart Leak Detection and Repair for Control of Fugitive Emissions," prepared by ICF International for American Petroleum Institute. June 2004.

approach…focuses on identifying and repairing the highest leakers since these are the source of almost all the mass emissions. Equivalence is obtained by more quickly finding and repairing these large leaks, which more than offsets the emission rates from components with low ppmv readings that leak for longer periods. The use of optical imaging could provide a more cost effective approach to more quickly find the high leakers."

Using a computer model (along with laboratory testing and field validation of instruments) solves many of the real-world difficulties of comparing the equivalency of different technologies in the field over time. This approach was also supported by the EPA in its 2006 amendment mentioned above, and the API in its 2004 report, indicating broad stakeholder agreement on its usefulness and validity. It is therefore also the approach we at Kairos use to arrive at our emissions reduction estimates. We use an open-source model called the Fugitive Emissions Abatement Simulation Testbed (or FEAST).[6] This model simulates natural gas leakage over time under different LDAR programs. We used a power-law distribution[7] fitted to the 2011 Fort Worth Air Quality Survey[8] data to generate the leaks from the gas field. We then modeled the average reduction (relative to a null scenario) in methane emissions with quarterly Optical Gas Imaging surveys and semi-monthly Aerial Methane Imaging surveys (which in this case is Kairos Aerospace's LeakSurveyor technology with a minimum detection limit of 120 g/hr or 500 ppm-m).

<u>We find that semi-monthly LeakSurveyor surveys result in 87% reduction of methane emitted and quarterly OGI surveys result in 76% reduction over a null scenario[9] over five years.</u>



[6] FEAST Documentation: https://pangea.stanford.edu/researchgroups/eao/sites/default/files/FEASTDocumentation_0.pdf

[7] See Appendix B.

[8] City of Fort Worth Natural Gas Air Quality Study. Eastern Research Group et al. for the City of Fort Worth, 2011. URL: http://fortworthtexas.gov/uploadedFiles/Gas_Wells/AirQualityStudy_final.pdf

[9] The null scenario is modeled as operators randomly noticing and fixing leaks in the normal course of operations, with no explicit LDAR program.

Therefore, LeakSurveyor would be a more effective LDAR program than OGI, which is an approved technology in the current regulatory draft. **(**See Appendix A for more detail on LeakSurveyor's capabilities, and Appendix B for more detail on FEAST.) Incidentally, the LeakSurveyor program is also cheaper than the OGI program, despite the increased frequency of surveys, since each LeakSurveyor survey is an order of magnitude less expensive than a conventional OGI survey. LeakSurveyor also offers leak rate quantification, direct imaging and georeferenced results, and an auditable record of surveys and results.

The same FEAST model can be used to compare other technologies as well, by adding new modules to the program. Thus an operator can choose the most cost-effective LDAR program based on their own needs and constraints, and ARB can estimate whether the proposed alternative compliance program will reduce emissions from an operator at least as much as quarterly OGI, ultimately resulting in more efficient regulation.

Conclusion

In LDAR, the current ARB draft actually falls behind EPA's NSPS OOOOa regulations, where instead it should be an opportunity for ARB to lead the EPA. California is home to Silicon Valley innovation and a long-time leader in air quality regulation, yet these rules do not leave space for innovation. NSPS OOOOa allows an alternative compliance pathway for LDAR of new or modified well sites and compressor stations, but the lack of criteria for judging equivalence is unclear and has led to confusion from many operators, and the demonstration period is prohibitively long and costly. ARB's oil and gas regulation applies to both new and existing sources, making LDAR even more cost prohibitive to operators, yet does not include an alternative compliance pathway option.

We strongly urge the agency to adopt an alternative compliance pathway that is robust, minimally prescriptive, and specifically creates an entry point for demonstrated methane detecting solutions. Such an approach will help catalyze a race to the top in technology, reduce costs for the regulated community, and boost environmental outcomes.

