BEFORE THE
PUBLIC UTILITIES COMMISSION OF OHIO

In the matter of the Application of Vectren Energy Delivery of Ohio, Inc. for Approval of an Alternative Rate Plan.	)))	Case No. 18-49-GA-ALT
	)	
In the Matter of the Application of Vectren Energy Delivery of Ohio, Inc. for Approval of an Increase in Gas Rates.	)))	Case No. 18-0298-GA-AIR
	)	
In the Matter of the Application of Vectren Energy Delivery of Ohio, Inc., for Approval of an Alternative Rate Plan.	)))	Case No. 18-0299-GA-ALT

DIRECT TESTIMONY OF
VIRGINIA PALACIOS
ON BEHALF OF
ENVIRONMENTAL LAW AND POLICY CENTER

Filed: November 7, 2018

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Q. Please state your name, title, and business address.

A. My name is Virginia Palacios. I am an independent consultant, and my business address is P.O. Box 27, Encinal, Texas 78019.

Q. Please provide a summary of your education and experience.

A. I hold a Masters of Environmental Management from Duke University and a B.S. in Aeronautical Science from Embry-Riddle Aeronautical University. In the past year I was the State and Local Policy Manager at South-central Partnership for Energy Efficiency as a Resource, where I managed a collaborative effort between investor-owned electric utilities and stakeholders interested in improving the achievements of energy efficiency programs in Texas.

In all, I have seven years of experience working on issues relating to the natural gas sector. Previously, as a Senior Research Analyst at the Environmental Defense Fund ("EDF"), I provided technical expertise on scientific and regulatory concepts related to local distribution pipeline safety, lost and unaccounted for gas, and quantification of methane emissions from local distribution system pipelines. I also analyzed quantitative and geospatial data related to methane leakage in the natural gas sector.

In my prior position as a Research Analyst at EDF, I investigated local, state, and federal rules related to local distribution pipeline safety and lost and unaccounted for gas, and developed an understanding of how methane emissions from local distribution system pipelines can be quantified. Some of my work, which involved geospatial attribution of methane emissions data, was published in two peer-reviewed articles.[1]

[1] Lyon, D., et al. (2015). Constructing a Spatially Resolved Methane Emission Inventory for the Barnett Shale Region. Environmental Science and Technology (http://doi.org/10.1021/es506359c); and Zavala-Araiza, D., et al. (2015). Towards a

When I began working for EDF as a Research Associate, I conducted regulatory comparisons and data analysis related to the oil and gas industry, with a particular focus on federal and state regulations on distribution system integrity management, SCADA leak detection systems, cost recovery mechanisms, lost and unaccounted for gas, and pipeline mileage and leakage data provided in Pipeline and Hazardous Materials Safety Administration ("PHMSA") Annual Distribution System reports.

I co-authored a paper titled "Integrating Leak Quantification into Natural Gas Utility Operations," which was published in Public Utilities Fortnightly May 2017, provided as Schedule VEP-02 to this testimony. Additionally, I have had the opportunity to participate in field research comparing several leak quantification methodologies. I have also met with advanced leak detection technology service providers and reviewed information supporting the technical basis for the services they offer.

Q. Have you previously filed testimony before regulatory or legislative bodies?

A. Yes. I submitted testimony to the New Jersey Board of Public Utilities in Docket No. GR17070776, the State of New York Public Service Commission in Case 16-G-0061, and the Illinois Commerce Commission in Docket No. 16-0376.

Q. On whose behalf are you testifying in this proceeding?

A. I am submitting testimony on behalf of the Environmental Law and Policy Center ("ELPC").

Functional Definition of Methane Super-Emitters: Application to Natural Gas Production Sites. Environmental Science and Technology (http://doi.org/10.1021/acs.est.5b00133).

I. Purpose of Testimony

Q. What is the purpose of your testimony?

A. The purpose of my testimony is to present information and recommendations relating to the use of advanced leak detection technology and leak quantification methods to assist Vectren Energy Delivery of Ohio, Inc.'s ("VEDO," "Vectren," or "Company") in its proposed leak repair and pipe replacement activities. In particular, my testimony describes the current status of advanced leak detection technology, leak quantification, and associated analytics. Next, I explain the benefits of advanced leak detection technology and using its resulting data to prioritize leak abatement and pipeline replacement decisions. My testimony also suggests potential pathways for incorporation of leak flow rate data derived from advanced leak detection technology into the Company's existing prioritization methods.

Q. Are you attaching any schedules to your testimony?

A. Yes. I am attaching the following schedules to my testimony:

- Schedule VEP-01: Resume
- Schedule VEP-02: "Integrating Leak Quantification into Natural Gas Utility Operations," Public Utilities Fortnightly (May 2017)
- Schedule VEP-03: Response of ABB Inc. ("ABB") – Los Gatos Research to Letter of Inquiry Dated May 9, 2017 from the Citizen's Utility Board submitted in Illinois Commerce Commission Docket No. 16-0376
- Schedule VEP-04: Response of Picarro, Inc. ("Picarro") to Letter of Inquiry Dated May 9, 2017 from the Citizen's Utility Board submitted in Illinois Commerce Commission Docket No. 16-0376

Q. Please provide a summary of your testimony and recommendations.

A. I first comment on the Company's proposed accelerated pipe replacement and leak management efforts, and the potential benefits to customers, and the environment associated with the use of new technological solutions such as advanced leak detection and leak quantification methods in designing and implementing leak repair and pipe replacement activities. By advanced leak detection, I am referring to high sensitivity (i.e. measuring methane concentrations in parts per billion and collecting data points at a rate of at least twice per second) methane detectors mounted on vehicles equipped with Global Positioning Systems ("GPS") that collect latitude and longitude coordinates at the same time as methane concentration data is being collected. "Leak quantification methods" refers to the advance analytics or algorithms that utilize data acquired from advanced leak detection technology to estimate the methane flow rate (e.g. in liters per minute) that can be attributed to a leak indication. Based on these factors, I support the Company's ongoing efforts to update and improve its leak detection and abatement program and recommend that it develop a plan for integrating advanced leak detection and data analytics into its pipe replacement and leak repair efforts.

II. VEDO's Distribution Accelerated Risk Reduction Program ("DARR")

Q. Please summarize your understanding of the Company's proposed leak prone pipe replacement efforts.

A. As explained by VEDO witness Mr. Redd, beginning in 2010, the Company established a distribution integrity risk model and developed, implemented and documented additional accelerated actions to mitigate distribution asset threats.[2] Mr. Redd also states that VEDO's ability to evaluate risks and threats continues to evolve and that the Company has implemented a set of asset-based risk models to assess risk on distribution pipelines, valves and pressure regulation equipment.[3] As detailed by VEDO witness Ms. Vyvoda, the Company's Distribution Accelerated Risk Reduction Program ("DARR") is comprised of six initiatives, including:

(1) Expanded Leak Management Program, targeting the remediation of open grade 3 leaks within VEDO's distribution system;

(2) Enhanced Damage Prevention Program, targeting and measuring the performance of efforts to reduce third party excavation damages;

(3) Public Awareness, focusing on increased public awareness campaigns in areas where VEDO is actively modernizing or performing work on assets and facilities;

(4) Workforce Training and Qualification for New Requirements, including conducting root-cause investigations to drive lessons learned type training;

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[2] Direct Testimony of Ellis S. Redd on Behalf of Vectren Energy Delivery of Ohio, Inc., Case Nos. 18-0298-GA-AIR- and 18-0299-GA-ALT at page 6, lines 12-14 (April 13, 2018) ("Redd Testimony").

[3] *Id.* at page 7, lines 1-8.

(5) Pipeline Safety Management System Implementation, involving the development and implementation of a framework designed to reveal and manage risks to gas assets; and

(6) Enhanced Risk Modeling and Threat Analysis, including the evaluation of data required to determine the threats present with each set of assets, the research and field investigation required to improve the completeness and accuracy of those data sets, the development of the models to determine the risks associated with each set of assets, and the validation and implementation of the asset-based risk model.[4]

Q. Has the Company acknowledged that a more systematic and proactive approach to eliminating leaky pipe infrastructure may be required?

A. Yes, Mr. Redd acknowledges this in his testimony and states that modifications or expansions of the scope of the Replacement Program may be needed in the future.[5]

Regarding the Company's "Enhanced Risk Modeling and Threat Analysis" DARR initiative, Ms. Vyvoda states that, "[a]s VEDO's DIMP was implemented over time, advancements in data quality and technology have allowed VEDO to enhance its models and risk assessment process to identify opportunities in data quality enhancements; evaluate a broader set of threats specific to certain asset types like pipeline, services, pressure regulation and valves; and predict the impact that system risk mitigation

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[4] Direct Testimony of Sarah J. Vyvoda on Behalf of Vectren Energy Delivery of Ohio, Inc., Case Nos. 18-0298-GA-AIR- and 18-0299-GA-ALT at page 12, lines 16-21 (April 13, 2018) ("Vyvoda Testimony").

[5] Redd Testimony at page 8, lines 11-17.

activities may have in order."[6] According to the Company's DARR, the DIMP team has identified the need for a more detailed, asset-based relative risk-ranking model to support threat identification and risk-mitigation activities:

> Under the risk model enhancement project, Vectren intends over the next two to three years to develop a proof-of-concept asset-based relative risk-ranking model and analysis tools for mains and services, and to develop additional factors based on system data, leak history, environmental factors, construction activity, and population to support a more granular risk profile.[7]

<u>III. Status of Advanced Leak Detection Technology and Recent Technological Advancements</u>

Q. Please describe how available advanced leak detection technologies work to identify and quantify natural gas leaks, as compared to traditional methods.

A. Utility estimates of leak size have typically been made using best available estimates of pipeline type, size and pressure, and historical leak data. However, this method has limitations; traditional leak surveys can miss up to 66% of leaks, rely on dated and sometimes incomplete records, and may not provide spatially-attributed information that can be easily linked to infrastructure asset maps.[8]

Advanced leak detection technologies, leak quantification methodologies, and the analytics and visualizations that can be developed using these methods can provide more accurate and useful tools in the Company's leak prioritization efforts. Advanced leak

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[6] Vyvoda Testimony at page 22, lines 17-22; *see also* Attachment H, pages 9-10 (discussing the progress and timing for VEDO's enhanced asset-based risk model implementation).

[7] Vyvoda Testimony, Attachment G, page 11.

[8] Picarro. 2016. "Pipeline Replacement and Emissions Reduction." Santa Clara, CA. http://naturalgas.picarro.com/support/library/documents/pipeline-replacement-and-emissions-reduction-using-picarro-emissions.

detection technology involves the use of sensitive sensors (e.g. methane sensors with detection limits on the order of parts per billion) installed on vehicles to collect emissions data such as methane and ethane while driving selected survey routes. The emissions data are then analyzed using algorithms (typically proprietary) to draw out key leak information such as estimated leak flow rate (e.g. liters per minute), leak density (e.g. leaks per mile), and probable grade (e.g. Grade 1, 2, or 3).

Q. Please further explain how the emissions data are analyzed.

A. As described by Picarro, a supplier of advanced leak detection technology and analytics software:

> Data is collected at driving speeds and multiple passes over the infrastructure of interest. Emissions data is determined through a combination of methane and ethane measurements, location and wind data taken by the vehicle and later processed with the cloud-based [proprietary software analytics]. As the vehicle drives through a natural gas plume, samples and are collected through the line of inlets located on the front of the vehicle and measured in real time. Wind sensors simultaneously calculate the wind speed and direction from which a gas plume profile is derived. Emissions rate and location are determined through the combination of multiple transects downwind of a leak.[9]

Data collected by providers of advanced leak detection technology and analytics are generally available in real-time, and can be displayed as an overlay on maps of a utility's infrastructure. This can facilitate investigation, communicate leak location to repair teams, and facilitate verification of repair efficacy.

Q. What is spatially-attributed leak flow rate data and how is it obtained?

A. Spatially-attributed leak flow rate data is information about the volume of emissions escaping from a leak over time, and for which the geographic location of the leak

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9 *Id.*

detection (e.g. latitude and longitude of the leak detection) is available. When it comes to above-ground pipeline leaks, data can be collected through the use of methane analyzers attached to vehicles that are equipped with GPS. After data collection, an algorithm can be used to calculate the leak flow rate, and the approximate location of the leak can be established using data collected through the GPS system. In short, spatially-attributed leak flow rate data is information about above- or below-ground infrastructure leaks that is linked to or mapped on specific locations, and can be obtained from several service providers.

Q. Please describe any recent improvements in technology or analytics that enhance the utility of data collected by advanced leak detection technology.

A. The recent improvements I describe below are primarily based on materials submitted in Illinois Commerce Commission Docket No. 16-0376 by ABB and Picarro, two companies that provide advanced leak detection technology, leak quantification and associated analytics. The materials are presented as attached schedules to my testimony, Schedule VEP-03 and Schedule VEP-04. These improvements include better source attribution, leak flow rate quantification software, leak locating and survey completeness features, and leak grade probability software.

Q. Please describe what is meant by source attribution.

A. ABB and Picarro both stated that they provide analyzers capable of reporting both methane and ethane at very low detection levels. Dual deployment of methane and ethane sensors allows for the separation of thermogenic methane (typically associated with natural gas leaks) and biogenic methane (typically associated with sewer or landfill methane emissions). Excluding biogenic methane from the population of leak indications results in fewer "false positives" during leak surveys.

Q. Please further describe leak flow rate quantification software.

A. ABB and Picarro also indicated that they provide leak quantification analytics as a part of their software packages. In addition, Picarro shared a white paper describing their emissions quantification ("EQ") analytics services.[10] Picarro's EQ analytics feature offers a report that attributes leak indications to the utility's infrastructure (if the utility provides this data), and summarizes the results of a leak quantification survey in a way that does not trigger the responsibility to investigate each leak indication. A utility can use the leak flow rate data derived from advanced leak detection technology to prioritize pipeline replacements or measure progress in reducing gas lost from leaks, without having to spend resources investigating individual leaks. Picarro's EQ reports contain the following information:

- Segment ID
- Segment Rank (based on aggregated leak flow rate of the segment)
- Emissions Rate in standard cubic feet per hour (SCFH)
- Emissions Range (confidence)
- Segment Length in feet (ft.)
- Emissions Factor (SCFH/ft.)
- Estimated Number of Leaks
- Number of Leaks per ft.
- Emissions Rate per Leak

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[10] *Id.*

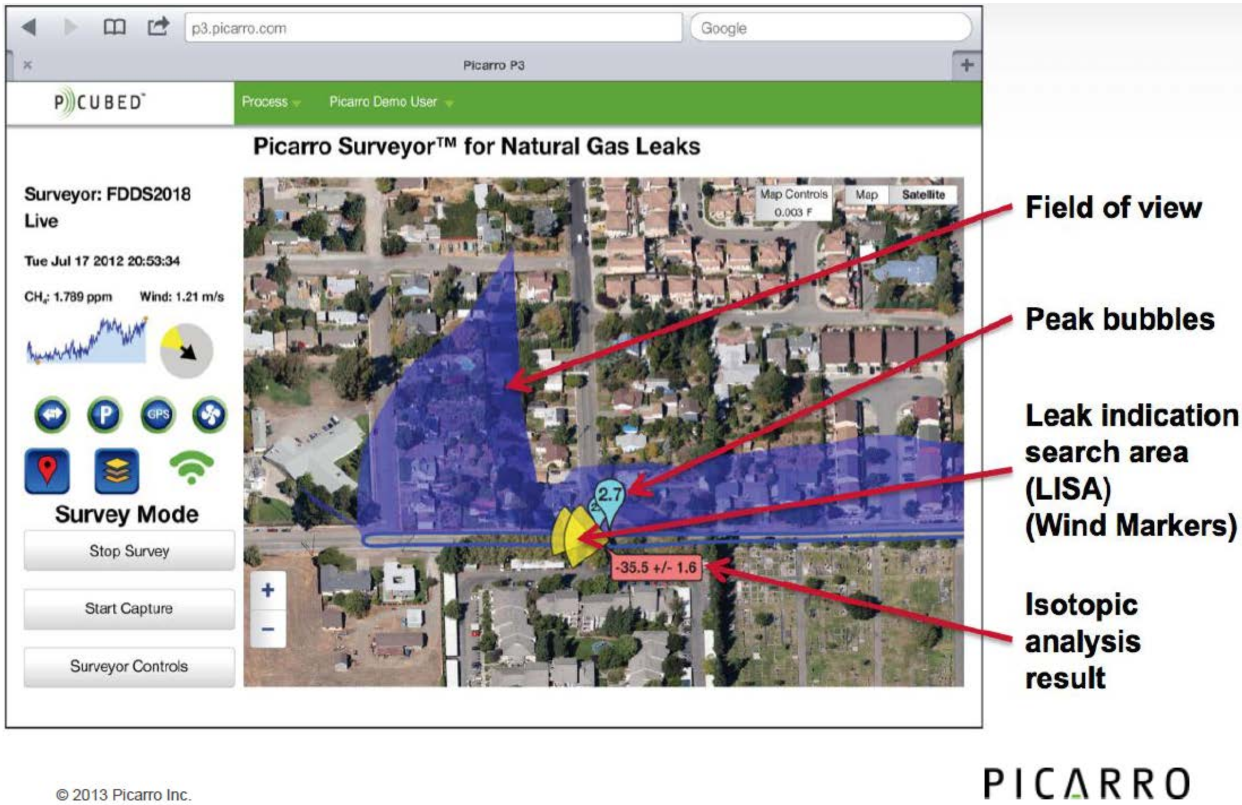
Q. Please further describe leak locating and survey completeness features.

A. ABB and Picarro collect wind data during mobile surveying. Wind data allows utilities to assess which search areas have already been surveyed, and to predict where leaks are located relative to the vehicle's position. The wind information is used to estimate the direction the elevated methane readings may have been coming from; combined with specialized algorithms, ABB and Picarro are able to calculate statistics that indicate the probable location of the leak. In addition to locating leaks, the wind data can be used to estimate areas where the equipment's field of view was likely to have covered—that is, the distance and direction from the vehicle where the methane sensors are likely to detect a leak, if one exists. Conversely, this also helps to identify geographic areas that the advanced leak detection technology is not able to reach.

An example of the "field of view" from Picarro's user interface is provided in the figure below:[11]

[11] Picarro, and PG&E. 2013. "Picarro Surveyor for Natural Gas Leaks." In Distribution Technology Transfer Workshop. Orlando, FL: U.S. Environmental Protection Agency. https://www.epa.gov/natural-gas-star-program/pacific-gas-and-electric-experience-picarro-technology.

Figure 1



Those areas that are not reached by the advanced leak detection technology's field of view can then be prioritized for foot surveys, if the utility determines a need to do so.[12] Traditional technologies for surveying typically do not allow for an extended field of view the way that advanced leak detection technology does, because the advanced technology uses more sensitive equipment and wind information. Because of this hindrance in sensitivity and field of view, use of only traditional technologies may result in a utility being unaware of leaks that exist on their system.

[12] Picarro. 2016. "PG&E Routine Regulatory Compliance Leak Survey of Distribution Pipelines." Santa Clara, CA. http://naturalgas.picarro.com/support/library/documents/routine-regulatory-compliance-leak-survey-distribution-pipelines.

Q. Please further describe grading probability software.

A. In its white paper "The Transition to Smart Gas Distribution," Picarro writes that analytics utilizing advanced leak detection technology can be used to "prioritize each leak indication by the likelihood that it corresponds to a hazardous leak"[13] With information about the probability of a leak being hazardous, utilities can prioritize leak investigations in a way that maximizes the number of hazardous leaks found per effort spent investigating leaks. Such a strategy would ultimately improve the performance of the utility at reducing the greatest number of hazardous leaks per dollar spent on investigations.