We greatly appreciate the opportunity to be part of the dialogue on GHG standards in California, and look forward to working with ARB and industry toward our common goals. We are happy to answer questions or discuss anything in these comments in greater detail.

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Appendix A: LeakSurveyor (Aerial Methane Imaging)

LeakSurveyor is a new methane detection service that combines an aerial methane detection instrument with a proprietary data analysis pipeline. Our goal is to provide customers with clear, actionable information about where, and how big, their methane emissions are. LeakSurveyor is designed to survey large areas frequently at an affordable cost – a single instrument can cover 30,000 acres in one day. Once an emission is detected aerially, the customer sends a directed ground crew to identify and repair the particular component that is leaking. This hybrid approach – frequent aerial surveys combined with targeted follow-up inspections – saves a company time and money, and saves more methane than sending ground crews to every site. This is because:

1) Sources are often remote and most are not emitting significant amounts of methane, so sending crews to each one wastes the time of engineers at a meaningful cost.
2) Finding a single large emission a day earlier can be more impactful than finding hundreds of small emissions, so time is best spent looking for the large emissions.
3) We can frequently survey unsafe- or difficult-to-monitor components that would otherwise rarely be surveyed, and recover gas that would otherwise go undetected by ground-based monitoring methods for long periods of time.

Ultimately, LeakSurveyor stops the large emitters that cause most of the environmental and economic damage earlier, for a greater cumulative impact.

Highly Specific Methane Imaging

The LeakSurveyor instrument consists of three parts: 1) an optical camera for visual verification of sites, 2) a GPS and inertial monitoring unit to record precise positions, and 3) a patented spectrometer that detects methane. The spectrometer is sensitive to infrared sunlight that reflects off the ground. When this light passes through a plume of methane, the methane absorbs certain frequencies and lets others pass through. The spectrometer identifies those absorption features, and associates them with a particular position on the ground. This makes our system highly specific for methane, as it is the only molecule that leaves this particular signature on the spectrum, and avoids signal confusion from other gases like propane. It is also specific to location; the resolution on the ground (~20 feet) is well-matched to most gas plumes. As a result, we produce direct images of plumes, overlaid on simultaneously captured optical imagery. After reviewing the specifications and capabilities of other categories of methane sensing technologies we believe LeakSurveyor belongs to a new class of instrument, which we have been calling "Aerial Methane Imagery."

LeakSurveyor's resolution allows us to distinguish between separate point sources of methane and differentiates us from air-sampling techniques. In the image below, for example, we separate the methane plume from natural gas production from the methane plume from the flooded rice field nearby, and would only report the former. What's more, we distinguish between the location and concentration of separate emissions within a single site, such that the ground crew following up on the emissions can go directly to a specific area to identify and repair a specific component.

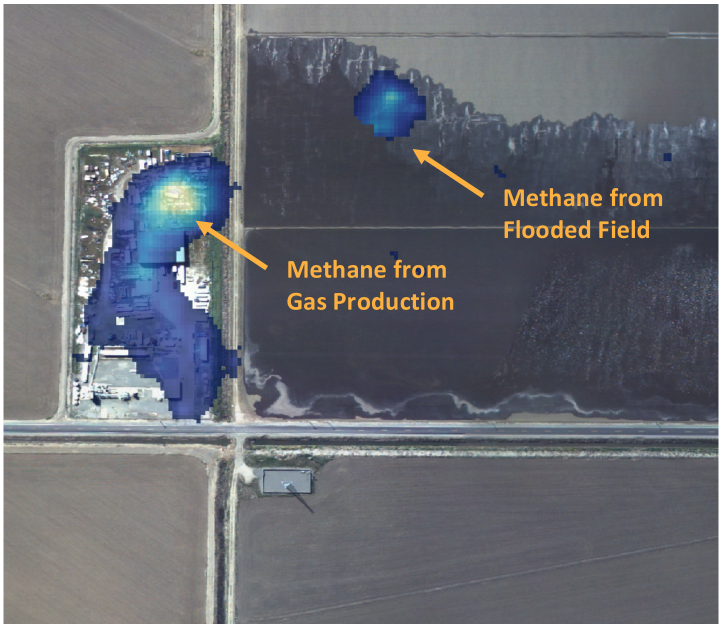

Figure 1: LeakSurveyor's direct point source methane imaging separates the gas production-related emission (on the left) from the nearby flooded field-related emission (on the right). This allows distinct attribution of methane between different sources.