In summary, these technology improvements, source attribution, leak flow rate quantification software, leak locating and survey completeness features, and grading probability software, allow utilities to maximize the return on investment when using advanced leak detection technology, from both a financial and safety perspective.

IV. Benefits of Advanced Leak Detection, Data Analytics and Quantification

Q. What are the advantages and benefits of operationalizing advanced leak detection technology and using leak flow rate data to make decisions relating to gas utility infrastructure?

A. Using advanced leak detection technology and leak flow rate data to prioritize pipelines for repair or replacement provides several benefits to the Company, ratepayers and the environment. Benefits include: (1) efficient use of ratepayer funding for infrastructure improvements; (2) availability of data that enhances system condition assessments, risk assessments, and decision making capability; and (3) transparency for utilities, regulators,

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[13] Picarro. 2016. "The Transition to Smart Gas Distribution." Santa Clara, CA. http://naturalgas.picarro.com/sites/default/files/2017-04/Picarro%20Analytics.pdf.

and ratepayers. Spatial attribution of data collected using advanced leak detection technology can provide additional advantages, by visualizing leaks in connection with specific geographic locations, and can also provide significant analytical capability to the Company, allowing the Commission to verify Company data. Each of these benefits is discussed in detail below.

Q. How can the use of advanced leak detection technology and leak quantification methodologies in leak prioritization ensure that ratepayer funding is deployed efficiently?

A. According to testimony submitted by Colorado State University professor Joe Von Fisher in New York Public Service Commission Case Nos. 16-G-0058 and 16-G-0059:

> We have found that leaks vary widely in magnitude such that the larger leaks are often 10-fold to 100-fold larger than the smaller leaks, so that a relatively small number of large leaks are responsible for the majority of methane emissions and natural gas leaked from distribution systems. Given the great costs associated with pipeline replacement, the most prudent economical approach would be to triage the leaks, focusing repair and replacement efforts first on safety needs and then on the largest leaks or leakiest pipeline stretches, as appropriate. Leak quantification can thus help utilities verify and validate the need for both leak repair and pipe replacement programs, facilitate the cost effective design and implementation of such programs by allowing for the prioritization of the largest emitters/leakiest segments of pipe, as the case may be, and allow public utility commissions to consider the need for, and progress of, the planned program.[14]

Integrating advanced leak detection technology into regular leak survey operations and using leak flow rate data to make decisions relating to gas utility infrastructure investments provides several benefits including cost savings, improved risk mitigation, current and accurate data to improve prioritization evaluations, improved scheduling of replacement programs, relevant metrics with which the Company and others can objectively assess replacement programs, and forward-looking modeling. Specifically,

[14] Testimony and Exhibits of Joseph von Fischer, New York State Public Service Commission, Case No. 16-G-0058 and 16-G-0059 at page 7, lines 4-14 (May 20, 2016).

prioritizing pipelines for replacement using leak flow rate data allows utilities to improve the efficiency and efficacy of pipeline replacement expenditures, for the benefit of ratepayers.

Q. Please describe the cost savings associated with prioritizing the leakiest replacement project areas sooner.

A. Prioritizing the leakiest project areas for replacement sooner in a pipeline replacement strategy allows for the capture of the greatest volume of gas that would otherwise be lost. In this way, the Company can achieve a better return on investment throughout the lifetime of the project. Cost savings are discussed in greater detail later in my testimony.

Q. Please explain how advanced leak detection technology and leak quantification methodologies can lead to improved risk mitigation.

A. Advanced leak detection technology and leak quantification methodologies can improve risk assessments by providing direct metrics of leak size, and other detailed information about leak expression and density—such as leak flow rate—in formats that are easy to compile and analyze. Advanced leak detection technology is essential for capturing leak flow rate data because it automatically provides spatially-attributed data about potential leak expressions and it is more sensitive than traditional leak detection technologies. Compared to other quantification methods, data can be captured in a more timely manner and can be easily analyzed with Geographic Information Systems (GIS) and/or in a comma separated value (.csv) format. Leak flow rate is a meaningful data point that can be used in risk assessments, to give a clear indication of the potential for leak expressions to migrate into an enclosed area. That is, by studying plume characteristics, advanced leak detection technology software can estimate the probability of a leak indication representing an immediate hazard.

Q. Is advanced leak detection technology typically able to find many more leaks than traditional technologies?

A. Yes. For example, CenterPoint Energy conducted pilots in Houston and Minneapolis using advanced leak detection technology and analytics. They reported that both pilots saw improvements in leak find rates five times greater than traditional methods.[15] Similarly, in three pilot studies using advanced leak detection technology and analytics, Pacific Gas & Electric found on average three times more gradable leaks when using advanced leak detection technology over traditional technologies.[16] In California, the Public Utilities Commission reported that utilities experienced a 21% increase in the number of leaks detected from 2013 to 2014, due partly to the use of advanced leak detection technologies being employed.[17] Finding the pipeline segments with the greatest number of leaks makes it possible to prioritize those segments sooner, thereby reducing the risk posed by those segments. Through reliable leak quantification and improved detection of leaks, advanced leak detection technology allows for a more complete assessment of pipeline risk, and provides data that can be used to assess risk mitigation from pipeline replacements over time.

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15 Centers, Tal, and Brad Coppedge. 2015. “Picarro Leak Surveyor.” Retrieved from: https://southerngas.org/component/content/article/102-corporateservices/committees/1027-pipeline-safety-council

16 Redding Sr., Stephen M., and Brenda Glaze. 2015. “Revolutionising Leak Management.” In World Gas Conference. 2015. Paris, France.

17 Mrowka, A., Charkowicz, E., & Magee, C. (2016). Analysis of the Utilities’ May 15th, 2015, Methane Leak and Emissions Reports Required by Senate Bill (SB) 1371 (Leno) and Rulemaking (R.) 15-01-008.

Q. Please explain how data from advanced leak detection technology can lead to more current and accurate data to improve prioritization evaluations.

A. Data from advanced leak detection technology, such as leak flow rate and leak density, also increases the accuracy of prioritization evaluations, which can lead to more effective and impactful replacement decisions. Use of advanced leak detection technology and analytics can help address and improve these observations. Picarro notes that "reliance on historical leak rates will lead to errors in prioritizing pipe segments for repair," because historical leak rate information does not depict the current state of the system.[18] Picarro notes that using advanced leak detection technology and analytics to evaluate the current state of leaks in the system to be assessed "would provide a much more accurate appraisal of the actual current risk of each pipe segment."[19] Furthermore, Picarro asserts that "traditional survey misses typically 60% of gas leaks in an area when compared to using a Picarro system."[20] Supplementing historical leak data with more robust and up to date leak data provided by advanced leak detection technology, leak quantification methodologies, and associated analytics can dilute the impact of errors made from reliance on historical data, and ensure that replacement activities prioritize the pipelines with the greatest need for replacement.

Q. Please comment on how data from advanced leak detection technology can lead to improved scheduling of replacement programs.

A. Leak flow rate data generated by advanced leak detection technology can improve the efficiency of replacement scheduling by allowing the company to schedule grids for

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[18] Schedule VEP-04 at page 12.

[19] *Id.*

[20] *Id.*

replacement based on real-time, accurate information regarding pipeline condition. VEDO's existing ranking approach could be structured in such a way to prioritize grids for replacement when they exhibit greater relative leak flow rates and leak counts. As leak counts and leak flow rates change with replacement levels each year, and new data is added, the grids can be easily reassessed with advanced leak detection technology and analytics. VEDO could incorporate that new data to reprioritize replacement scheduling based on efficiency and risk reduction goals, thereby ensuring that the schedule of main replacements is consistently optimized.

Q. Can the metrics associated with advanced leak detection technology and analytics provide useful information for regulators, the Company, and ratepayers?

A. Data collected using advanced leak detection technology and analytics can also provide useful input to assist the Company, ratepayers, and the Commission in evaluating the efficacy of the Company's pipeline replacement program. Having data on leak flow rates that is spatially attributed results in metrics that can be verified, as advanced leak detection technology can provide insightful DARR performance analysis. By supplying spatially attributed data that can be used to report on meaningful evaluation metrics, advanced leak detection technology and leak quantification can improve the information stakeholders and the Commission use to evaluate the Company's DARR. Specifically, information including leak flow rate data and leak frequency can be used to evaluate the pace at which risk is mitigated, and whether the scheduling of each grid for replacement has been prioritized in a way that optimizes risk mitigation, and allows for replacement program progress to be tracked and assessed frequently and easily.

Q. Please explain how the use of advanced leak detection technology and analytics can enhance forward looking modeling.

A. Using the best available data, gathered from advanced leak detection technology and leak quantification methodologies, can enhance forward-looking models of risk by including direct data on the current state of the system. These data, when considered as a part of the VEDO's grid prioritization strategy, allow for predictions about pipeline integrity in the future, and can be updated on a regular basis as new data is made available. Predictive capabilities can improve the efficiency of replacement plans, and help optimize the expenditure of ratepayer funds.

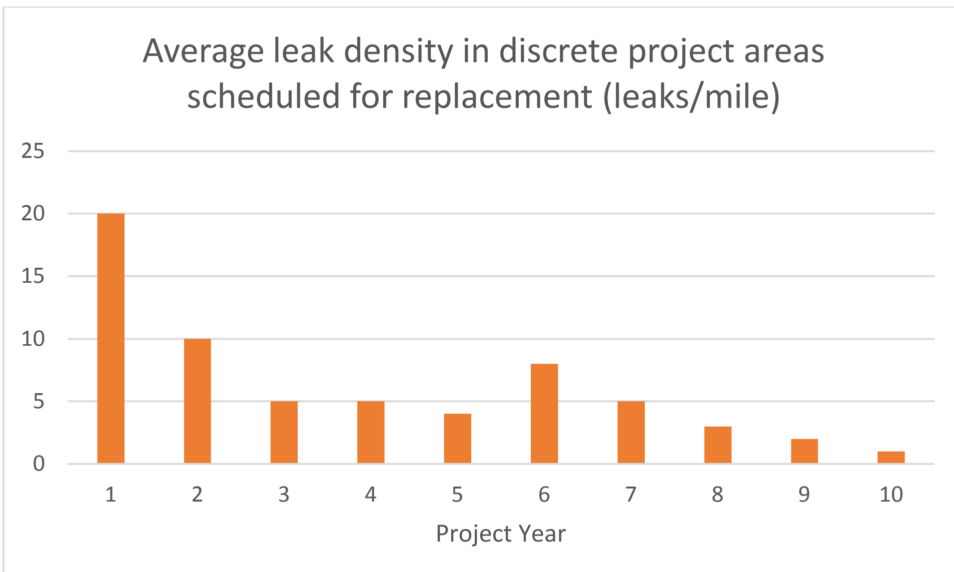
Q. How can advanced leak detection technology and leak quantification provide meaningful information for assessing the risk that will allow VEDO to make appropriate adjustments in prioritizing pipeline replacements?

A. Advanced leak detection technology and leak quantification can provide data that is relevant to predictive risk models, which would integrate well with VEDO's current risk modeling approach.[21] Through capturing the current state of the system in each project area with advanced leak detection technology and leak quantification, the Company can determine the number of leaks per mile in each project area and the leak flow rate per mile in each neighborhood. Using these two data points and VEDO's current risk models, the company can assess the known magnitude of leak densities (i.e. leaks per mile) over time, and can assess the known magnitude of leak flow rates per mile (i.e. liters per minute per mile) over time. When considered along with traditional metrics, leak flow rates per mile can be a valuable factor in risk assessment. While leak flow rates are not always correlated with hazard ranking, it is naturally evident that a larger leak has

[21] Vyvoda Testimony, VEDO EXHIBIT NO. 7.0, Attachment G, Page 11 of 15.

a greater ability to flow into an enclosed space and present a potential hazard. In this testimony, I propose that VEDO include another metric in their reporting, the percent of total leak flow rate reduced per year over the percent of pipeline miles replaced per year. The benefits of such a metric are evident in the following example. Consider a situation where the Company is replacing pipes in several project areas per year, and the leak density distribution for each planned project year is as follows:

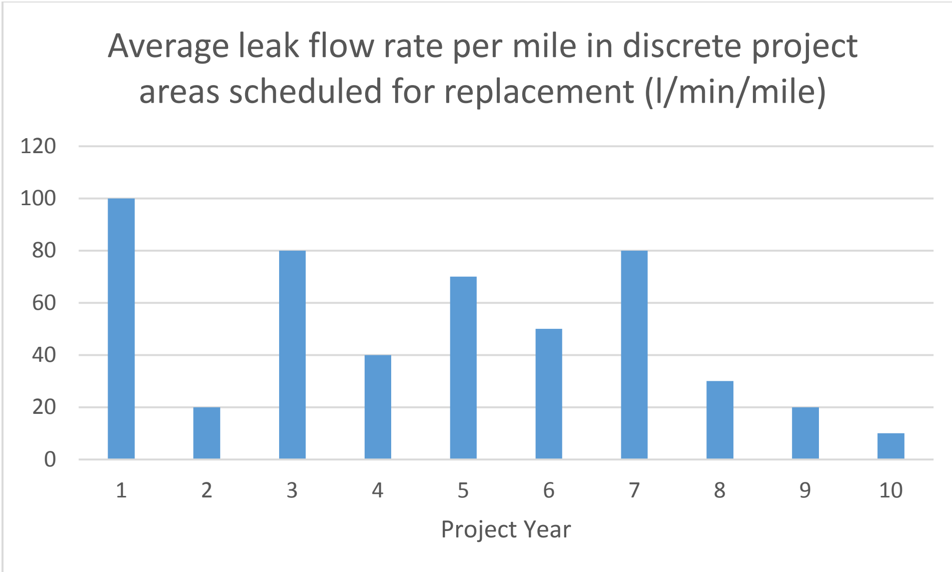
Figure 2:



Ideally, project areas with the highest leaks per mile would be scheduled first, but this may not necessarily be the case, because of other factors that may influence prioritization.

If the Company used leak flow rate per mile as a means of assessing the acceptable level of risk, the distribution could be projected as follows after advanced leak detection technology and leak quantification have been deployed:

Figure 3:



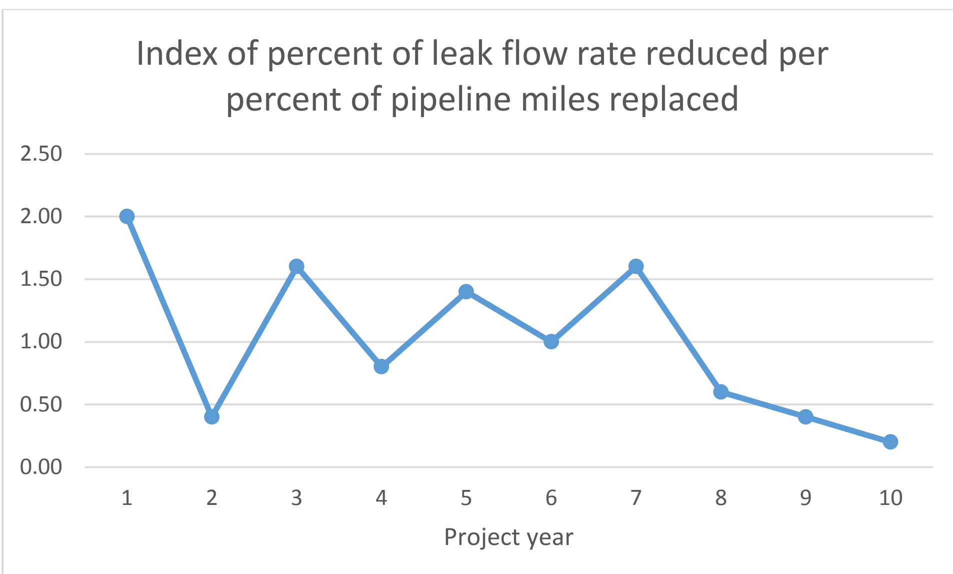
Empirical research has shown, as is hypothetically demonstrated in the examples above, that leak flow rates per mile are not necessarily correlated to leak densities. The lack of correlation between leak density and leak flow rates indicates that a utility could achieve reductions in large numbers of leaks without also achieving comparable reductions in overall leak flow rates.

This is evident by comparing project years in Figure 2 and Figure 3. In Figure 3, year one demonstrates the highest average leak flow rate per mile for the neighborhoods scheduled for replacement in year one. This is ideal, because it shows that greater volumes of potentially lost gas will be captured earlier on in the program. However, in year two, the average leak flow rate is much lower, even though the average leak densities are relatively high. This means that a replacement program that only considers leak density, as in Figure 2, will not optimize replacements based on overall volume of leakage, as in Figure 3.

Considering leak flow rate in pipeline replacement scheduling can help VEDO capture greater volumes of gas earlier in their replacement program, improving efficiency and benefiting ratepayers. Because leak flow rate is an indicator of the overall volume of gas lost from a system, a prioritization ranking that includes leak flow rate at a relatively high weight will result in a replacement program that addresses the leakiest pipes sooner.

In addition to simply having a forward-looking metric that will predict changes in risk level with replacement, the metric I am proposing, percent of total leak flow rate reduced per year over the percent of pipeline miles replaced per year, will directly relate costs expended to risk mitigation accomplished. In a scenario like those above, where project areas are not prioritized solely based on leak flow rate (and therefore some project years in the future have higher leak flow rates than earlier years), the index of leak flow rate reduced to pipeline miles replaced would appear as follows, if the pipeline miles replaced remained at 10% each year for ten years:

Figure 4:



Using this metric, the Company and the Commission can see that in years three, five, and seven, higher leak flow rate reductions could be achieved per expenditure than in the other years. Leaving high-emitting leaks flowing for longer periods of time results in increased risk and lost gas over time, which results in inefficiencies. With respect to leak flow rate reductions and lost gas, it makes more sense to prioritize greater reductions in leak flow rate for earlier years, to maximize the cost savings of the program.

Using the best available data, gathered from advanced leak detection technology and leak quantification methodologies, can enhance forward-looking models of risk by including direct data on the current state of the system. These data, when considered as a part of the VEDO's risk ranking models, allow for predictions about pipeline integrity in the future, and can be updated on a regular basis as new data is made available.

Q. What are the cost savings advanced leak detection technology and leak quantification potentially offer?

A. There are many possible sources of cost savings from the use of advanced leak detection technology and leak quantification. Using advanced leak detection technology for the prioritization of pipeline replacements can lead to both savings of lost gas, which has a value in itself, but also reduced numbers of leaks that would have to be investigated and repaired, incurring operation and maintenance costs. In addition to these two most obvious cases, advanced leak detection technology and associated analytics can be used to improve efficiency of leak surveys that are taken on for a variety of reasons, whether targeting leaks that are likely to be hazardous, or surveying for potential new leaks that could occur after a disaster. Using advanced leak detection technology and leak quantification to improve the efficiency of pipeline replacement programs and leak repair programs results in more gas captured, fewer leaks in a system, and cost savings for ratepayers. Potential cost savings could be found through:

- Capturing gas through identification and remediation of high volume leaks

- Reducing risk through replacement of pipe segments with high leak density
- Reducing risk through auditing a walking survey
- Responding to fewer odor calls
- More quickly locating hard-to-find leaks
- Conducting rapid post-emergency survey
- Finding leaks during post-construction quality control
- Real-time source attribution, if using methane/ethane sampling
- Verifying quality of a system prior to asset acquisition

Q. Have the benefits from incorporating these cutting edge technologies been measured?

A. Yes. A 2016 report by PricewaterhouseCoopers which discusses the benefits of using new data analytics for improved utility asset management, and opportunities to integrate data gathered using cutting edge technologies, such as mobile leak detection technology, into utilities' risk management efforts[22] includes a case study relating to a major gas distribution utility which sought to optimize its prioritization of capital replacement projects. The company used data gathered using mobile leak detection technology along with historical data to develop a predictive leak model. For a $15 million asset portfolio, this effort led to the following outcomes: an estimated 3.9 times more leaks avoided, 3.6 times greater leaks/mile replaced and 4.1 times more O&M expense cost savings for the same capital investment. This is a powerful example of the significant benefits to utilities

[22] PricewaterhouseCoopers, "A new view on pipeline risks: How spatial analytics can empower asset management for gas utility companies," April 2016, https://www.pwc.com/us/en/power-and-utilities/publications/assets/pwc_gas_pipeline_spatial_analytics_april_2016.pdf.

from using data that can now be gathered using cutting edge technologies to enhance their asset management efforts.

<u>V. Regulatory and Utility Context</u>

Q. Please explain relevant aspects of the prevailing regulatory and utility context as it relates to the use of advanced leak detection technology and data analytics by utilities.

A. ***<u>Regulatory context:</u>*** Under federal rules establishing integrity management requirements for gas distribution pipeline systems (the "Distribution Integrity Management Program for Natural Gas Distribution Sector" or "DIMP"), operators are required to develop and implement a distribution integrity management program.[23] While the rules do not explicitly require utilities to quantify leak flow rates, they state that (a) pipeline operators must consider all reasonably available information to identify threats to pipeline integrity and (b) the number and severity of leaks can be important information in evaluating the risk posed by a pipeline in a given location. Operators are required to consider the following categories of threats to each gas distribution pipeline: corrosion, natural forces, excavation damage, other outside force damage, material or welds, equipment failure, incorrect operations, and other concerns that could threaten the integrity of its pipeline. Sources of data may include, but importantly, are <u>not</u> limited to, incident and leak history, corrosion control records, continuing surveillance records, patrolling records, maintenance history, and excavation damage experience.

With technology evolving to make leak quantification methods commercially available, and PHMSA rules requiring operators to consider all relevant data points in identifying

[23] Redd Testimony at page 4, lines 2-7.

threats to pipeline integrity, it is clear that the prevailing regulatory framework not only allows for newly available data such as spatially referenced leak flow rate data to be considered in evaluating threats to pipeline integrity, but in fact, underscores the need to do so.

Utility context: Since the 2011 PHMSA/DOT Call to Action to accelerate the repair, rehabilitation, and replacement of the highest-risk pipeline infrastructure, sophisticated technologies allowing for the collection of previously unavailable data on utility asset conditions have emerged. Utilities are beginning to employ such data to supplement existing information on asset risks, and thereby design and target system modernization and maintenance efforts more effectively. Gas utilities are now moving beyond regulatory compliance towards proactive asset risk and integrity management in response to a number of factors, including regulatory advancements, and an increased focus on pipeline safety.[24] Advanced leak detection and quantification methods have significant ratepayer, environmental and system-wide benefits, as I detail below. A number of major utilities including Public Service Gas and Electric ("PSE&G"), New Jersey's oldest and largest utility, National Grid in New York, and Peoples' Gas Light and Coke Company ("PGL") in Chicago have recognized the benefits of these methods and created pathways for the adoption of such advanced technologies.

Q. Please elaborate on these utilities' efforts to integrate advanced leak detection, data analytics and quantification into their operations.

[24] PricewaterhouseCoopers, "A new view on pipeline risks: How spatial analytics can empower asset management for gas utility companies," April 2016, https://www.pwc.com/us/en/power-and-utilities/publications/assets/pwc_gas_pipeline_spatial_analytics_april_2016.pdf.

A. In November 2015, the New Jersey Board of Public Utilities ("BPU") approved a settlement agreement among New Jersey's largest utility, Public Service Electric & Gas ("PSE&G"), and other stakeholders on the Company's accelerated pipe replacement program.[25] As part of this settlement, PSE&G received BPU approval to implement a $905 million pipe replacement program over a three-year time period. Under the terms of this settlement, after taking into account safety considerations, PSE&G was required to consider data on the volume of methane emissions leaked from its pipes, in conjunction with other relevant factors, to identify those that are most in need of replacement.[26] By using leak flow rates for prioritization, PSE&G achieved an 83% reduction of methane emissions early on by replacing one-third fewer miles of gas lines than that needed to achieve the same result under a business as usual scenario.[27] This difference is noteworthy considering that the typical cost to replace one mile of gas line on PSE&G's system is $1.5 to $2.0 million.

PSE&G built upon these efforts in the second phase of its gas system modernization program. As part of a settlement agreed to in BPU Docket No. GR17070776, PSE&G

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[25] Decision and Order of the New Jersey Board of Public Utilities In The Matter Of Public Service Electric And Gas Company for Approval of a Gas System Modernization Program and Associated Cost Recovery Mechanism, Docket No. GR15030272, November 16, 2015, retrieved from http://www.nj.gov/bpu/pdf/boardorders/2015/20151120/11-16-15-2F.pdf.

[26] Johnson, "Utilities must reduce methane leaks from natural gas pipelines, says new bill," February 5, 2016, retrieved from http://www.njspotlight.com/stories/16/02/04/utilities-must-clamp-down-on-methane-leaks-from-natural-gas-pipelines-says-new-bill/. The methodology used by PSE&G to integrate leak flow rate data into its pipe replacement prioritization scheme is described in a white paper titled "Integrating Leak Quantification into Natural Gas Utility Operations" available at https://www.fortnightly.com/sites/default/files/whitepapers/2017_Palacios%20et%20al_Integrating%20Leak%20Quantification%20into%20Natural%20Gas%20Utility%20Operations.pdf.

[27] Further information about this analysis can be accessed at https://www.edf.org/climate/methanemaps/pseg-collaboration.

has committed to contract with a third party vendor to conduct a leak survey in 2018 on 280 miles of leak prone pipeline grids.[28] Leak survey data will be used to generate an "Estimated Flow Rate per Mile (Liter/min/mile)."[29] PSE&G will then develop a ranking threshold which will be used to prioritize grids for replacement in subsequent program years.[30]

Recognizing the value of leak quantification methods in terms of enhancing operational safety, reducing methane emissions, and advancing ratepayer interests, KeySpan Gas East Corporation d/b/a National Grid ("KEDLI") and the Brooklyn Union Gas Company d/b/a National Grid ("KEDNY"), both subsidiaries of National Grid, are working on a suite of pilot projects in National Grid's service territory in Long Island, New York, leveraging these new technological capabilities, as envisioned in settlement agreements approved by the Commission in the 2016 KEDNY and KEDLI Rate Cases. The Joint Proposal states that "KEDNY will utilize internal personnel or a qualified contractor to develop the means to quantify emission flow rate data on an ongoing basis."[31] The settlement agreement provides that leak flow rate data gathered as part of these projects will be used by National Grid to enhance leak repair and pipe replacement efforts in its Long Island service territory, and that the companies shall develop the means to quantify leak flow rate from their systems in order to better prioritize their leak repair and LPP

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[28] In the Matter of the Petition of Public Service Electric and Gas Company for Approval of the Next Phase of the Gas System Modernization Program and Associated Cost Recovery Mechanism, BPU Docket No. GR17070776, Stipulation of Settlement and Agreement at P 24 (April 18, 2018). The BPU approved this settlement in a June 1, 2018 order.

[29] *Id*.

[30] *Id.*

[31] Proceeding on Motion of the Commission as to the Rates, Charges, Rules and Regulations of KeySpan Gas East Corporation d/b/a National Grid for Gas Service, NYPSC Case No. 16-G-0058 *et al.*, page 51, section 8.2.2 (Sep. 7, 2016).

replacement projects on an ongoing basis. Niagara Mohawk, National Grid's upstate New York utility, built upon these efforts in a January 19, 2018 Joint Proposal. That settlement obligates Niagara Mohawk to continue to "develop a methodology for assessing leak size and volume using leak quantification methods" and consider "best practices for identifying and abating high volume leaks."[32]

Most recently, the Peoples' Gas Light and Coke Company ("PGL") in Chicago, Illinois agreed to conduct a pilot program in which "leak flow rate data, collected by a contracted service provider or PGL using advanced leak detection and quantification technology, will be considered in prioritizing leak-prone pipe ("LPP") replacement under the [System Modernization Program]."[33] The Illinois Commerce Commission approved the pilot, and directed PGL to report the following metrics on an annual basis:

- A metric that reports a list of the neighborhoods that are re-prioritized based on the result of leak flow rate data; and
- A metric that measures annual methane leak flow rate reduction based on the mileage of retired pipe and the leak flow rates estimated for those miles using advanced leak detection technology and leak quantification methods.[34]

VI. Recommendations and Conclusion

Q. Please outline potential opportunities to integrate leak quantification methods into the Company's operations in the context of its proposal in this case.

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32 Proceeding on Motion of the Commission as to the Rates, Charges, Rules and Regulations of Niagara Mohawk Power Corporation d/b/a National Grid for Gas Service, NYPSC Case No. 17-G-0239 *et al.*, Joint Proposal at page 42, Section 7.6 (January 19, 2018).

33 Illinois Commerce Commission On its Own Motion v. The Peoples Gas Light and Coke Company, ICC No. Docket 16-0376 at page 77 (January 10, 2018 Final Order).

34 *Id.* at page 81.

A. In her testimony, Ms. Vyvoda describes VEDO's six initiatives within VEDO's Distribution Accelerated Risk Reduction (DARR) program:

- Expanded Leak Management Program
- Enhanced Damage Prevention Program
- Public Awareness
- Workforce Training and Qualification for New Requirements
- Pipeline Safety Management System Implementation
- Enhanced Risk Modeling and Threat Analysis

Data derived from advanced leak detection technology and leak quantification analytics could be incorporated into the Expanded Leak Management Program, Pipeline Safety Management System Implementation and Enhanced Risk Modeling and Threat Analysis initiatives.

Q. Please explain how advanced leak detection technology and leak quantification analytics could be incorporated into the Expanded Leak Management Program.

A. This program is primarily aimed at addressing VEDO's grade 3 leak backlog. Data derived from advanced leak detection technology and leak quantification analytics can be used in two ways to optimize the Expanded Leak Management Program. First, VEDO can prioritize the grade 3 leak backlog by the leaks that represent the highest leak flow rate, achieving higher cost savings early in the program. Second, VEDO can use the data to identify zones, grids, or segments of pipeline that have a high density of leaks (e.g. leaks per mile) and prioritize those areas for replacement rather than individual leak repair.

Q. Please explain how advanced leak detection technology and leak quantification analytics could be incorporated into the Pipeline Management System (SMS) Program.

A. The SMS is a framework used to reveal and manage risks and threats to VEDO's gas assets. The initiative is designed based on best practices following PHMSA guidelines. Ms. Vyvoda notes "The implementation plan consists of five years of milestones associated with implementing a safety controls framework with a risk register process for collecting and prioritizing risks, a risk assessment process to continually identify and prioritize risks, and a process to document the mitigation plans and monitor their progress and effectiveness."[35] Data derived from advanced leak detection technology and leak quantification analytics can be integrated into the SMS in two ways. First, service providers of advanced leak detection technology are using algorithms that help to estimate the probability of each leak indication being hazardous, which can aid distribution system managers in prioritizing leak indications for investigation. Second, data on leak flow rate (e.g. leakage in liters per minute) can be used in mitigation plans to prioritize repair or replacement of the leakiest pipelines first, improving cost-effectiveness of the mitigation strategy.

Q. Please explain how advanced leak detection technology and leak quantification analytics could be incorporated into the Enhanced Risk Modeling and Threat Analysis.

[35] Vyvoda Testimony at page 15, lines 2-6.

A. VEDO's Enhanced Risk Modeling and Threat Analysis initiative uses GIS and document management systems to allow field personnel to access system data in the field.[36] The data is also used in risk models associated with distribution system asset types.[37] Data derived from advanced leak detection technology and leak quantification analytics would easily integrate into VEDO's GIS database and could be used both to assist field personnel in locating leaks, but also in risk modeling, and leak remediation and pipeline replacement prioritization efforts. Advanced leak detection and data analytics methods can help to reduce operational inefficiencies early on in the program and reduce system risks by targeting the leakiest pipelines first, and helping to prioritize pipelines that are likely to be more hazardous.

Q. Will integrating advanced leak detection and data analytics methods into the Company's operations help the Company optimize its efforts to reduce its grade 3 leak backlog?

A. Yes. Ms. Vyvoda states that "VEDO resources were consumed remediating grade 1 and grade 2 leaks as required by federal pipeline safety regulations resulting in a backlog of grade 3 leaks – non-hazardous leaks that are allowed to remain open in the system under PHMSA regulations."[38] The Company's backlog of grade 3 leaks grew to 4,000, with more being discovered each year. As acknowledged by witness Vyvoda, "open leaks within the system create risk and duplicate leak or odor calls, reduce sensitivity of the public to detect gas odors and report leaks, and contribute to the methane emissions of the

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[36] *Id.* at page 15, lines 15-18.

[37] *Id.* at page 15, lines 21-22.

[38] *Id.* at page 18, lines 5-8.

Company."[39] Since implementing its Expanded Leak Management Program in 2016, VEDO has reduced the backlog of leaks by almost 1,000 from 2016 to 2017.[40] Rather than focusing limited efforts on reevaluations of grade 3 leaks and responses to duplicate leak and odor calls, VEDO can achieve operational efficiencies and a more comprehensive assessment of leak prone pipes using advanced leak detection technology and leak quantification. These data can be used to improve program cost effectiveness through allowing high volume leaks to be remediated first and to remove zones, grids, or segments of pipeline that exhibit higher leak densities (i.e. leaks per mile) thereby reducing the number of re-evaluations needed.

Q. Do you have any additional recommendations for the Commission's consideration?

A. Yes, based on the precedent established by the Illinois Commerce Commission in Docket No. 16-0376,[41] I recommend that VEDO be required to submit annual reports detailing its progress in implementing advanced leak detection technology and leak quantification. Specifically, VEDO should be required to report a metric that measures annual methane leak flow rate reduction based on the mileage of retired pipe and the leak flow rates estimated for those miles using advanced leak detection technology and leak quantification methods.

Q. Please summarize your recommendations and conclusions.

A. Based on my review of testimony submitted on behalf of the Company, VEDO should adopt advanced leak detection technology and leak quantification methodologies and

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[39] *Id.* at page 18, lines 9-12.

[40] *Id.* at page 18, lines 16-18. Attachment H, page 2 provides a status update on the progress towards eliminating the grade 3 leak backlog.

[41] Illinois Commerce Commission On its Own Motion v. The Peoples Gas Light and Coke Company, ICC No. Docket 16-0376 at page 77 (January 10, 2018 Final Order).

associated analytics. The resulting data from the use of these technology and methodologies should be incorporated into VEDO's Expanded Leak Management Program, Pipeline Safety Management System Implementation, and Enhanced Risk Modeling and Threat Analysis. Furthermore, VEDO should be required to report a metric that measures annual methane leak flow rate reduction based on the mileage of retired pipe and the leak flow rates estimated for those miles using advanced leak detection technology and leak quantification methods.

Q. Does this conclude your testimony?

A. Yes.

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EDUCATION

MASTER OF ENVIRONMENTAL MANAGEMENT

Duke University – Durham, NC - May 2012

Concentration: Global Environmental Change

Relevant coursework: Energy and Ecology, Natural Resources Economics, Climate Change Economics, Human Health and Ecological Risk Assessment

BACHELOR OF SCIENCE IN AERONAUTICAL SCIENCE

Embry-Riddle Aeronautical University – Daytona Beach, FL - May 2007

Commercial pilot, airplane single- and multi-engine land, instrument-rated

Relevant coursework: Physics I and II, Calculus I, Meteorology I and II

WORK EXPERIENCE

INDEPENDENT CONSULTANT

Self-employed – Oct. 2017 to present

Advise on strategic considerations for projects aimed at reducing methane leakage and risks from natural gas distribution systems.

Write testimony for regulatory proceedings explaining how to use methane leakage data to achieve cost-savings and greenhouse gas emission reductions.

STATE AND LOCAL POLICY MANAGER

South-central Partnership for Energy Efficiency as a Resource (SPEER)
Austin, TX – Oct. 2017 to Oct. 2018

Managed collaborative group of investor-owned utilities and stakeholders to discuss expanding utility energy efficiency programs in Texas.

Shared expertise on energy efficiency in buildings as a member of the Energy and Buildings Working Group for the City of San Antonio's Climate Action Plan.

SENIOR RESEARCH ANALYST

Environmental Defense Fund (EDF) - Austin, TX - Apr. 2016 to Oct. 2017

Provided technical expertise on scientific and regulatory concepts related to local distribution pipeline safety and methane emission quantification.

Compared state and federal regulations on local distribution pipeline safety.

Solved complex analytical problems using geospatial analysis

RESEARCH ANALYST

Environmental Defense Fund (EDF) - Austin, TX – Apr. 2014 to Apr. 2016

Investigated local, state, and federal rules related to distribution pipeline safety.

Analyzed data related to environmental impacts of oil and gas development.

RESEARCH ASSOCIATE

Environmental Defense Fund (EDF) - Austin, TX – Jul. 2012 to Apr. 2014

Wrote reports on distribution system leak detection technology and regulations.

Researched distribution system integrity management and leakage.

Analyzed data on distribution system material mileage and leak frequencies.

RESEARCH AND CAMPAIGN ASSOCIATE

Rio Grande International Study Center - Laredo, TX - May 2011 to Aug. 2011

Organized expert panels for town halls including representatives of state agencies, industry leaders, advocacy groups, and scientists to educate the community about potential environmental impacts of oil and gas development.

Drafted letters and other documents to establish public positions of coalition.

PUBLICATIONS

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Lyon, D., Zavala-Araiza, D., Alvarez, R., Harriss, R., Palacios, V., Lan, X., … Hamburg, S. (2015). Constructing a Spatially Resolved Methane Emission Inventory for the Barnett Shale Region. *Environmental Science and Technology.*

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Palacios, V. (2018). Moderator: Capturing Air and Climate Benefits of Energy Efficiency. *SPEER Summit.* Austin, Texas.

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Palacios, V. (2014). Environmental Perspective on Methane Emissions and EDF Research Program Overview. In *Government/Industry Pipeline R&D Forum - Leak Detection/Fugitive Methane Working Group*. Rosemont, IL: U.S. Department of Transportation, Pipeline and Hazardous Materials Safety Administration. https://primis.phmsa.dot.gov/rd/mtg_080614.htm

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Palacios, V., and Simi Rose George. (2016). Managing Methane: New Jersey's Largest Utility Using Better Data for Better Decisions. *EDF Energy Exchange.*

Palacios, V., and Holly Pearen. (2016). New Technologies Deliver Data That Can Make Gas Pipelines Safer. *EDF Energy Exchange.*

Integrating Leak Quantification into Natural Gas Utility Operations

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Simi R. George, Manager of Natural Gas Distribution Regulation, Environmental Defense Fund
Joseph C. von Fischer, Associate Professor at Colorado State University
Kristina Mohlin, Senior Economist, Environmental Defense Fund

May 2017

Abstract

Natural gas utilities can incorporate leak flow rate data into existing pipeline replacement and leak repair prioritization frameworks to more rapidly and efficiently reduce leakage on their system. Leak distributions typically demonstrate a "fat-tail," where a few, large leaks are responsible for the majority of lost gas volumes. Through ranking and ordering leak flow rate data, utilities can identify a subset of the largest leaks to repair or the leakiest pipelines to replace, and capture more gas per dollar spent on leak repair or pipeline replacement. This benefits ratepayers, who pay for the cost of lost gas, and also carries broader environmental and societal benefits.