Clear, Actionable, Prioritized Results

The image below is an example of the results we provide. Methane plumes, highlighted in blue, are overlaid on optical imagery of a survey area about a mile wide with ten separate well pads.

Figure 2: Sample LeakSurveyor false color image; blue areas represent methane plumes.

The minimum detection threshold for LeakSurveyor in controlled settings is 500 ppm-m. With a 5 mph wind, this corresponds to an emission rate of 10 Mscf/day (that is, 8 kg/hr, or 2 g/s.) Our conservative real-world detection limit is 2500 ppm-m, which corresponds to an emission rate of 50 Mscf/day. In the real world, LeakSurveyor detects a statistical fraction of emissions below 50 Mscf/day. As we continue to collect vast quantities of data – we have recently set up partnerships to do so with a number of operators, non-profits, and government agencies – we will continue to refine the "probability of detection" curve we have built that shows the probability of detecting emissions as a function of the emission rate and of external conditions like weather and terrain.

LeakSurveyor distinguishes between different sizes of methane emissions with a precision within ±25%; in Figure 4 above, areas of dark blue represent lower concentrations, ranging towards lighter areas which represent higher concentrations. Our ability to identify, over a wide area, the size of emissions allows prioritization of repair work to stop the biggest emissions fastest for greater impact on the environment, and improves on the quality of data on which academic research and policy decisions are currently based. Figure 3 below shows a controlled methane release where we simultaneously operated LeakSurveyor from an airplane flying at 3,000 ft., a FLIR GasFinder 320 IR camera pointed at the release valve from 50 ft. away, and a Method 21 analyzer held 20 ft. from the valve. The LeakSurveyor results show a clear relationship between the methane release size and our signal size. As with our minimum detection threshold, we continue to refine our quantification ability as we collect more LeakSurveyor data combined with ground truth measurements. We also continue to conduct calibration studies with controlled releases, often flying a controlled release at the same time as we are flying operators' fields.

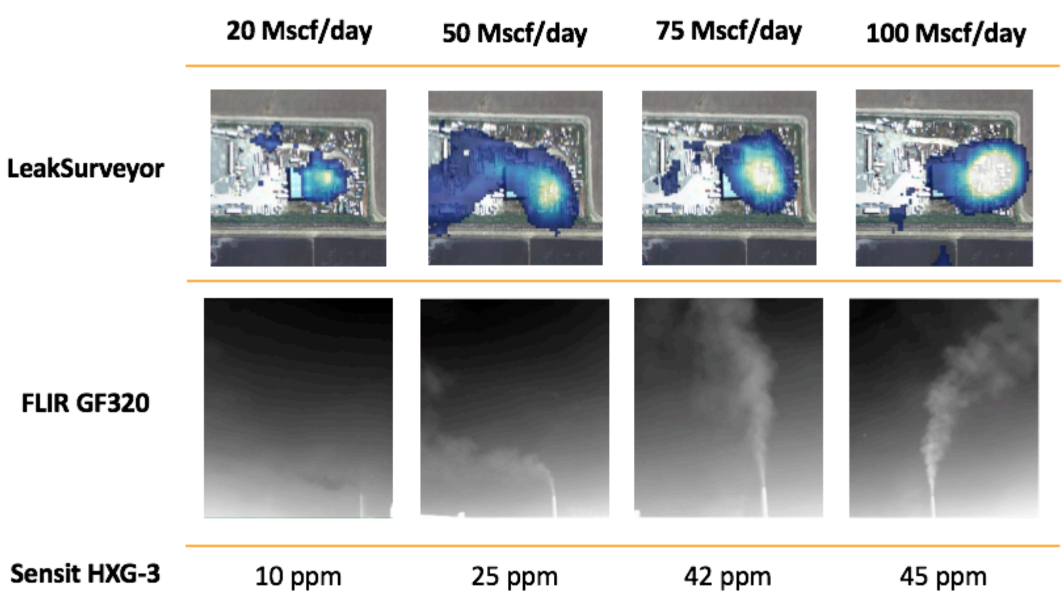

Figure 3: Side-by-side comparison of emissions monitoring technology results during a controlled methane release. LeakSurveyor is able to distinguish between different leak sizes.

Faster, Cheaper, Safer

The LeakSurveyor instrument is easily mounted on light aircraft and flown at standard general aviation altitudes of 3,000 ft., making it orders of magnitude faster than a ground crew and able to access terrain that would be difficult or dangerous to reach by car. LeakSurveyor is also faster and safer than helicopters. It can fly longer and farther than commercially available drones, which rarely have battery lives of more than 30 minutes, limiting their flight range and increasing their cost. Drones are also subject to complex and shifting state-by-state regulatory issues.

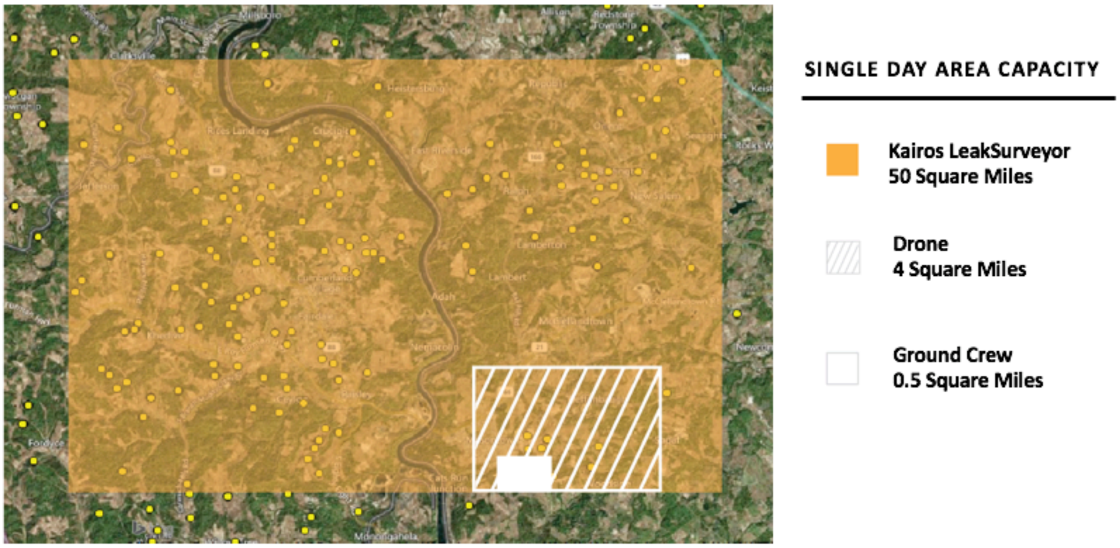

Figure 4: LeakSurveyor covers orders of magnitude more area than a ground crew, allowing frequent revisits.

Plug and Play Service

We operate the pod as a service, so there is no training, calibration, or instrument maintenance or repairs needed on the part of our customers. We eliminate the possibility of operator error or variation, as all protocols, from pre-survey calibration to post-survey data quality assurance, are performed by highly trained Kairos engineers or automatically through our cloud-based data pipeline. Results are thus directly comparable from flight to flight. Each pod attaches to a plane with no tools, wiring, or modifications required (see image below), which means we do not need FAA approval.

Figure 5: Pod attaches to the wing strut of light aircraft with no tools, modifications, or wiring connections.