1. Introduction

Studies of natural gas distribution pipeline leaks indicate that a relatively small subset of leaks is responsible for a disproportionate share of total observed emissions (Brandt et al., 2016; Lamb et al., 2015; Hendrick et al., 2016; von Fischer et al., 2017). Even though natural gas distribution utilities must expeditiously repair hazardous leaks, many large leaks can persist for months or years prior to repair because the standard used to grade a leak's risk generally places greater weight on the proximity to structures than to leak size. Recently, mobile monitoring has been used to detect the presence of underground pipeline leaks and estimate their size (von Fischer et al., 2017). If utilities used such leak quantification systems to prioritize abatement of the largest non-hazardous leaks, after taking safety into account, the climate benefits of leak repair and pipe replacement programs could be enhanced. By eliminating more natural gas losses per dollar spent on leak repair and pipeline replacement, leak quantification also helps constrain ratepayer costs.

Information on the size of leaks can also help utilities to verify and validate the need for leak repair and pipe replacement programs and allow regulatory agencies responsible for authorizing utility leak abatement projects to better assess the need for such efforts. In addition, leak quantification can improve project management by allowing utilities and public utility commissions to evaluate the progress of leak repair and pipeline replacement programs by considering the reduction in volumes of leaked gas achieved through implementation of such programs. This paper describes the implications of integrating leak quantification into utilities' regular leak operations and explores potential frameworks for implementation based on currently employed utility practices.

2. Leak Repair and Pipeline Replacement Programs: Current Regulatory Framework and Utility Practice

Natural gas leaks and leak-prone infrastructure impose costs and pose safety risks to society. Natural gas leaks are also harmful to the climate and environment because they consist primarily of methane, a potent short-lived climate pollutant and an ozone smog precursor. Traditionally, local gas distribution utilities focus their repair programs on finding, assessing, and repairing leaks in their infrastructure to prevent explosions. The occurrence of pipeline leaks is influenced by the following factors (U.S. Department of Transportation, 2011; American Gas Foundation and Yardley Associates, 2012):

- Exposure to extreme weather (e.g. temperature, moisture),
- Corrodible or brittle pipeline materials (cast iron, bare steel, copper, and certain vintage plastic pipes),
- Age,
- High occurrence of joints,
- Material or weld failures,
- Location of pipeline in the vicinity of excavation, or
- Areas where soil is unstable (e.g. earthquake-prone areas, karst-prone systems or in shrink/swell soils).

The Pipeline and Hazardous Materials Safety Administration (PHMSA) rules require operators to annually report data on the number of leaks repaired and the number of known leaks remaining on their system at the end of each year, but do not require operators to quantify leak volume (49 C.F.R. §191.11 and Form PHMSA F 7100.1-1).

PHMSA also offers non-binding guidance to operators on how to grade leaks based on safety risk, thereby establishing leak repair priority, and assisting operators in complying with federal safety rules that require them to "evaluate and rank risk" posed by their distribution pipeline systems (49 C.F.R. § 192.1007). Some states have incorporated or adapted PHMSA's leak grading guidance into their rules and statutes (NAPSR, 2013). The grading categories are based solely on an evaluation of the risk to persons or property and primarily considers proximity to building envelopes (PHMSA, 2000). Moreover, some researchers have observed the size, or leak flow rate, of grade one (i.e. "immediately" hazardous) leaks to be no different from other grades of leaks (Hendrick et al., 2016). Under the existing regulatory framework, utilities are generally not required to repair non-hazardous leaks (i.e. leaks that are not immediately hazardous) within a specific timeframe. As a result, non-hazardous leaks may continue unabated for long periods, in some cases decades,[1] thereby wasting a valuable resource and hurting the economic interests of ratepayers, who bear the costs of leaked gas.

[1] Two jurisdictions in the U.S., California and Massachusetts, require gas distribution utilities to report leak inventories with relevant characteristics. Leak data made available through the California Public Utilities Commission R. 15-01-008 – Natural Gas Leakage Abatement Rulemaking indicates that as of May 22, 2015, there were some leaks discovered in the 1990s that still had not been scheduled for repair.

PHMSA guidance on leak grading suggests comparing the concentration of gas in air around the leak to the lower explosive limit (LEL) of natural gas.[2] However, methane concentrations in air (e.g. parts per million) in and around a leak are not necessarily proportional to the rate at which gas is being lost (i.e. flow rate, typically measured in standard cubic feet per hour). Current utility practices, therefore, are insufficient for: (1) prioritizing leak repair using flow rate, or (2) verifying the effectiveness of leak repair and pipeline replacement initiatives at reducing system-wide losses of methane from natural gas.

It is important to distinguish between leak repairs, which occur on a regular basis and are paid for through operation and maintenance budgets, and pipeline replacements. On average leak repairs cost from $2,000 to $7,000 per leak (Aubuchon and Hibbard, 2013; Pacific Gas and Electric Company, 2015a). Considering that utilities are required to repair hazardous leaks immediately while non-hazardous leaks can persist for longer periods of time, leak quantification can be used to prioritize non-hazardous leaks for repair, thus improving cost-effectiveness by capturing the highest volumes of gas per dollar spent on leak repair without negatively impacting safety.

Similarly, leak quantification can be used to prioritize pipelines for replacement. Pipeline replacement can cost between $900,000 and $3 million per mile of pipe depending on a variety of factors (Aubuchon and Hibbard, 2013; Anderson et al., 2014). Utilities across the country are looking to replace many, if not most, of the 70,000 miles of leak-prone distribution pipes still in operation in the U.S. over the next two decades at an estimated cost of $270 billion (U.S. Department of Energy, 2015).[3]

The size of these investments underscores the need to thoughtfully design and execute these programs. In order to prioritize leak repair and pipe replacement programs, many utilities use hazard assessment algorithms to estimate the relative safety risk posed by leaks on their system, considering factors such as pipe material, environmental conditions, leak history, etc. After hazard assessment data is considered, leak flow rate data provides additional information that can be considered in prioritizing leak repair and pipeline replacement activities, and by so doing optimize the benefits of both operating and capital expenses.[4] Typical utility practices do not include leak flow rate assessments and therefore do not allow for this kind of improved prioritization.

[2] The PHMSA guidance document, “Gas Leakage Control Guidelines for Petroleum Gas Systems,” gives several examples of a Grade 1 leak:

- *Any leak which, in the judgment of operating personnel at the scene, is regarded as an immediate hazard*
- *Escaping gas that has ignited*
- *Any reading of 80% LEL or greater in a confined space*
- *Any reading of 80% LEL or greater in small substructures (other than gas associated substructures) from which gas would likely migrate to the outside wall of a building*

[3] The estimated 70,000 miles of leak-prone pipe includes cast iron, unprotected bare steel, copper, ductile iron, and “other,” as listed in PHMSA 2015 Annual Distribution Data. Cost estimates provided from the U.S. Department of Energy (2015) may be based on older mileage values, and it is unclear which materials are included in the U.S. Department of Energy’s estimate.

[4] The availability of additional data points indicating the character of pipeline infrastructure is naturally useful for the purposes of integrity management as well. Utilities may find that it is beneficial to integrate leak flow rate values into hazard assessments.

3. Benefits of Using Leak Quantification

In 2011, PHMSA issued a "Call to Action" to state pipeline regulatory agencies, pipeline operators, and technical and subject matter experts after a series of natural gas distribution pipeline explosions. Recognizing the safety risks associated with cast iron gas mains, PHMSA urged state agencies to facilitate accelerated pipeline replacement programs for cast iron and other high-risk pipeline segments (U.S. Department of Transportation, 2011). Accelerated pipeline replacement programs are necessary from a safety standpoint, but also carry significant ratepayer and environmental implications.

With advanced leak detection technology and leak quantification, a utility can quickly and comprehensively assess the leakiness of its infrastructure with geospatial awareness. Using leak flow volume to further prioritize leak repair and pipeline replacement programs, once safety considerations have been taken into account, offers benefits to both ratepayers and society as a whole. First, the larger reductions in lost gas that leak prioritization can achieve translates into savings for ratepayers who generally pay both for gas delivered as well as gas lost on the pipeline system, which is considered an accepted cost of service (Webb, 2015). Second, there are societal benefits from reducing the amount of gas leaked because natural gas is composed primarily of methane,[5] a powerful short-lived climate forcer 84 times more potent than carbon dioxide over a 20-year time horizon (IPCC, 2013).

Researchers have estimated the social costs of greenhouse gas emissions by considering their effect on the climate and subsequent impacts such as changes in agricultural productivity, heat-related illness, and property damages from increased flood risk. The social cost of methane is a monetized value of the damages occurring as the result of an additional unit of methane emissions. Specifically, it represents society's aggregate willingness to pay to avoid the future impacts of one additional unit of methane emitted into the atmosphere in a particular year (Martens et al., 2014). Estimates of the social cost of methane can be used in a cost-benefit analysis of proposed regulations or projects with an impact on methane emissions. That is, the social cost of methane can be used to assess the benefits to society of a leak repair or a pipeline replacement program. The estimate for the social cost of methane used by federal agencies to value the climate impacts of new rulemakings is $1000/ton of methane (Interagency Working Group on Social Cost of Greenhouse Gases, 2016).[6] This estimate translates into social damages of $17 per thousand cubic feet (Mcf) of natural gas leaked and hence each reduced Mcf of gas leaked to the atmosphere spares society as much in climate change-related damages.[7]

4. Using Leak Quantification to Prioritize Pipe Replacement and Leak Repair

Studies show that distributions of leaks often exhibit a "fat-tail," where a small number of large leaks, often referred to as superemitters, account for the majority of measured gas losses in a sample (Brandt et al., 2016; Lamb et al., 2015; von Fischer et al., 2017). Leak quantification can help utilities facilitate cost-effective design and implementation of leak repair and pipe replacement programs by allowing for

[5] On average, pipeline-quality natural gas is composed of over 90% methane by volume (Demirbas, 2010).
[6] This specific estimate refers to the damages associated with a ton of methane emitted in 2015 monetized in 2007 dollars. The current value therefore would be higher when adjusted for inflation. The value is also higher for emissions in later years because future emissions are expected to produce larger incremental damages (see Interagency Working Group on Social Cost of Greenhouse Gases, 2016).
[7] Assuming a mass of 19,200 g/Mcf natural gas, and a methane share of 78.8% per mass unit of natural gas. This estimate is in $2007 for one Mcf of natural gas leaked in 2015.

prioritization of the highest-emitting leaks or pipe segments, as the case may be. The methodology also allows public utility commissions to consider the need for, and progress of, the planned program.

4.1 Information that improves efficiency

Utilities are starting to adopt the use of advanced leak detection equipment capable of finding more leaks more rapidly. For example, the California Public Utilities Commission reports that utilities experienced a 21% increase in the number of leaks detected from 2013 to 2014, due partly to the use of advanced leak detection technologies (Mrowka et al., 2016). Additionally, the use of advanced leak detection technology has been shown to reduce the time needed to complete a leak survey, have a longer-distance field of view for detecting leaks, and can be used overnight when atmospheric conditions are more stable (Clark et al., 2012).

Applied efficiently, advanced leak detection technology can be used to obtain (on a continuous basis) leak information sufficient for determining the most hazardous and/or largest emitting leaks that in turn can be prioritized for remediation. Rather than continuing the paradigm that leaks are found and remediated one at a time, industry and regulators can foster innovative strategies that involve obtaining leak survey information as the first step, and application of advanced analytics as a second step, in order to prioritize remediation of the most hazardous and largest leaks.

4.2 Leak repair and pipe replacement prioritization methodology

One key consideration in employing leak quantification methodologies to leak repair programs is how to systematically translate a database of measured leak flow rates into a prioritized list. This consideration is equally applicable to pipe replacement programs, where the corresponding challenge is to prioritize pipeline segments for replacement. In providing the data necessary, the primary emphasis should not be on the accuracy of individual leak measurements, but rather on the precision of the characterization of the leaks, the ability to provide a prioritized list and a cost-effective path to reducing leak volumes.

A cumulative distribution, ordering leaks by size, is a useful tool to determine the relative priority of leaks for repair, which is made possible with the use of sufficiently precise leak quantification methodologies. A cumulative distribution can both help identify the largest leaks, and determine their relative contribution to overall leakage.

As shown in Figure 1 (A), the flow rate of leaks can vary significantly. When ranked from largest to smallest as shown in Figure 1 (B), the relative importance of different leaks is transparent and the relative contribution of each leak to overall leak flow rate is easily quantified (Figure 1 [C]). The cumulative distribution is created by integrating the ranked distribution in Figure 1 (B) from left to right. The first data point from the left on the X-axis in the CD plot is the leak determined to have the largest leak volume, the second point is the cumulative leak flow rate of the top two leaks, the third point is the sum of leak flow rates of the top three leaks, and so on. Thus, the last data point is the sum of leak flow rates of all known leaks. This distribution is then normalized to 1 (or 100% in Figure 1 [C]) so that we can readily consider the relative contribution of a certain number of leaks to the total system-wide leakage.

While this discussion focuses on the particular context of leak repair, a similar analytical approach can be applied to prioritize pipeline segments for replacement (see Appendix).

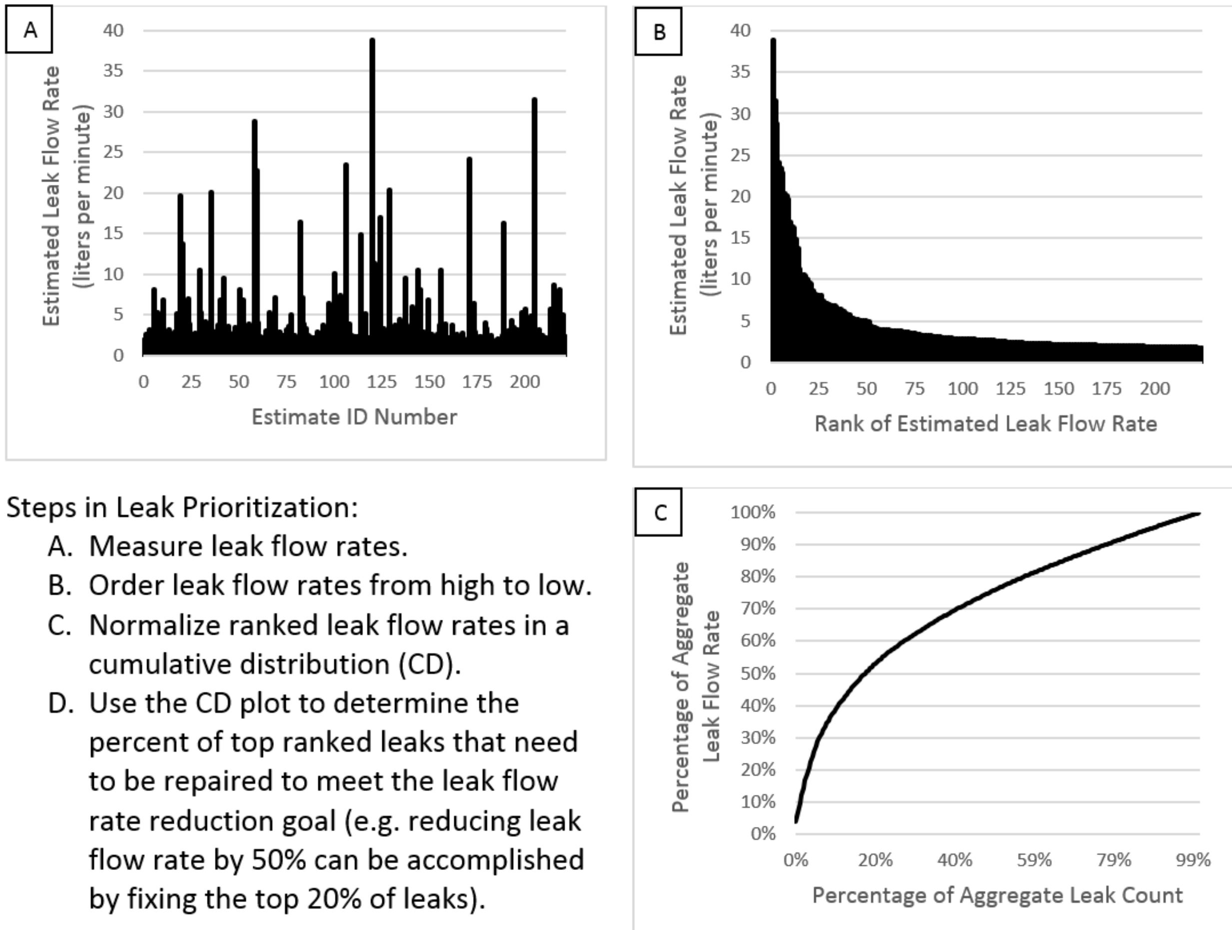

Figure 1 An example step-by-step model depicts how to construct a cumulative distribution curve for the purpose of leak prioritization, using data collected by EDF in Syracuse, NY.

In the near term, leak quantification can help utilities reduce the volumes of gas lost through leakage, and thereby save ratepayers money and reduce methane emissions, by enabling the prioritization of both leak repair and leak-prone pipeline replacement projects based on leak flow rate. In the longer term, as leak quantification methodologies become more sophisticated, utilities will be able to easily quantify leak rates for their entire system, measuring progress in reducing emissions.

In the context of leak repair programs, leak volume may be considered to prioritize the repair of non-hazardous leaks, with the utility addressing larger leaks first. Similarly, in the context of leak-prone pipe replacement, a utility may prioritize the leakiest pipeline segments on its system for replacement first. In either case, as discussed below, utilities are starting to recognize the benefits of a “bundling” or “grid-based” approach whereby leaks or pipeline segments in a given geographic area are bundled together for repair or replacement, as the case may be, in order to allow for efficient use of time and resources (Clark et al., 2012).

5. Case Studies: Applying Leak Quantification Data to Utility Operations

Using leak data collected by Environmental Defense Fund (EDF), Public Service Gas & Electric (PSE&G), New Jersey’s largest utility, is applying a spatially-attributed grid-based method to prioritize pipe segments for replacement. This effort is part of a large-scale $905 million pipe replacement program that was recently approved by the New Jersey Board of Public Utilities (Public Service Electric and Gas, 2012). The methodology developed by EDF in collaboration with PSE&G is discussed below.

First, PSE&G's distribution system was plotted using geographic information systems (GIS) divided into roughly equally sized polygons of one square mile. Using its Hazard Risk Index Model, PSE&G ranked grids for pipeline replacement based on the hazard index per mile of cast iron pipes in each grid, which is calculated based on an assessment of safety risk factors.[8] The hazard index per mile for each grid for which EDF quantified leak flow rate is depicted in Table 1 of the Appendix.

Next, using a Google Street View car equipped with methane detection equipment and geographic positioning systems (GPS), EDF surveyed 30 grids targeted for pipe replacement based on their ranking by the Hazard Risk Index Model. A leak quantification algorithm developed by Colorado State University was applied to the resulting data such that the leak flow rate for each leak observed was calculated (von Fischer et al., 2017). Flow rates for all leaks detected in a given grid were then summed and averaged over the number of miles of pipe in each grid to arrive at the estimated leak flow rate per mile of pipe in each grid. The resulting normalized metric resulted in a ranking of grids by their leak flow rate per mile of pipe (Table 1 of the Appendix).

This methodology was used to develop spatially attributed leak data for each grid cell (Figure 2),[9] presenting a visual depiction of the relative size, frequency, and location of leaks in each grid cell, and attributing each leak to particular segments of utility infrastructure. This information when sorted by comparable Hazard Risk Index results, used in making the initial prioritization of the grids, allowed PSE&G to prioritize grids for pipeline replacement. Specifically, for grids with comparable hazard ranks, the overall leak flow rate/mile of pipe was considered to identify and prioritize the leakier grids for replacement.