Unique Software Capability, Continuous Improvement

Our proprietary software and data analysis capabilities are unique in the market. Our modern "big data" analytics pipeline immediately, automatically, and uniformly processes the data we collect into usable form – whether that form is an individual report that integrates with existing infrastructure management software used by operators, or a mainstream tool like Google Earth. Our process reduces the possibility of user error in interpreting results, lowers compliance costs, and increases reporting accuracy. An additional benefit is that the accuracy and correctness of each new survey will be improved by the overall analysis of all the data we have ever collected, as results taken over time are used as a feedback loop to improve the LeakSurveyor service.

No Capital Expenditures on Equipment or Training

Because we operate LeakSurveyor as a service, there are no upfront expenditures on capital (e.g. instruments or trucks) or labor (e.g. training or hiring). This means that starting up an LDAR program can yield savings for a company immediately. It also gives companies flexibility in crafting an LDAR program that works for their particular needs. For example, a company that uses an IR camera for one area may want to use LeakSurveyor to monitor another hard-to-reach area. A company that has only enough labor capacity to conduct semiannual surveys can increase its monitoring frequency to quarterly or even monthly with LeakSurveyor.

Lower Cost Per Survey Than Alternatives

LeakSurveyor also reduces costs per survey because we have greatly reduced the need for on-the-ground surveyors, the most significant cost in a traditional program, whether an operator conducts his own surveys or hires a third party. As a quick back-of-the-envelope comparison, Carbon Limits[10] estimated that it costs $600 to hire a contractor to survey a single well site, whereas LeakSurveyor costs $100 per well site. Realistically, most of the operators we have spoken to report that an IR camera contractor costs more than $600 per well site, particularly as the companies still need to send in-house engineers to accompany the contractors on-site; anecdotally, the cost has also increased due to increased demand and a shortage of both OGI cameras and qualified contractors. We have also run cost analyses using assumptions from other sources, for various sizes of producer and for other monitoring options (i.e. owning an IR camera versus hiring a contractor, using a Method 21 analyzer instead of an OGI).

Simplification of Reporting and Recordkeeping

In addition to no upfront costs and low ongoing costs, our post-survey costs are lower as well – our software and secure data pipeline streamlines necessary activities like recordkeeping and reporting for compliance purposes, as well as more in-depth analysis. We generate automatic reports regarding data quality and completeness during each survey and for the entirety of the survey. All of our raw data and metadata is stored in the cloud indefinitely for recordkeeping and time-series analyses for operators. And our automated survey greatly reduces the time it takes to record component locations and IDs for any fugitive emissions detected.

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[10] "Quantifying Cost-effectiveness of Systematic Leak Detection and Repair Programs Using Infrared Cameras," Carbon Limits SA. March 2014. URL: http://www.catf.us/resources/publications/files/Carbon_Limits_LDAR.pdf

Appendix B: FEAST, the Fugitive Emissions Abatement Simulation Testbed

For an in-depth description of the FEAST model, please see the documentation online at https://pangea.stanford.edu/researchgroups/eao/sites/default/files/FEASTDocumentation_0.pdf. This appendix is meant to serve as a basic summary of the model's structure and how we used it to model the efficacy of different LDAR programs.