PSE&G's approach allowed it to focus its expenditures and resources on the leakiest pipeline segments and also recover the largest volume of usable natural gas per section of pipeline replaced. An analysis of emission reductions from PSE&G's final prioritized grid replacement strategy indicated that PSE&G was able to control 83% of the measured leak flow rate by replacing 58% of the pipeline mileage in measured grids (Appendix, Table 1 at grid 2B-42). In the business-as-usual case, PSE&G would have needed to replace 99% of the pipeline mileage in the surveyed grids to reach the same level of emission reductions (Appendix, Table 2 at grid 2C-43). Therefore, PSE&G achieved an 83% reduction in leak flow rate by replacing approximately one-third fewer miles of pipe than would have been necessary to achieve the same level of emission reductions if they had not used leak flow rate data. All of the pipes

[8] PSE&G conducts an annual study using this model to evaluate each cast iron main segment that has had a break, to rank each segment for replacement based on a combination of break history and environmental factors. Each geographic grid is ranked by adding the hazard indexes for individual pipe segments within the geographic grid and dividing them by the total miles of utilization pressure cast iron (UPCI) in the grid, arriving at a hazard index per mile for each geographic grid. Using the hazard index per mile results, grids were ranked by highest to lowest and then placed into A, B, C, and D priority grid categories.

[9] PSE&G's infrastructure data is protected under a non-disclosure agreement, and is not shown here. However, an example of the grid method, using fictitious data, is provided in Figure 2.

targeted for replacement will eventually be replaced, but emission reductions were achieved sooner than they would have been in a business-as-usual scenario.

Cast iron pipelines make up roughly 4% of pipelines nationwide. The avoided leak rates assumed here are based on roughly 9% of cast iron pipeline mileage having been prioritized for replacement out of the PSE&G miles where leak flow rates were quantified. In the case of PSE&G, those 9% of cast iron pipeline miles were equivalent to 37% of the estimated leak flow rate. Let us assume that utilities across the nation find and replace superemitting pipeline segments in a similar proportion to PSE&G — that is, where the prioritized grids represent 37% of the measured emissions and 9% of the pipeline miles. If this is possible, then 37% of emissions would be reduced by prioritizing 9% of nationwide cast iron pipeline miles, or roughly 2,500 miles. Reducing 37% of national cast iron pipeline emissions would be equal to reductions of 600,000 Mcf/year (+/- 70,000 Mcf/year).[10] This would have the same climate impact as taking 200,000 passenger vehicles off the road each year (+/-24,000 passenger vehicles).[11]

There are of course, uncertainties in the proportional presence of superemitting pipeline segments, the actual leak flow rates of those segments, and whether superemitting pipeline segments would be coincidentally classified as hazardous, regardless of leak flow rate. Even in PSE&G's system, the frequency of superemitters is unknown on a system-wide basis, because only some areas were surveyed, and because little is known about the "birth rate" of superemitters on a system. Nonetheless, these results from PSE&G indicate that there are likely to be sizeable benefits of leak quantification and prioritization for the climate and ratepayers.

PSE&G is already beginning to capture the benefits of prioritizing high-emitting (or "superemitting") grids for replacement. If other utilities find and prioritize superemitting pipeline segments or leaks at a similar rate nationwide, significant climate benefits could be achieved earlier than might otherwise be possible under a business as usual efforts.

As mentioned above, the grid approach can also be used to prioritize geographic zones not only for pipeline replacement, but also for leak repair. In 2015, Consolidated Edison of New York (CECONY) had the highest percentage of leak prone pipeline mains out of any utility in New York.[12] Just as PSE&G is using leak quantification to prioritize pipeline segments for replacement, CECONY recently completed a pilot program in collaboration with EDF to prioritize the utility's non-hazardous leaks for repair (Environmental Defense Fund and Consolidated Edison Company of New York, 2016). CECONY provided EDF with location and infrastructure information for its non-hazardous leak backlog. EDF surveyed the areas indicated by CECONY and quantified these leaks. CECONY will rank and prioritize leaks for repair based on the emissions flow volume. Preliminary results show that more than half of the emissions identified through our survey efforts could be eliminated by addressing the largest 18% of the leaks.

[10] This estimate only includes the removal of cast iron pipelines. The calculation of potential reductions of national cast iron pipeline emissions is derived by multiplying the average emission factor of 60.1 Mcf/mile/year for cast iron by the total miles of cast iron in the nation and multiplying that product by 37%. The estimate does not account for the added potential emissions of plastic mains — the most likely replacement material — which have an estimated average emission factor of 0.5 Mcf/mile/year (Lamb et al., 2015; U.S. Environmental Protection Agency, 2016).

[11] Assuming a 20-year Global Warming Potential of 84 for methane.

[12] "Leak prone pipeline mains" includes miles of unprotected bare steel mains and cast iron mains.

By enabling the ranking of the leakiest pipeline segments and individual leaks, leak quantification can help utilities decide where to repair leaks or replace pipelines when comparing sections of infrastructure with comparable risk rankings, thereby balancing safety and efficiency considerations. This approach, now pioneered by two major utilities, presents significant safety, capital efficiency, ratepayer, and environmental benefits, and is ready for adoption by other utilities.

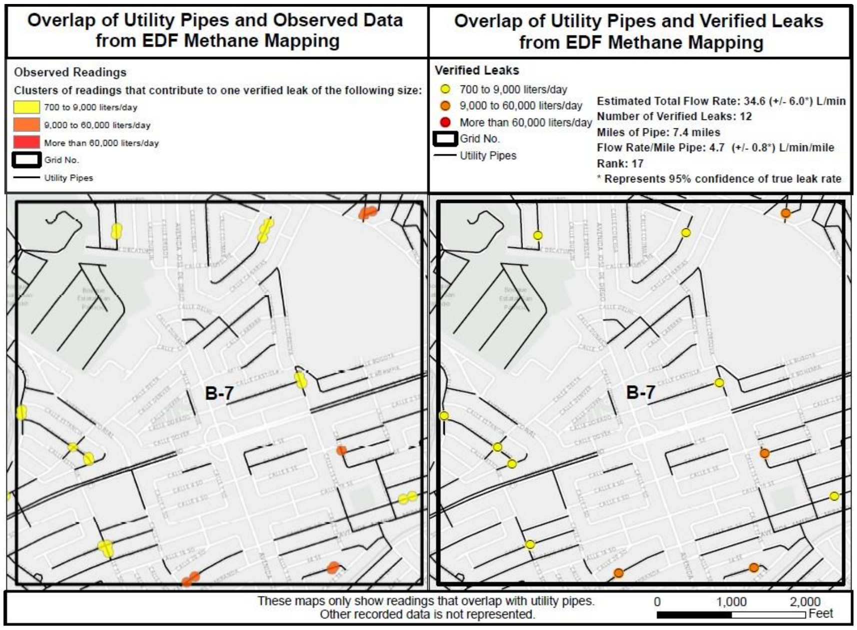

Figure 2 This simulated depiction of leaks in one grid cell of a utility's pipeline system demonstrates how overlapping observed readings are treated as individual "verified leaks," attributable to pipeline infrastructure. The result of such spatial attribution is a visual depiction of the relative size, frequency, and location of leaks in each grid cell.

6. Opportunities for Further Methodological Improvements

Leak quantification methodologies offers utilities an opportunity to use leak quantification to establish a baseline system-wide leak flow rate for their entire distribution system and measure progress in reducing emissions over time. Applied in this manner, quantification would be informative when considering major pipeline repair or replacement initiatives, allowing regulators and other stakeholders to assess the effectiveness of leak repair and pipe replacement programs in a transparent, measurable way.

Currently, utilities are building out and integrating advanced leak detection technology and spatial analysis into their routine pipeline safety and inspection programs. The federal rules establishing integrity management requirements for gas distribution pipeline systems ("Distribution Integrity Management Program for Natural Gas Distribution Sector") came into effect in 2011 (49 C.F.R. §192 [2009]). Under those rules, operators are required to develop and implement a distribution integrity management program. While the rules do not explicitly require utilities to quantify leaks, they state that: (1) pipeline operators must consider all reasonably available information to identify threats to pipeline integrity, and (2) the number and severity of leaks can be important information in evaluating the risk posed by a pipeline in a given location (49 C.F.R. §192.1007 [2009]). Under the rules, operators are required to consider the following categories of threats to each gas distribution pipeline: corrosion, natural forces, excavation damage, other outside force damage, material or welds, equipment failure, incorrect operations, and other concerns that could threaten the integrity of its pipeline. Sources of data may include, but importantly, are not limited to: incident and leak history, corrosion control records, continuing surveillance records, patrolling records, maintenance history, and excavation damage experience.

With technology available that makes leak quantification methods commercially available and viable, and PHMSA rules requiring operators to consider all relevant data in identifying threats to pipeline integrity, it is clear that the prevailing regulatory framework not only allows for leak flow rate to be considered in evaluating threats to pipeline integrity, but in fact, underscores the need to do so.

Some utilities, in addition to those described above, are already making use of leak quantification technology for this purpose. In California, Pacific Gas & Electric Co. (PG&E) is exploring how to integrate leak quantification technology into its leak management efforts (Pacific Gas and Electric Company, 2015b; Pacific Gas and Electric Company, 2012). This includes collecting leak data in a format that supports predictive analytics for assessing and mitigating risks to PG&E's infrastructure. CenterPoint Energy has also begun pilot testing advanced leak detection technology in Houston, Texas, and Minneapolis, Minnesota (Centers and Coppedge, 2015). The company has implemented a phased deployment strategy to evaluate and use advanced leak detection technology for leak surveys, and integrated the resulting data into leak prediction models that rely on spatial analytics. A collaborative, utility-led effort exploring leak quantification methods is also underway.[13]

A recent report by researchers at PricewaterhouseCoopers discusses the benefits of using spatial analytics to predict when and where pipeline leaks will occur (Wei et al., 2016). The authors describe how using quantitative failure history data, customer calls, and condition assessments can enable utilities to transparently manage their system, reduce human error, and cost-effectively improve decision-making (Wei et al., 2016). Traditional risk assessment has relied heavily on subject-matter experts who may use subjective data to make decisions about prioritizing risk mitigation actions. The report proposes that integrating spatial analytics with condition assessment data can allow operators to obtain a quantitative snapshot of asset risks in near real-time to inform investment planning and pipeline replacement project prioritization. The report further indicates that advanced leak detection technology can be used to provide data on leak density that can be integrated into a predictive model of leaks, further enabling capital prioritization. Such an approach can lead to efficiency and cost savings. For example, a case study presented in the report found that the client's quantitative spatial analytics model "delivered an estimated 3.9 times more leaks avoided, 3.6 times greater leaks/mile replaced, and 4.1 times more O&M (operations and maintenance) expense cost savings for the same capital investment" (Wei et al., 2016).

7. Conclusion

Quantifying and ranking leak flow rates for prioritization of leak repair and pipe replacement programs makes it possible to achieve larger reductions in gas lost for the same amount of time and resources, resulting in more cost-effective leak repair and pipeline replacement programs. As demonstrated by PSE&G's successful use of new practices to prioritize a large-scale pipe replacement program, leak

[13] i.e. NYSEARCH. 2014. "Technology Evaluation and Test Program For Quantifying Methane Emissions Related to Non-Hazardous Leaks." https://www.nysearch.org/tech_briefs/TechBrief_Methane-Emissions-Quantification.pdf

quantification technologies and methodologies can currently be deployed to prioritize leak repair and pipeline replacement programs. Using leak quantification allows for more robust leak prioritization, which helps to improve safety, minimize waste of natural gas, and reduce greenhouse gas emissions. Moving forward leak quantification will allow utilities to establish a baseline of system leaks that can provide an improved mechanism for comparing pre- and post-repair/pipe replacement outcomes to evaluate the success of such programs.

Acknowledgements

The authors wish to thank Rob Roscioli, Ramon Alvarez, Steven Hamburg, and David Lyon for their feedback and guidance in developing this work.

Appendix A: Emission Reduction Analysis

EDF quantified leak flow rates in 30 grids that PSE&G had designated as needing pipeline replacement. PSE&G replaced pipes in the most hazardous grids first, then used leak flow rate as an additional layer for prioritizing pipes for replacement in grids with lower, but comparable hazard indexes. This appendix describes the estimated emissions impact of this prioritization scheme.

The goal of this analysis was to quantify the amount of avoided methane emissions resulting from EDF's methane mapping activities in PSE&G's system, particularly with respect to pipeline grids that were prioritized for replacement as a result of having leak flow rate data available.

To determine this impact, leak flow rate reduced per replacement effort was considered. This includes an analysis of the percent of leak flow rate avoided under each scenario (i.e. business as usual or prioritized based on leak flow rate) and a comparison to the percent of mileage replaced under each scenario. This would give a comparison of the relative leak flow rate reduced per mile of expenditures, rather than a direct estimate of the leak flow rate reduced over time. Calculating the leak flow rate reduced over time was not possible, because we did not have data demonstrating when each grid would have undergone replacement in a business-as-usual scenario.

A.1 Procedures

PSE&G indicated that any grid with a hazard index per mile (HI/mi) greater than 25 would hold the highest priority for replacement (Table 1; grids shaded in orange). Where HI/mi was comparable (between 25 and 10 HI/mi), leak flow rate data was used to help sub-prioritize the grids by leak flow rate normalized by the number of miles in each grid. This parameter was expressed as liters per minute per mile (L/min/mi). In the datasheet, grids that met the above criteria and were prioritized based on leak flow rate were shaded in green. Three grids were prioritized this way.

The first step in determining the amount of avoided methane emissions was to sort all of the grids in order of final ranking (Table 1). Next, the cumulative percent of leak flow rate (L/min) and the cumulative percent of mileage for each successive grid was calculated (see far right columns). Finally, the same calculations were made ordering the grids by "GSMP UPCI Grid Rank" to represent the business-as-usual case (Table 2).[14] These calculations allow a demonstration of the leak flow rate avoided for each successive replacement effort, and allow a comparison between the business-as-usual case and the final ranking that includes leak flow rate.

A.2 Calculating uncertainty

Researchers at Colorado State University calculated a measure of uncertainty for the flow rate (L/min) and flow rate per mile (L/min/mi) in each grid. The measure of uncertainty, or confidence interval, was based on two times the standard deviation, which was calculated as 60% of the flow rate divided by the square root of the number of verified leaks found in each grid. Within this confidence interval, the flow rate range is expected to be true 95% of the time. In calculating a confidence interval for a select number of grids, the measure of uncertainty was summed for the total estimated flow rate (L/min) in the selected grids.

[14] GSMP stands for "Gas System Modernization Program." UPCI stands for "Utilization Pressure Cast Iron."

A.3 Avoided leak flow rate by mileage replaced

Three grids (2B-42, 2L-43, and 2C-43) met PSE&G's criteria for prioritization based on leak flow rate, and had not already been prioritized based on the hazard index. Three other grids (2A-48, 2K-44, and 2A-45) had a flow rate of greater than 10 L/min/mi, but were already prioritized based on hazard index. The green shaded grids that were prioritized based on leak flow rate, rather than hazard index, add up to a flow rate (L/min) of 37% of the total flow rate. Table 1 shows the grids in order of final ranking and demonstrates the leak reductions that could be achieved through prioritization of each successive grid, as well as the corresponding percentage of pipeline miles that had to be replaced to reach each successive leak flow rate reduction.

The grids were replaced in order of final ranking, with the orange-shaded grids having been replaced first. The total emissions reduced are calculated as a cumulative percentage from the time that the first grid (2A-48) undergoes pipeline replacement, until the last-ranked green-shaded grid (2B-42) undergoes pipeline replacement. By the time pipeline replacement takes place in all three green-shaded grids with an HI/mi less than 25, the total flow rate reduced is 83% (Table 1 at grid 2B-42). This flow rate reduction was achieved through replacing less than 60% of the surveyed pipeline mileage (Table 1 at grid 2B-42).

In this prioritization, 11 grids out of 30 (Table 1, grids 1Y-48 to 2D-53) were ranked as a lower priority than the three non-hazardous, green-shaded grids. If the business-as-usual ranking based only on hazard is considered (Table 2), the three green-shaded grids would have been prioritized lower, and all but three grids out of 30 (Table 2, grids 2B-42 to 2D-53) would need to be replaced to reach the same level of avoided emissions (83%) that came as a result of prioritization based on leak flow rate. In the business-as-usual prioritization, by the time a flow rate reduction of at least 83% would have been achieved, 99% of the pipeline miles would have to have been replaced (Table 2 at grid 2C-43).

Grid	Miles of UPCI Pipe in Grid	Total Estimated Flow Rate (L/min)	Estimated Flow Rate per Mile (L/min/mi)	Hazard Index per Mile (HI/mi)	GSMP UPCI Grid Rank	Rank by Estimated Flow Rate per Mile	Final Ranking	Cumulative Percent of Miles	Cumulative Percent of Total Estimated Flow rate (L/Min)
2A-48	1.07	16.08	15.03	54.9381	1	19	1	1%	1%
1Z-47	7.49	52.46	7.00	25.9084	15	10	2	5%	4%
2L-57	4.21	9.15	2.18	45.3544	2	24	3	7%	5%
2K-57	4.23	2.33	0.55	27.8521	11	25	4	10%	5%
2L-58	1.77	1.93	1.09	27.7219	12	27	5	11%	5%
2K-45	5.49	51.03	9.30	37.2695	3	9	6	14%	8%
2K-44	3.43	119.20	34.75	36.7325	5	5	7	16%	15%
2B-46	2.54	10.19	4.01	36.1869	6	23	8	17%	15%
2A-45	2.25	329.34	146.37	28.0060	10	1	9	19%	34%
2K-55	12.89	24.85	1.93	32.5147	7	17	10	26%	36%
2L-55	10.64	20.65	1.94	20.8300	28	14	11	32%	37%
2J-51	9.34	36.13	3.87	29.1177	8	11	12	37%	39%
2H-50	5.75	34.58	6.01	24.7551	17	12	13	41%	41%
2D-58	2.87	9.94	3.46	28.1752	9	20	14	42%	42%
2C-43	6.91	426.80	61.77	19.6449	39	2	15	46%	66%
2L-43	7.41	189.20	25.53	23.6801	20	3	16	50%	77%
2L-51	8.05	68.93	8.56	24.1780	18	4	17	55%	81%
2H-45	4.28	11.95	2.79	24.1516	19	22	18	57%	82%
2B-42	1.09	15.81	14.50	20.6577	32	16	19	58%	83%
1Y-48	4.14	23.29	5.63	23.3831	22	18	20	60%	84%
1V-50	8.2	58.26	7.10	22.2527	23	6	21	65%	88%
1V-49	2.52	1.98	0.79	20.6865	29	26	22	67%	88%
2P-53	1	0.00	0.00	22.0075	24	28	23	67%	88%
2J-52	8.95	50.98	5.70	20.6443	33	8	24	72%	91%
2G-51	10.38	28.43	2.74	20.4184	34	15	25	78%	92%
1T-60	1.97	0.00	0.00	20.3291	35	29	26	79%	92%
2 E-43	4.18	22.97	5.50	20.1753	36	13	27	82%	94%
2N-44	14.21	94.22	6.63	19.8060	37	7	28	90%	99%
2J-53	12.49	14.88	1.19	19.0926	42	21	29	97%	100%
2D-53	4.88	0.00	0.00	19.0639	44	30	30	100%	100%

Table 1 Grids in order of final ranking. Grids with flow rates shaded in green were prioritized based on leak rate. Grids with hazard index shaded in orange were replaced based on hazard index. Final ranking incorporates both hazard and flow rate. An additional 22 grids scheduled for replacement where leak flow rates were not quantified are not included in this table.

Grid	Miles of UPCI Pipe in Grid	Total Estimated Flow Rate (L/min)	Estimated Flow Rate per Mile (L/min/mi)	Hazard Index per Mile (HI/mi)	GSMP UPCI Grid Rank	Rank by Estimated Flow Rate per Mile	Final Ranking	Cumulative Percent of Miles	Cumulative Percent of Total Estimated Flow Rate (L/min)
2A-48	1.07	16.08	15.03	54.9381	1	5	1	1%	1%
2L-57	4.21	9.15	2.18	45.3544	2	21	3	3%	1%
2K-45	5.49	51.03	9.30	37.2695	3	7	6	6%	4%
2K-44	3.43	119.2	34.75	36.7325	5	3	7	8%	11%
2B-46	2.54	10.19	4.01	36.1869	6	16	8	10%	12%
2K-55	12.89	24.85	1.93	32.5147	7	23	10	17%	13%
2J-51	9.34	36.13	3.87	29.1177	8	17	12	22%	15%
2D-58	2.87	9.94	3.46	28.1752	9	18	14	24%	16%
2A-45	2.25	329.34	146.37	28.0060	10	1	9	25%	35%
2K-57	4.23	2.33	0.55	27.8521	11	27	4	28%	35%
2L-58	1.77	1.93	1.09	27.7219	12	25	5	29%	35%
1Z-47	7.49	52.46	7.00	25.9084	15	10	2	33%	38%
2H-50	5.75	34.58	6.01	24.7551	17	12	13	36%	40%
2L-51	8.05	68.93	8.56	24.1780	18	8	17	41%	44%
2H-45	4.28	11.95	2.79	24.1516	19	19	18	43%	45%
2L-43	7.41	189.2	25.53	23.6801	20	4	16	47%	56%
1Y-48	4.14	23.29	5.63	23.3831	22	14	20	50%	57%
1V-50	8.2	58.26	7.10	22.2527	23	9	21	55%	61%
2P-53	1	0	0.00	22.0075	24	28	23	55%	61%
2L-55	10.64	20.65	1.94	20.8300	28	22	11	61%	62%
1V-49	2.52	1.98	0.79	20.6865	29	26	22	63%	62%
2B-42	1.09	15.81	14.50	20.6577	32	6	19	63%	63%
2J-52	8.95	50.98	5.7	20.6443	33	13	24	68%	66%
2G-51	10.38	28.43	2.74	20.4184	34	20	25	74%	68%
1T-60	1.97	0	0	20.3291	35	29	26	75%	68%
2 E-43	4.18	22.97	5.50	20.1753	36	15	27	78%	69%
2N-44	14.21	94.22	6.63	19.8060	37	11	28	86%	74%
2C-43	6.91	426.8	61.77	19.6449	39	2	15	90%	99%
2J-53	12.49	14.88	1.19	19.0926	42	24	29	97%	100%
2D-53	4.88	0	0	19.0639	44	30	30	100%	100%

Table 2 The business-as-usual ranking, with grids in order of hazard index per mile (GSMP UPCI Grid Rank).

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RESPONSE OF ABB INC. - LOS GATOS RESEARCH TO LETTER OF INQUIRY DATED MAY 9, 2017 FROM THE CITIZEN'S UTILITY BOARD

12 June 2017

1. Introduction to ABB-LGR

ABB, a global leader in electric power and automation with over 135,000 employees and offices in over 100 countries, acquired Los Gatos Research (LGR) in October 2013 to fill a technology gap in its portfolio of analyzers. LGR provides analyzers and services to a wide range of customers needing real-time measurement of trace gases and isotopes for research and environmental monitoring, industrial processes and gas leak detection. LGR's instruments have been deployed by scientists for acquiring the most accurate measurements possible on all seven continents, in unmanned aerial vehicles, in mobile laboratories, on research and commercial aircraft, and in undersea vehicles.

ABB-LGR's novel, innovative and patented laser-based analyzer technology is based on Off-Axis Integrated Cavity Output Spectroscopy (OA-ICOS) that has a substantially higher sensitivity, precision and accuracy than other traditional sampling and laser-based technologies.

2. Leak Detection Capabilities

2.1 Type of Sensors

- **Methane only**
- **Methane and Ethane**

ABB sells (laser-based) analyzers capable of simultaneously reporting methane and ethane while driving. Unlike older technology, these new analyzers report methane and ethane with single-digit ppb sensitivity every second. ABB also sells man-portable, battery-powered analyzers for reporting methane with single-digit ppb (part-per-billion) sensitivity while walking. These portable units bridge the gap that exists between advanced mobile leak detection (ppb detection) and conventional handheld detection (ppm or part-per-million detection).

2.2 Sensitivity (lowest/highest detection level)

Our Mobile Gas Leak Detection system is capable of reporting methane with a precision below 1 ppb and ethane concentrations below 10 ppb. While these levels are more than sufficient to detect gas pipeline leaks 100 meters (or further) away, we are developing next-generation analyzers that will be 100x more sensitive.

The highest detection levels for these two different analyzers can be as high as several percent methane. ABB's analyzers are unique in advanced leak detection solutions because of the large measurement dynamic range.

However, please note that ABB also produces other laser analyzers for measuring natural gas purity than allows quantification of levels to 100% methane.

2.3 Underlying technology

ABB's underlying technology is patented and based on a laser absorption spectroscopy technique called Off-axis ICOS, the latest generation of the cavity enhanced absorption spectroscopy methods.

LGR, which was acquired in 2013 by ABB, invented cavity ringdown spectroscopy (CRDS) and all the major cavity enhanced spectroscopy techniques, including off-axis ICOS, the fourth-generation of these techniques, which LGR patented. This unique perspective gives us the ability to discuss various laser-based techniques with authority and experience.

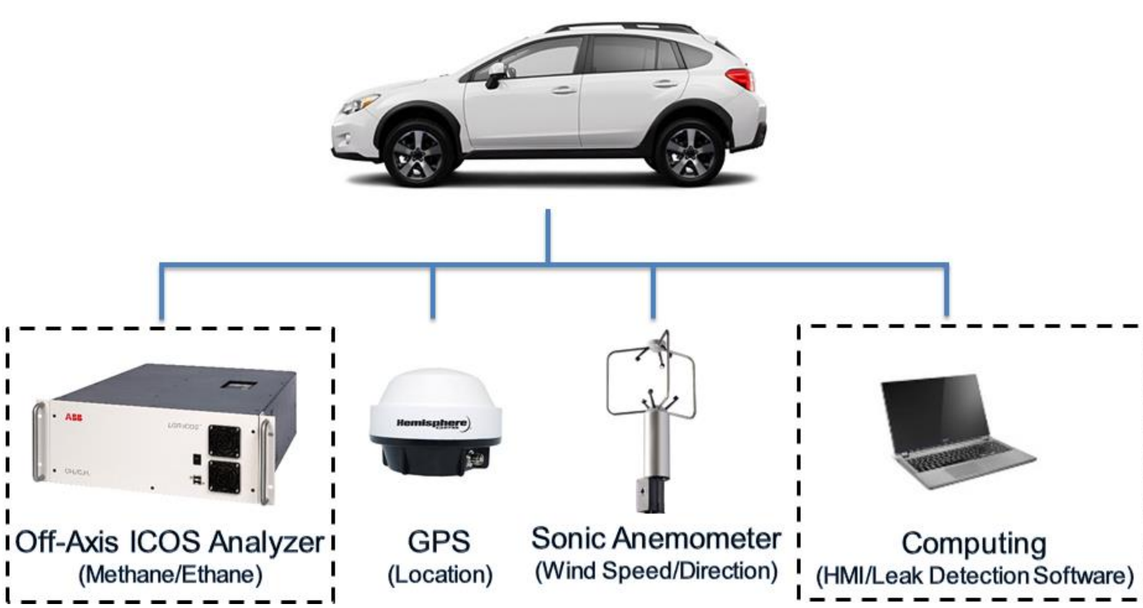
Off-axis ICOS is superior to conventional cavity ringdown spectroscopy in several ways, including, but not limited to, the following:

1. highest reliability
2. most robust to harsh environments (vibration, extreme temperature, etc.)
3. simplest to service
4. widest dynamic range
5. unsurpassed sensitivity
6. fastest time response

Details regarding each of these attributes is provided below.

2.4 Type of survey using sensor technology

ABB sells a comprehensive solution for Mobile (Gas Leak Detection) surveys that measure, quantify and locate leak locations on Google Earth maps in real time. This technology can be attached to and installed in a wide variety of new or used vehicles including automobiles, SUVs, trucks and UTVs that the customer presently owns, and consists of:



1. Patented gas analyzer (19" wide, 7" height, 24" deep) and proprietary computational software

platform for measuring methane and ethane simultaneously and displaying likely leak locations on Google Earth maps or other GIS platform.

2. GPS antenna (on the roof) and GPS receiver (included inside the analyzer)

3. sonic anemometer (located on the roof) for measuring wind velocity while the vehicle is either stationery or moving

4. vacuum pump for pulling the sampled air from an inlet located below the front bumper to and through the analyzer which is typically located in the trunk.

Installation and full commissioning of the entire system (in the customer's vehicle) takes less than one day.

To compliment the vehicle-based system, which provides the likely areas in which the leak originates, ABB also sells a lightweight, battery-powered, purse-size methane analyzer to quickly perform the investigation or "pinpointing" of leak indications. This 'microportable' methane analyzer, based on the same patented technology as the vehicle-based system, employs a smartphone or tablet as the User Interface. Importantly, this analyzer allow users to bridge the sensitivity gap between ppb sensitivities of advanced mobile leak detection systems and ppm sensitivity of conventional handheld detectors. The matched sensitivity dramatically decreases the time required to investigate leak indications and preliminary testing indicates the time to find goes from 30-45 min with conventional equipment to 10-15 min with ABB's portable unit.

2.5 Cost of sensors/hardware

LGR offers two purchase models for utilities interested in deploying Advanced Leak Detection Technology and analytics, rental or purchase.

Interested customers can evaluate ABB's Mobile Gas Leak Detection system for extended periods at very small rental rates of approximately $5000/week. Moreover, the rental fees can be applied towards the purchase price of the system.

The retail price for the new Mobile Gas Leak Detection solution capable of providing surveys that measure, quantify and locate leak locations on Google Earth maps in real time, sells for between $250k-$300k (hardware costs only) and does not include the vehicle.

After purchasing the system, the owner possesses and owns all the data reported by the analyzer. ABB does not sell the data back to the customer nor does ABB charge for generation of reports. Also, since the customer owns, and does not lease, the system, the equipment can be depreciated as a capital expense.

2.6 Software costs

ABB charges an annual license fee to maintain and enhance the software, provide support, and to effectively provide an evergreen software package that continuously provides new features and capabilities, in response to customer needs. ABB offers this for $45k, although the costs can be differently amortized depending on customer needs.

2.7 Estimated annual O&M costs

The operations and maintenance costs of the mobile system, excluding the vehicle, are small (typically less than $1500/year), and include re-building vacuum pumps, cleaning optics, if needed.

2.8 Cost of transport method

This is simply the cost of driving the vehicle in which the Mobile system installed and includes gas, maintenance, and driver costs. There is no need for purchasing a new vehicle for this application. In fact, utilities such as Pacific Gas and Electric, Atmos Energy, Sempra Energy, Google, Enbridge Gas, generally incorporate the system into existing (i.e. used) fleet vehicles.

2.9 Staffing requirements

After only a few days of training, virtually anyone can drive the car and operate the technology to find leaks. Aside from the power switch, the system is fully controlled with the intuitive software interface.

2.10 Product certification

The product passes all FDA and CE requirements.

2.11 GIS/geographic/mapping capabilities

The system offers several methods of viewing and analyzing the reported leak indications.

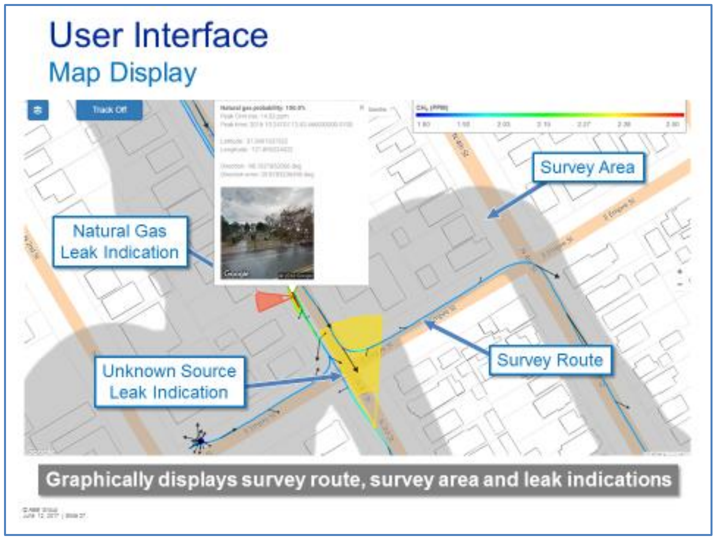
- The in-vehicle UI plots all the results on Google Maps (default or satellite view) in real-time. Leak indications can be clicked to raise additional information about gas concentration, location and time of find.

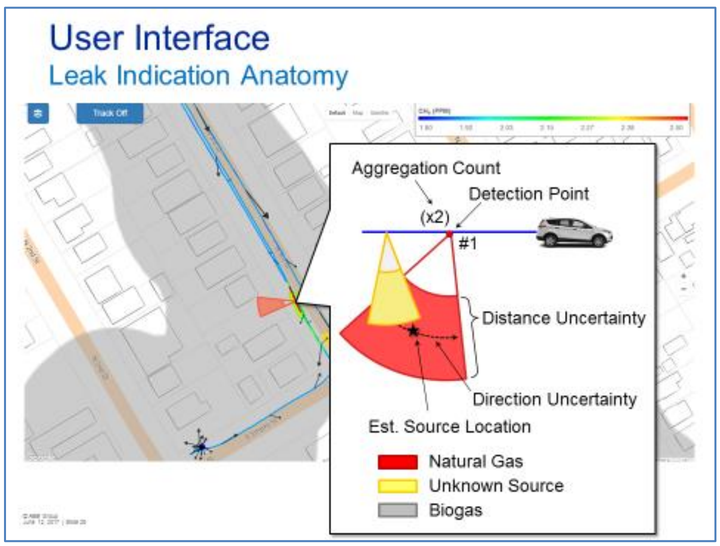
- The automatically generated report includes a KML/KMZ output of all the recorded data, including drive path with color coded methane concentration, wind velocity, estimated survey area and leak indications. All of this data can be view interactively in Google Earth.

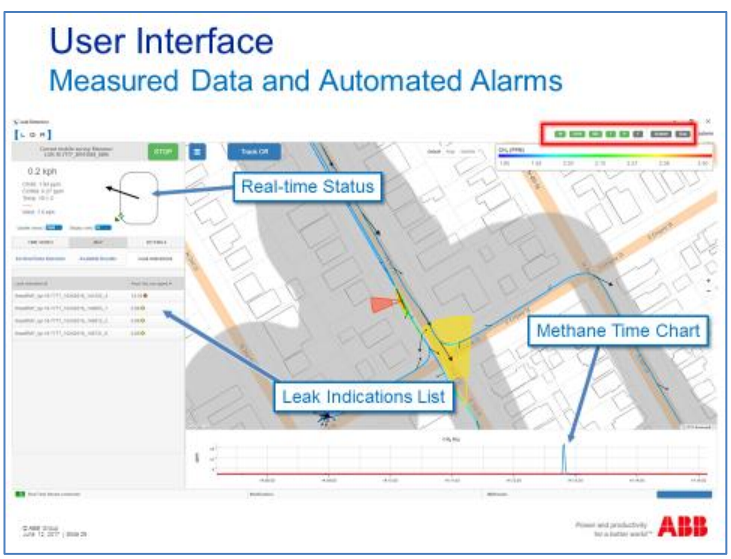
- Finally, the report also includes KML/KMZ in individual layers that can be imported into common GIS tools such as ArcGIS and Smallworld for further analysis and comparison to utility data.

Additionally, the in-vehicle UI allows users to import utility assets for viewing in real-time. This permits users to overlay and compare the locations of mains and services with the leak indications found by the vehicle.

Some examples of User Interface screens presented while driving allows users to see survey routes, surveyed areas and leak indications:


User Interface
Map Display
Track Off
Survey Area
Natural Gas Leak Indication
Unknown Source Leak Indication
Survey Route
Graphically displays survey route, survey area and leak indications


User Interface
Leak Indication Anatomy
Track Off
Aggregation Count
Detection Point
(x2)
#1
Distance Uncertainty
Direction Uncertainty
Est. Source Location
Natural Gas
Unknown Source
Biogas


User Interface
Measured Data and Automated Alarms
STOP
Track Off
0.2 kph
Real-time Status
Methane Time Chart
Leak Indications List
ABB

2.12 Unique capabilities of service/product offered, relative to competitors

The ABB Ability Mobile Gas Leak Detection system is based on ABB's *patented* Off-axis ICOS technology. Off-axis ICOS is superior to conventional mobile leak detection systems and cavity ringdown spectroscopy in practically every performance metric, including, but not limited to:

- **Speed of response**
  The mobile system provides a 5-Hz data rate to allow spatially resolved measurements even while driving at highway speeds (i.e. to 65 miles/hour). The microportable methane analyzer reports data at a 10 Hz data rate (and with ppb sensitivity) for similar reasons while walking. Conventional methods based on walking report data at speeds of about 1-2 miles/hour and often lack a digital record.

- **Accuracy**
  Unlike other analyzers based on older cavity based methods, these novel laser-based analyzers provide measurements that are inherently accurate because they record "fully resolved" (i.e. detailed) absorption spectra (that are displayed on screen to the user).

- **Precision**
  ABB analyzers report data with single parts per billion precision for measurements of methane and ethane. Based on field trials conducted by large utilities, this allows users to find leaks far from the source very quickly and reliably – 5 to 10 times faster than conventional legacy methods, which must be close to the leak and only report methane or total hydrocarbons, and thus get confused between natural gas leaks and other methane sources.

- **Measurement dynamic range**
  ABB reports natural gas concentrations at both extremely low concentrations with parts per billion sensitivity and precision but also reports high concentrations of methane to well over 1% in air. This large dynamic range gives users the ability to accurately detect leaks both from far away as well as nearby – i.e., there is no saturation when large leaks are detected as with cavity ringdown based advanced leak detection.

- **Overall robustness/ruggedness**
  Unlike older methods like CRDS, ABB's technology does not require extraordinary thermal control and nanometer alignment tolerances to operate. As a result, ABB analyzers can easily operate anywhere and over a far wider temperature range (0 to 45 C) compared with CRDS, which is constrained by much narrower mechanical tolerances.

- **Simplicity of service**
  Unlike older methods like CRDS, ABB's technology does not require extraordinary thermal control and nanometer alignment tolerances to operate. As a result, ABB analyzers can be easily serviced in the field – even cavity mirrors -- in the unlikely event that this is necessary. This reduces total cost of ownership and maximizes total measurement time.

- **Cost to own**

Due to higher reliability, simplicity and ruggedness, ABB technology is simpler to build and service, which leads to greater uptime, far lower purchase price (cf. $1.4 million or more for cavity ringdown systems), and easily the lowest maintenance costs. Finally, we expect the equipment to easily last for more than ten years, so the annual cost to operate the system is very low.

- **Cost to operate**
  Since the customer owns the equipment, after purchasing the system, the only annual costs are software licensing. Since ABB does not lease the solution, the customer can depreciate the capital equipment and thus reduce annual costs even further. Maintenance and service costs are typically less than $1500/year primarily for rebuilding the vacuum pump, changing particle filters, and possibly cleaning mirrors.

  In addition, ABB's mapping capability provides detailed geospatial maps of likely leak locations based on proprietary algorithms that have been proven for accuracy and reliability by numerous gas utility operators.

- **Data ownership**
  Unlike other laser-based companies that only lease their solutions, ABB sells the entire package to the customer. Thus, the customer owns and has immediate and direct access to all data recorded by the system.