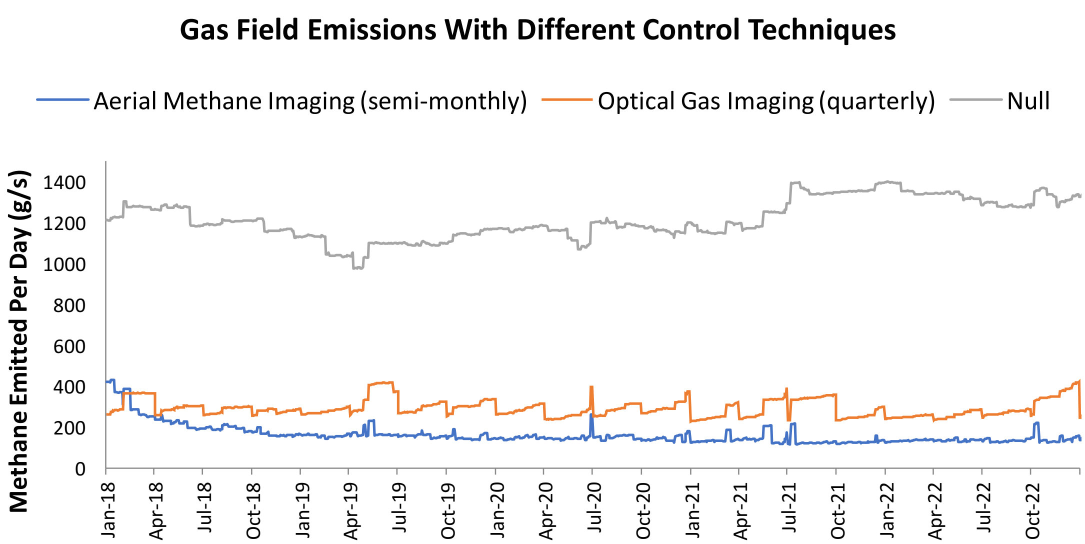
As described in the documentation: "FEAST simulates the leakage from a natural gas field as a function of time under different LDAR programs. It defines an LDAR program as a technology used for leak detection, the implementation of the detection technology, and the leak repair process. Based on a plume simulation, FEAST applies detection criteria for several LDAR methods, identifies the leaks that will be detected under each LDAR program, and removes them from the set of leaks at the appropriate time. The total gas saved by the LDAR program is calculated as the time-integrated difference between the leakage in a null scenario and a scenario with the applied LDAR program. The null scenario represents the status quo: it allows a steady leakage rate through time as new leaks are produced and old leaks are repaired randomly without an explicit LDAR program."

The input data for FEAST include field parameters (number of wells, number of components per well, average distance between wells), a dataset of leak rates, atmosphere data in order to simulate the gas plumes (measured wind speeds and directions), and LDAR parameters (detection criteria, time to find leaks).

Leak distribution: The FWAQS study sampled 375 well sites one time, which represents a relatively small sample size unlikely to capture the full range of extreme results. In order to account for super-emitters, we extended the FWAQS data with a power law distribution, which is usually used to model data whose frequency of an event varies as a power of some attribute of that event – in this case the event is a leak and the attribute is leak size. The power law distribution we used has an upper bound of 500 Mscf/day (meaning the simulation never generates a leak larger than that.) We chose -1.75 for the power, or exponent, in the power law formula $y = ax^k$, to match the national top-down estimates of petroleum-sector methane emissions. If the exponent is more negative, excessive numbers of tiny leaks are required to produce the methane from the top-down estimates. This results in many more leaks than wells, such that the typical well would have three to five leaks. This is out of sync with reality, as many wells and facilities are not leaking at all. If the exponent is less negative (closer to zero), then more of the methane comes from truly enormous emissions. We don't have enough data to support that, although it could still be true.

LeakSurveyor: We added a module for LeakSurveyor, which is an implementation of a method we have termed Aerial Methane Imaging. We formed our expectations for performance based on extensive calibration tests, both in a controlled setting – where a controlled methane release was gradually turned up while a LeakSurveyor plane flew back and forth overhead and an IR camera operator and a Method 21 instrument operator stood on the ground and recorded images and readings for comparison – and in the real world, where we collected results for an operator and then performed ground truth measurements to validate our field results. This real-world performance was then added to the FEAST simulation with the consultation of one of the original authors of the code to ensure correct integration.

The chart below shows one simulation of the FEAST model over five years (labeled as January 2018-December 2022.) The blue line represents total emissions from the 1,100 wells in the natural gas field with a semi-monthly Aerial Methane Imaging program, which in this case is LeakSurveyor. The red line represents total emissions from the natural gas field with a quarterly OGI program. The grey line represents total emissions from the field in the null case, where leaks are randomly fixed in the normal course of operations. Over the time represented, the LeakSurveyor program reduces methane from the null scenario by 87%, and OGI reduces methane by 76%.



The chart below shows the cumulative volume of methane reduced over time relative to the null scenario.