  In brief, ABB's system provides users with unsurpassed capabilities at a price that is 5-10 times less on an annual basis than competitive (and less capable) systems based on conventional CRDS laser methods.

3. Leak Quantification Capabilities

3.1 What analytics packages does your company offer that are capable of quantifying leaks?

3.2 What is the cost of the quantification package?
ABB includes leak quantification metrics with the annual software licensing fee (at no additional cost). These metrics utilize evolving proprietary models that incorporate the measured data recorded by the system.

To maximize public safety and accelerate the development and testing of advanced leak quantification models, ABB collaborates openly with scientists and engineers from universities, industry and advocacy groups.

4. Operationalization and Integration

ABB's Mobile Gas Leak Detection Systems have been integrated into the operations of several major gas utilities throughout the US and Canada, and many other utilities will evaluate our systems within the next several months.

These systems provide utilities quantitative information that is available in easily read (i.e. in nonproprietary) data formats and maps of leak locations and relative sizes continuously while driving.

ABB has a long-standing tradition of collaborating with leading academic, governmental and industrial researchers worldwide through local and corporate research initiatives. We continue this practice of open collaboration for the development of the Mobile Leak Detection solution in order to refine this product quickly and most efficiently.

PICARRO

RESPONSE OF PICARRO, INC. to
LETTER OF INQUIRY DATED MAY 9, 2017 FROM THE CITIZEN'S UTILITY BOARD

Introduction to Picarro

Founded in 1998, Picarro is a leading provider of hardware and analytics solutions to measure greenhouse gas (GHG) concentrations, trace gases and stable isotopes across many scientific applications and industrial markets. The company holds over 50 patents, some exclusively licensed from Stanford University and has a global headquarters, R&D, manufacturing in Silicon Valley, California with offices in Europe & Asia with 145 employees, 35 PhDs and over 3,000 Picarro instruments deployed in 60+ countries world-wide.

Cavity Ring-Down Spectroscopy

Our patented Cavity Ring-Down Spectroscopy (CRDS) is at the heart of all Picarro instruments and solutions, enabling the detection of target molecules at part per billion, or better, resolution.

Natural Gas Solutions

Picarro is the industry leader in analytics-driven leak detection and quantification solutions, enabling our energy customers to increase capital efficiency while simultaneously improving the safety of their infrastructure.

Picarro helps utilities reduce O&M costs in their leak survey and repair budgets while also reducing risk. The Picarro mobile detection system coupled with customized data analytics produces leak indications ranked by potential risk. This lets utilities focus on the most important leaks without increasing leak backlogs. Picarro's Risk Ranking Analytics enables utilities to maximize the yield of important leaks per leak found. This maximizes the safety impact per dollar of expense. The analytics can also calculate emissions on pipe segments to aid in prioritization of pipe replacement for DIMP.

Picarro's vehicles conduct multiple patrols through a natural gas infrastructure, collecting methane plume data and sending it to the Picarro cloud – driving becomes simply data collection. Leak managers then run Picarro's Risk Ranking Analytics, transforming the data into actionable results for leak investigators. Armed with the indications and locations that are most likely to lead to important leaks, crews maximize their impact while keeping costs and backlogs under control. This same data can be used with Picarro's Emissions Quantification Analytics, allowing leak density and aggregate emissions to be calculated on different pipe segments. The pipe segments can then be ranked by emissions or leak density, providing significant O&M cost avoidance due to avoided leaks when this ranking is used to inform capital replacement priorities.

Scientific Instruments
Our portfolio of Picarro gas analyzers and systems enables scientists around the world to measure GHGs, trace gases and stable isotopes found in the air we breathe, water we drink and land we harvest. The ultra-precise and easy-to-use instruments are deployed across the globe offering unmatched performance in a variety of field conditions.
Industrial Solutions
Picarro's industrial solutions range from methane detection and analytics technology for energy companies to trace gas analysis for semiconductor fabrication and pharmaceuticals isolators.

Leak Detection Capabilities

- **Type of Sensors**
  - **Methane only**
  - **Methane and Ethane**

The Picarro system consists of an analyzer that measures both methane and ethane in addition to some additional gases that aid in discriminating natural gas from other methane sources like sewers or other vehicles.

- **Sensitivity (lowest/highest detection level)**

The Picarro system detects methane with a 4ppb precision at ambient levels (roughly 0-15ppm methane concentration) and has a detection range of approximately 0-500ppm of methane in air. For comparison, 100% gas escaping from an underground leak near the vehicle is quickly diluted by the atmosphere to 10s of ppms at the point the gas enters the Picarro system's inlet.

- **Underlying technology**

The Picarro system is based on Cavity Ring Down Spectroscopy (CRDS) which is a near-infrared optical measurement technology. The Picarro system has a closed-path gas flow configuration that continuously draws air flowing from inlets on the vehicle's front bumper into the CRDS analyzer. CRDS is capable of measuring concentrations of methane at levels below one part-per-billion (ppb) in the air.

- **Type of survey using sensor technology**
  - **Mobile survey**
  - **Other**

The Picarro system is a mobile system that is typically installed in a utility's SUV, truck, car, van or equivalent.

- **Cost of sensors/hardware**
- **Software costs**

The hardware is bundled with a software license and support. The incurred cost of the entire system (hardware purchase or lease, software license and annual service and support) is approximately $105 per mile of distribution main. This assumes full utilization of the system (driving and collecting data for one standard daily shift over 250 working days per year). *Please see detailed cost information in Appendix 2 and ROI analysis in Appendix 1 of this document.*

- **Estimated annual O&M costs**

The majority of the O&M cost relates to vehicle operation and maintenance and are approximately $0.65 per mile of distribution main. This excludes the labor component to drive the vehicle. Otherwise, the maintenance costs for the system are included in the price above.

- **Cost of transport method**

The cost of transport is limited to fuel costs and is approximately $1.64 per mile of distribution main, assuming fuel is $2.50/gal.

- **Staffing requirements**
    - **new staff required**
    - **utilization of existing utility staff**

To fully utilize the Picarro system, one dedicated hourly employee is required per vehicle. This could be a contracted or current employee since no specific skills are required. To coordinate the mobile data collection and to run reports using Picarro's analytics report generation software, one employee in a functional area such as leak survey or integrity management would be utilized. For compliance leak survey or emissions quantification using Picarro, this employee would be utilized at a rate of about two (2) hours per day annually for each 3000 miles of distribution main driven by the Picarro system. Existing full time or existing contract staff that are currently used for routine compliance leak survey would be used to investigate the leak indications reported by the Picarro system. In other words, instead of conducting routine survey on the miles of distribution main and services covered by Picarro, they would instead focus just on pinpointing and grading leaks found within the leak indication areas identified by the Picarro system.

Picarro's risk ranking analytics allows utilities to concentrate their limited leak survey and repair budgets on the most important leaks. Risk ranking prioritizes the most potentially hazardous leaks and provides utilities the option to defer repair of non-hazardous leaks in favor of the higher risk leaks in their distribution system. In this way, Picarro's analytics allow mobile leak survey to be accomplished without ballooning non-hazardous leak backlogs.

- **Product certification**

The Picarro system is compliant with the following specifications, standards and regulations regarding its use in this mobile application: DOT, CSA, military MIL-STD 810F shock/vibration test standard, FCC Part15B Class A, CE: EN61326, Safety: EN61010, EN60825-1 (Class 3B laser). The product is being used for DOT Compliance Leak Survey in the following states: CA, TX, AR, MN, LA, MS by three major U.S. utilities with additional states and utilities planning to come online in 2018. The product has been tested and validated in 40 double-blind, Directed Field Trials with 25 LDCs beginning in 2011, several involving independent, third-party validation by GTI, NYSEARCH and PRCI and several natural gas utilities worldwide.

- **GIS/geographic/mapping capabilities**

The system is compatible with any utility GIS system via direct import or API and supports real-time updates and GIS visualization from utility GIS system (ESRI, SAP, GE Small World, Integraph, etc.) using a variety of file formats including GeoDB, ShapeFile, kml, etc. The GIS information is shown in a map-based user interface within the Picarro vehicle and is also viewable for live and past surveys through Picarro's web-based interface. The Picarro analytics and reporting engine produces map-based output including utility GIS information (via PDF, Shape File or via an API to a utility's GIS system). Overlaying GIS information with Picarro leak indications greatly enhances a utility's ability to locate leaks.

- **Unique capabilities of service/product offered, relative to competitors**

Multi-pass Analytics: Picarro's system combines data from multiple passes over an area, and Picarro's algorithms process these runs (often collected on different days), producing actionable results. No other available solution uses analytics to collect and combine multiple data collection runs in this way. Picarro's patented Field of View coverage area and patent-pending algorithms for leak locating, methane emissions quantification and leak indication risk-ranking all take advantage of multi-pass data collection and analytics.

Risk-Ranking and Emissions Quantification: Picarro's analytics produce leak indications that are ranked by their potential hazard and can calculate point-source methane emissions (in cubic feet per hour) and can aggregate total emissions and calculate leak density over an area or pipeline segment. There is no other available mobile solution that offers these capabilities.

Avoiding False Positive Indications: Picarro has seven independent algorithms that act to avoid false positives (and false negatives) including: discriminating between biogas and methane from gasoline and diesel vehicles using multi-gas spectroscopy and Bayesian analytics, removing redundant indications, removing false indications from natural gas vehicles, compensating for high background concentrations of methane, identifying leak indications by using plume shape analytics and identifying search areas using atmospheric and wind vectoring analytics. The removal of false positives significantly improves O&M cost efficiency during investigation of leak indications. No other available solutions have this combination of capabilities.

GIS Integration: The bi-directional integration with a utility's GIS and ERP systems described above is unique to the Picarro system.

Cloud-based Data Storage and Reporting: Picarro offers a unique cloud infrastructure for collecting, storing and visualizing data taken by one or more Picarro vehicles: This web-based platform provides the user access to the various multi-pass analytics routines and reporting engines described above. Various, customizable reports in various formats are available to the utility for download. Picarro ensures the utility has full access to the raw data produced by the Picarro hardware, available in usable *.csv format

Data Security: Picarro's system incorporates third-party audited, industry standards for backup and disaster recovery and security in the areas of information, datacenter, IT systems, cloud application and customer data. Data is encrypted and the in-vehicle computer is hardened and secure.

Support: Picarro's service offing includes on-site training, installation, guaranteed service-level support, immediate response via 24x7x365 phone support and on-demand, on-site support.

Data Quality: The Picarro system suppresses data collection if system malfunctions, drifts out of calibration, or for excessive wind conditions. The system also offers an optional inertial GPS that enables mobile survey in dense urban canyon environments where normal GPS systems fail, such as in Manhattan. These capabilities are unique to Picarro.

Field Investigation Application via Tablet or Smart Phone: Picarro's unique Mobile View application is a live, map-based tool used to investigate leak indications and catalog search results. It offers real-time GPS location and utility GIS system situational awareness for the field technician and provides a record of the walking path and survey results of ground survey crews.

Utility GIS and ERP Connectivity Options: Picarro's system has API-level interoperability with GIS and enterprise systems such as SAP for logging leak information, scheduling, etc.

- **Other relevant information relating to leak detection capabilities**

Picarro's system has been extensively tested (both in real-world and controlled settings) by dozens of utilities and multiple gas industry partners. The testing consistently shows that the Picarro system is significantly more effective than legacy methods of leak detection. The testing and validation includes metrics on leak find rate, Field of View coverage percentage, efficiency, false positives and false negatives.

Picarro's risk-ranking analytics prioritizes leak indications by potential risk, a capability that is unique in the industry. Hazardous leak plumes have unique signatures that can be measured, allowing analytics to rank indications by potential risk. By combining multiple data collection runs by multiple Picarro vehicles, Picarro's risk-ranking analytics allow utilities to maximize operational efficiency by prioritizing leak indications that are most likely to be hazardous. Addressing the highest priority leak indications retires more risk per dollar than any available survey methodology.

Leak Detection Capabilities

- **Does your leak detection equipment have the capability to detect methane, ethane, or both? Are there any other chemical constituents that your equipment detects, which would be relevant to attributing the source of methane detections? If so, please name the constituents and describe their relevance.**

The Picarro system measures and reports concentrations of methane, ethane, the ethane-to-methane ratio and the related measurement uncertainties. For any methane indication reported, it calculates and reports the confidence percentage that the indication is either natural gas, biogenic methane or methane from vehicle exhaust. These determinations are calculated based on the known ethane content in the particular utility's natural gas. This is a configurable, utility-specific parameter in the Picarro analytics. The system also compensates for the presence of H_2S, CO, N_2O, propane and higher hydrocarbons, and mercaptans in the ambient air, and measures and compensates for CO_2 and water concentration changes in the air. To accurately discriminate between natural gas and other methane sources, and to avoid false positives, the system has been designed to measure and/or compensate for these interfering gases that are often found in ambient air and is the only commercially available system that has these capabilities.

- **What is the sensitivity of the leak detection equipment (i.e. the lowest and highest calibrated levels of detection for each constituent that can be detected by the equipment)?**

The detection rages are: Methane: 0-500ppm, Ethane: 0-200ppm, All other gases (H_2S, CO, N_2O, propane and higher hydrocarbons, mercaptans, CO_2 and water) are measured and/or compensated for but not provided as calibrated outputs to the user.

- **Can the leak detection equipment be mounted to a vehicle for the purposes of detecting natural gas pipeline leaks?**

Yes, the Picarro solution is inherently mobile in design.

- **Does your company provide a vehicle with the leak detection equipment, or would a vehicle be provided by the organization that chooses to purchase the leak detection equipment?**

Picarro does not provide a vehicle. The vehicles used are typically a utility fleet vehicle or contractor's vehicle.

- **What is the cost of the leak detection technology?**

The Picarro system is offered as a bundled system including the hardware, system software, access to Picarro's web-based analytics engine, and support and maintenance. The incurred cost of the entire system (purchase or lease) is approximately $105 per mile of distribution main. *Please see detailed cost information in Appendix 2 and ROI analysis in Appendix 1 of this document.*

- **What is the cost of software that is associated with verifying the location of natural gas leaks associated with methane emission indications identified by the technology?**

The Picarro system is offered as a solution and the various elements are not priced separately. The price is inclusive of all the elements required to collect methane and atmospheric data, process and analyze it and deliver reports and other processed output.

- **What is the cost of the vehicle, if a vehicle is included with the leak detection technology system that your company offers?**

Picarro does not sell the vehicle itself and it is not included in the cost.

- **What is the estimated number of new staff required to operate the leak detection technology?**

To fully utilize the Picarro system, one dedicated hourly employee is required per vehicle. This could be a contracted or current employee since no specific skills are required. Picarro provides training to utility staff.

- **What is the estimated number of new staff required to analyze the data generated by the leak detection technology?**

To coordinate the mobile data collection and to run reports using Picarro's analytics report generation software, one employee in a functional area such as leak survey or integrity management would be utilized.

- **What is the estimated utilization of existing utility staff for the above- mentioned purposes?**

For compliance leak survey or emissions quantification using Picarro, this employee would be utilized at a rate of about two (2) hours per day annually for each 3000 miles of distribution main driven by the Picarro system. Existing full time or existing contract staff that are currently used for routine compliance leak survey would be used to investigate the leak indications reported by the Picarro system. In other words, instead of conducting routine survey on the miles of distribution main and services covered by Picarro, they would instead focus just on pinpointing and grading leaks found within the leak indication areas identified by the Picarro system.

- **Has the technology been certified for use for any particular purpose? If so, what purpose has your technology been certified for? What capability does the technology or accompanying software have to generate approximate geographic locations of leaks or the maps of the estimated field of view of areas surveyed?**

The product is being used for DOT Compliance Leak Survey in the following states: CA, TX, AR, MN, LA, MS and has been certified to do so by three major US utilities with additional states and utilities planning to come online in 2018[1].

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[1] Picarro's natural gas detection system is being used by PG&E in California and by CenterPoint Energy in Minnesota, Arkansas, Louisiana, Mississippi and Texas. Due to confidentiality reasons, Picarro is not able to disclose the specific customer in other states.

The Picarro system is specifically designed to use vehicle GPS position and wind speed and direction data to localize the point of origin of natural gas plumes and to define regions that have been surveyed by the Picarro system's Field of View. The map-based visualization capability (both live and from reports produced by the software) combines satellite and street maps with utility GIS information to provide the user with information-rich, geospatial views of potential leak locations and the Field of View.

Leak Quantification Capabilities

- **Sensors/analytics packages capable of quantifying leak flow rate**

The Picarro system includes an analytics package that takes data collected by the Picarro hardware and produces output that calculates methane emissions and leak density on point sources, areas or pipe segments and ranks them by total emissions.

- **Cost of quantification capabilities**
  - **hardware**
  - **software**
  - **services**
  - **estimated annual O&M costs**

The Picarro system is offered as a solution and the various elements are not priced separately. The price is inclusive of all the elements required to collect methane and atmospheric data, process and analyze it and deliver reports and other processed output. The incurred cost of the entire system is approximately $105 per mile of distribution main.

The majority of the O&M cost relates to vehicle operation and maintenance and are approximately $0.65 per mile of distribution main. This excludes the labor component to drive the vehicle.

- **Unique capabilities of service/analytics package offered, relative to competitors**

No other competitors offer vehicle-based emissions quantification and analytics. No other competitors offer the unique capability to combine data taken on an infrastructure over a period of time and run analytics on the combined passes to improve the accuracy of the results with each pass included in the analysis.

- **Other relevant information relating to leak quantification capabilities**

Picarro's system informs pipeline replacement decisions based on current, measured emissions data. Picarro's emissions quantification analytics uses data collected by the Picarro hardware to calculate methane emissions of individual open leaks, pipeline segments, or entire infrastructures. This allows utilities to rank pipe segments by overall emissions and prioritize pipe replacement projects – construction dollars are saved by identifying and eliminating segments with the most leaks before those leaks trigger expensive repairs. Actual emissions data and leak density also informs pipeline repair vs. replace decisions.

Leak Quantification Capabilities

- **What analytics packages does your company offer that are capable of quantifying leaks?**

The standard Picarro system includes both leak quantification and leak detection capabilities. The data collection is done with the same vehicle-based hardware. The two different applications (leak quantification and leak locating) are served by two different analytics packages that are both included in the analytics software package of standard Picarro product.

- **What is the cost of the quantification package?**

The emissions quantification analytics software is included at no additional cost in the standard Picarro product.

Leak Data Analysis Capabilities

- **Sensors/analytics capable of ranking leaks by size, spatial characteristics**

The Picarro system can measure emissions of individual or aggregate sources and rank these points or segments by leak flow rate (i.e. leak size or emissions in cubic feet per hour). Since the emissions ranking takes into account a measurement of the entire plume that could come from a point source or from a larger spatial migration pattern, the ranked emissions is reflective of the entire volume of gas escaping.

- **Cost of analytics services (disaggregated by category, to the extent possible)**

The various analytics capabilities of Picarro's system are all included in the cost of the system and are not offered individually.

Leak Analysis Capabilities

- **What analytics does your company offer that are capable of ranking leaks by order of potential hazard?**

Picarro's system has the ability to rank potential leak indications by risk (i.e. likelihood of the indication being from a grade-1 or grade-2 leak for example) based on measured characteristics of the plume. Each leak indication is assigned a percentile ranking score by the analytics according to its potential risk.

- **What is the cost of this service?**

The risk-ranking analytics software is included in the cost of the overall Picarro system and not offered as an individual module.

Operationalization and Integration

- **Specific description of how products and services can be integrated into PGL's "neighborhood method" described in Appendix A**

Please see the response below regarding integration into the neighborhood method.

- **Cost of integration (disaggregated by category, to the extent possible)**

Please see the response below regarding cost.

- **Timeline for integration, including key milestones**

Please see the response below regarding timeline.

- **Number of gas distribution companies that are currently using the product, service or technology offered**

Seven (7) major natural gas utilities around the world are currently using the Picarro system; five (5) being U.S. based (including CenterPoint Energy and PG&E) and four (4) are using it for compliance leak survey. The system has been used and evaluated by a total of 37 utilities across North America, Europe, Asia and Australia.[2]

- **Description of operations or integration with other distribution utilities**

In the utilities where the system is being used actively, the use cases include DOT compliance survey, special non-compliance survey (rapid, emergency surveys, post-construction quality control, etc.), assessment surveys to inform pipe replacement (DIMP) and source discrimination and leak pinpointing applications. Please see additional information in the response below regarding integration.

[2] Due to confidentiality reasons, Picarro cannot disclose the names of all utilities that have used the Picarro system.

Operationalization and Integration

- **Please provide a specific description of how your company's products and services can be integrated into "neighborhood method"**

The data from Picarro's emissions quantification analytics would significantly improve the accuracy with which individual pipe segments (and entire neighborhoods) could be prioritized for repair based on potential risk. As is shown in PGL Ex. 1.1 "South Austin Gas Leak Comparison" on p. 4 of the "Appendix B – PGL initial brief" there are pipe segments in the "Before AMRP" which were replaced but which appear to have no existing leaks. It has been shown, however, that traditional survey misses typically 60% of gas leaks in an area when compared to using a Picarro system. It is therefore likely that a reliance on historical leak rates will lead to errors in prioritizing pipe segments for repair. Using the Picarro system would allow *current* emissions and leak density to be used – with a higher weighting factor than the 10% now used for historical leaks. Doing so would provide a much more accurate appraisal of the actual *current* risk of each pipe segment. Segments with no emissions (and low risks from the other weighting factors) could be removed from consideration for replacement, saving significant construction costs. A stepwise plan is described in the response below on timeline.

Data from the Picarro system can be processed using emissions quantification analytics which does not calculate individual leak indications. Instead, this analytics report mode is designed to provide a measurement of aggregate emissions over a pipe segment and an estimate of the number of leaks on that segment. Importantly, since individual leak locations are not calculated when using the Picarro system in this analytics mode, the process does not trigger the duty to investigate and repair leaks. Rather, this report provides a means by which pipe segments can be ranked by emissions and/or leak density and prioritized for repair. An example of this output is shown in the figure below.

Segment ID	Segment Rank	Emissions Rate (SCFH)	Emissions range (confidence)	Segment Length (ft)	Emissions Factor (SCFH/ft)	Estimated # of leaks	# Leaks/ft	Emissions Rate / Leak
4	1	7.0	4 – 16 SCFH (90%)	1579	0.0044	5	0.0032	1.14
1	2	5.1	2 – 8 SCFH (90%)	3090	0.0017	5	0.0016	1.0
3	3	2.4	1 – 4 SCFH (90%)	2535	0.001	4	0.0016	0.6
2	4	1.5	0.5 – 2 SCFH (60%)	2514	0.0006	1	0.0004	1.5

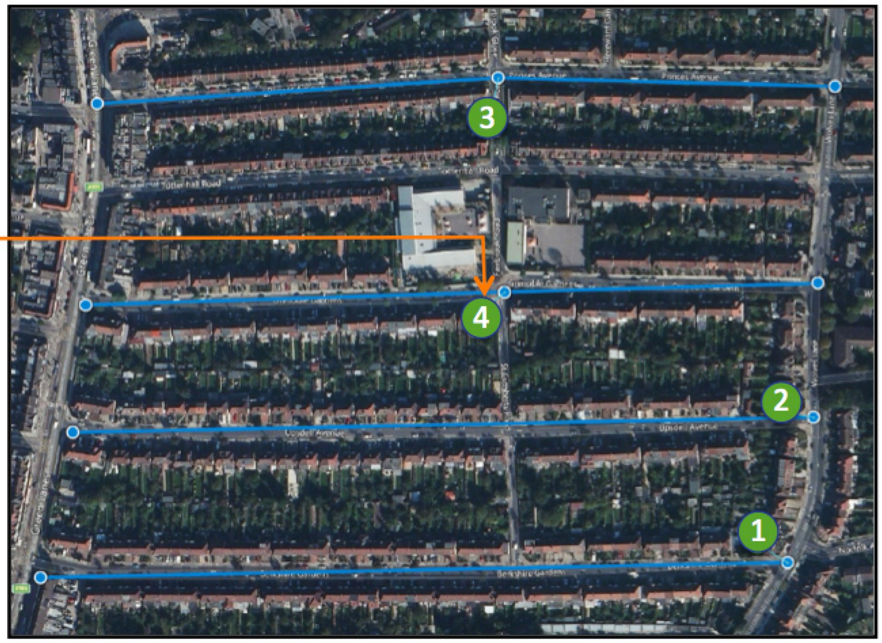

Figure 1. Picarro data processed with Picarro's Emissions Quantification Analytics to calculate emissions and leak density, allowing segments to be ranked and prioritized for replacement.

PGL also states that the "neighborhood approach" allows them to "continually evaluate" their construction priorities. The Picarro system has the ability to rapidly assess emissions and changes in leak density along leak-prone pipe in the winter months. Adding such "frost survey" data taken by the Picarro system could expose new pipe segments that should be prioritized for replacement. Picarro partnered with National Grid and GTI to study the effectiveness of this approach and concluded it was a more effective means of rapidly detecting changes in pipeline integrity under a cover of ice and snow than current practices.

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- **Cost of integration**

The costs of utilizing the Picarro system for this application would be consistent with the costs described previously: $105 per mile of distribution main. *Please see detailed cost information in Appendix 2 and ROI analysis in Appendix 1 of this document.*

- **What would be the potential timeline for being able to integrate your company's products and services into the "neighborhood method?"**

Implementing Picarro to provide this informative data in the current prioritization model used by PGL could be done in a matter of a few months. A stepwise plan is detailed below:

Steps to Operationalize EQ Analytics for Optimizing Capital Pipe Replacement Decisions:

1. Identify sections of pipe that are candidates for replacement
2. Using Picarro's driving protocol, collect data on all these sections of pipe with the Emissions Quantification (EQ) mode of Picarro vehicle
   - In this mode, no leak indications are provided to the user – the system simply collects methane concentration, GPS and wind data for further processing with EQ analytics.
   - The EQ driving protocol essentially recommends six (6) or more passes at night, on at least two different nights, along street(s) near the pipe segments to be measured. Picarro's in-vehicle Field of View coverage will show if the pipelines are being sufficiently covered and measured.
3. After all data is collected, use Picarro's EQ Analytics report engine to identify the geographic location of each section that has been driven. Each section will be given an ID number by the system.
4. The report produced by EQ Analytics will rank these sections by overall emissions and provide an estimate of the total number of leaks on that section.
5. This ranking can be compared and/or used to further inform whatever current method of pipe replacement prioritization is being used. For example, PGL could assess individual pipes or an entire neighborhood and combine the resulting reports with the other data used in prioritizing pipeline replacement work.
   - EQ Analytics provides a current snapshot of the state of the infrastructure that can be superior to only using pipe type, age, pressure, historical leaks, risk etc. to prioritize replacement.
   - By selecting more leak-dense pipes for replacement than would be selected with other risk models, more O&M cost in leak repairs can be avoided. In

addition, PGL can focus on replacing the most leak-dense pipe segments first – whether on a neighborhood-by-neighborhood approach or otherwise.

- **Please describe the extent to which your company's products and services have been integrated into the operations of other distribution utilities.**

At the utilities that are using it for compliance leak survey, the Picarro system is tightly integrated with monthly GIS data input from the utility. The Picarro analytics results and leak find information from the field is tied directly into the SAP work order and data collection system at the utility. Data collection drives are scheduled by SAP over multiple days. Once complete, a utility employee runs Picarro's analytics on the collected data. This generates leak indications which are searched for leaks by utility or contract leak surveyors with the aid of Picarro's Mobile View smart phone application. Leak grade, location and other data is collected in the field and uploaded into SAP which drives leak repairs or monitor orders.

These utilities use the system for other non-compliance use cases, scheduled on an as-needed basis. Utilities not yet using the system for compliance leak survey are exclusively using the system for any number of use cases described below:

- Special Non-compliance surveys
  - Rapid, emergency survey, post-disaster evaluation (earthquakes, tornadoes, floods)
  - Surveying high-risk pipe
  - Frost survey patrols (high-frequency survey)
  - Surveying public assemblies and high-consequence areas
  - Rapid survey of areas prior to public events (NFL Super Bowl, parades, official visits etc.)
  - Pre/post building demolition
  - Identification of large lost & unaccounted for gas sources
- Emissions Quantification
  - Construction prioritization (capital main replacement)
  - Targeted emissions reduction (identification & repair of highest emitting open leaks)
  - Post-construction QC – rapid survey of new or modern infrastructure
  - Due-diligence for asset acquisition
  - Risk-based assessment surveys
  - Support DIMP initiatives and analysis (high risk pipe, business districts, annual survey)
- Special use cases
  - Pinpointing hard-to-find leaks
  - Investigation of odor complaints

- Real-time source attribution (on-site chemical analysis: is source natural gas or not?)

Please see detailed cost information in Appendix 2 and ROI analysis in Appendix 1 of this document related to the use cases described above.

The responses to this letter of inquiry were prepared by Aaron Van Pelt, Director of Product Marketing and Product Management at Picarro Inc. Mr. Van Pelt is responsible for Picarro's energy products including the leak detection and emissions quantification hardware and analytics. Mr. Van Pelt has been in various technical and business roles at Picarro since 2007 and has managed Picarro's leak detection products since their development and introduction in 2010 and has managed the multiple campaigns with utilities and product validation by third parties.

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Leak Management Cost Savings

Summer 2017

Appendix 1

Summary

This document provides detail on the return on investment of the Picarro Leak Management System applied to various use cases within Leak Management. The financial assumptions for each use case are listed and the ROI is shown on an annual and 5-year basis. Various use cases included real examples from LDCs using Picarro, and the financial model for ROI in these cases is based on the financials of these examples. In cases where an example is not cited, the estimates come from typical estimates Picarro has obtained in its discussions with current gas distribution customers.

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Common uses of Picarro Surveyor

- **Regulatory compliance leak survey**
- **Special Non-compliance surveys**
  - Rapid, emergency survey, post-disaster evaluation (earthquakes, tornadoes, floods)
  - Surveying high-risk pipe
  - Frost survey patrols (high-frequency survey)
  - Surveying public assemblies and high-consequence areas
  - Rapid survey of areas prior to public events (parades, official visits etc.)
  - Pre/post building demolition
  - Identification of large lost & unaccounted for gas sources
- **Emissions Quantification**
  - Construction prioritization (capital main replacement)
  - Targeted emissions reduction (identification & repair of highest emitting open leaks)
  - Post-construction QC – rapid survey of new or modern infrastructure
  - Due-diligence for asset acquisition
  - Risk-based assessment surveys
  - Support DIMP initiatives and analysis (high risk pipe, business districts, annual survey)
- **Special use cases**
  - Pinpointing hard-to-find leaks
  - Investigation of odor complaints
  - Real-time source attribution (on-site chemical analysis: is source natural gas or not?)

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Emissions Quantification Use Cases

1. Pipeline replacement prioritization
   - Inform repair vs. replace decisions before construction
     - Avoid leak *repair* construction costs by prioritizing removal of leaky segments
   - Evaluation of high-risk pipe – DIMP

2. Fugitive emissions reporting
   - Identification of largest emitting leaks

3. Post-construction QC evaluation
   - Quality control audits of (pre/post) construction by contractors

4. Monitoring of leak rate changes over time
   - High-frequency frost survey
   - Seasonal comparison (Fall/Spring) survey to detect frost damage
   - Long-term monitoring of Grade-3 leaks in high risk areas

Cost Savings: Emissions Quantification (EQ)

- Pipeline replacement prioritization
  - EQ measures emissions *and* leak density on pipe segments
  - EQ is superior to using traditional leak history and identifies the *most* leak-dense pipe segments for replacement
  - Inform repair vs. replace decisions before construction
    - Avoid leak *repair* construction costs by prioritizing removal of segments with highest leak density

EQ Cost Savings

Total HARD cost savings			Total SOFT cost savings		
Yearly Replacement Budget	$146,720,000		**Risk Reduction:**		
Total Miles of Main	2,000		Hazardous leak find multiple	2.2	
Burdened cost of Picarro survey per mile of main	$156		Current annual risk reduced from replacement**	$537,600	
Total yearly cost to survey "Yearly Replaced Miles"*	$34,944		Annual risk reduced from replacement with EQ	$1,164,800	
Cost per Mile Replaced	$1,310,000		Five year risk reduction:	-->	**$5,824,000**
Cost per Leak	$3,000				
Yearly Replace Miles	112				
			Reduction in Odor Calls:		
Leaks/mile without EQ**	0.6		Cost of Odor Calls	$300,000	*($150/call, 1 call/ mi)*
Yearly Cost Avoidance without EQ	$201,600				
			Reduction or Odor Call by replacement	28.56%	
Leaks/mile with EQ**	5.7		Reduced Cost from Odor Calls	$85,680	
Yearly Cost Avoidance EQ	**$1,880,256**				
EQ Extra Savings	$1,678,656				
Five year cost savings-->		**$8,393,280**	Five year cost savings:	-->	**$428,400**

*Assumes to prioritize the Yearly Replace Miles, that you have to drive 2x that many of miles of pipe to prioritize the sections needing replacement

**Assumes 0.6 hazardous leaks/mi (traditional), 1.3 hazardous leaks/mi (Picarro), 5.7 total leaks/mi (Picarro) from Field Trial data

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Cost Savings: Compliance Leak Survey

- Hard savings from increased efficiency with Picarro
- Soft savings from:
  - Risk reduction due to finding more hazardous leaks with Picarro
  - Reduction of penalties from losing paper survey records due to Picarro digital records

Routine Regulatory Compliance Leak Survey

Total HARD cost savings			Total SOFT cost savings		
Annual spend on leak survey	$1,800,000		Hazardous leak find multiple	2	*(x traditional, typical)*
Miles of mains surveyed annually	10000		**Risk Reduction:**		
Picarro efficiency gains	38%	*(typical)*	Current annual risk reduced from leak survey activity	$1,000,000	
Survey cost per mile	$180		Five year incremental risk reduction:	-->	**$5,000,000**
			Non-Compliance Penalties:		
Five year savings:	-->	**$3,420,000**	Cost of losing a survey record	$25,000	
			Surveys completed per year	3000	
			Risk of record loss per survey	0.10%	
			Five year risk reduction:	-->	**$375,000**

*Customers report savings from 15% to 60% over traditional survey. 38% is an average.
**Based on risk reduction at higher leak find rate
***Estimate of lost productivity and labor cost to find replicate lost records

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Cost Savings: Customer Odor Calls

Investigation of Odor Complaints

Total HARD cost savings			Total SOFT cost savings		
Annual odor calls	10000	*(10k mi x 1 call/mi)*	Risk per missed hazardous leak	$8,000	
Response cost	$150	*(typical)*	No-leaks where Picarro finds a hazardous leak	16%	*(CenterPoint example)*
Picarro reduction from repeat calls	10%	*(CenterPoint example)*	Number of no-leaks	2000	
Five year savings:	-->	**$750,000**	Five year risk reduction:	-->	**$12,640,000**

- **CenterPoint Energy Example:**
  - Respond to 81k odor calls per year
  - 31% of leaks are from customer odor calls
  - In 34% of cases, technicians come back reporting no gas found
  - When they send a Picarro vehicle to a no-gas-found case, it finds gas 79% of the time
  - Of those cases, 20% are hazardous leaks
  - This means: 81k x 34% x 79% x 20% = 4,351 hazardous leaks are found that would not otherwise be found
- CenterPoint's goal to reduce the 34% NGF by half
  - Picarro would be key to quantifying & tracking
  - Could institutionalize use of Picarro for no gas found reports from odor calls
  - Expand use to construction monitoring, etc. using Picarro

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Cost Savings: Large Odor Cloud, Emergencies, Hard-to-Find Leaks

- There are several examples from current Picarro customers of these use cases

Responding to Massive False Odor Clouds

Total HARD cost savings

Large-scale false alarms per year	1	
Calls needing a response per incident	1000	
Cost per odor call response	$150	
Cost to respond with Picarro vehicle	$2,000	
Five year savings:	-->	**$740,000**

Rapid Post-Emergency Survey

Total HARD cost savings

Emergencies per year	0.3	
Extra cost for emergency survey	$500,000	
Five year emergency survey savings:	-->	**$750,000**

Total SOFT cost savings

Goodwill from gas company driving streets post-incident	$100,000	
Five year value of goodwill	-->	**$150,000**

Locating Hard-to-find Leaks

Total HARD cost savings

Overnight cost of crew	$5,000	
Avg number of nights spent in field on unfound leaks	1.5	
Hard to find leaks per year	20	
Amount Picarro finds before nightfall	65%	
Five year pinpointing savings:	-->	**$487,500**

Total SOFT cost savings

Morale and health impact of emergency all night work	$2,000	
5-year avoidance:	-->	**$195,000**

Cost Savings: Special Survey & QC after Construction

- There are several examples from current Picarro customers of these use cases

Non-Scheduled Mandated Leak Survey

Total HARD cost savings

Annual spend on non-scheduled survey	$500,000	
Efficiency savings	38%	
Five year savings:	-->	**$190,000**

- Public news report: PG&E dispatched 64 workers to a recent over-pressurization event:
  - http://www.kcra.com/article/pgande-gas-problem-prompts-concern-in-folsom/8643190
  - There is also a benefit for finding leaks faster, if they actually occurred due to the overpressure event

Post-construction Quality Control

Total HARD cost savings

Total annual repair costs	$5,000,000	
Construction jobs that will cause a problem in the next survey cycle	5%	
Five year future cost avoidance:	-->	**$1,250,000**

- Amount spent on repairing or replacing assets
- Contractors should fix problems if they are discovered quickly

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Cost Savings: Source Attribution, Auditing Traditional Survey, Asset Acquisition

- There are several examples from current Picarro customers of these use cases

Real-time Source Attribution

Total HARD cost savings			Total SOFT cost savings		
Gas samples processed per year	500		Hourly crew cost	$500	
Cost per gas sample	$100		Hours for a crew to collect a sample	2	
Cases resolved with Picarro	50%		Five year collection savings:	-->	**$1,250,000**
Five year gas sample savings:	-->	**$125,000**			

- There is also a reduction in risk from finding out faster if there is actual risk due to a gas leak

Auditing walking survey

Total HARD cost savings			Total SOFT cost savings		
Annual spend on survey	$1,000,000		Risk per missed leak	$10,000	
Improvement knowing Picarro auditing	20%		Current annual leaks found	2000	
Five year value of additional survey:	-->	**$1,000,000**	Improvement from Picarro audits	20%	
			5-year risk reduction:	-->	**$20,000,000**

- Utilities have seen an improvement in leak survey quality when traditional surveyors know they are being followed by Picarro

Due-diligence for Asset Acquisition

Total SOFT cost savings		
Gas systems purchased per five years	2	
Value of knowing if system was well maintained	$500,000	
Five year risk avoidance on acquisitions:	-->	**$1,000,000**

Cost Savings: Lost Gas & Community Outreach

- There are several examples from current Picarro customers of these use cases

Identification of Lost and Unaccounted for Gas Sources

Total HARD cost savings			Total SOFT cost savings		
Gas delivered per day (Bcf)	2.0		Social cost of carbon† per ton of CO_2	$42	(highly variable)
Cost per Mcf	$3.50		Tons of CO2 equilivent‡ per Mcf methane	0.054717	
Lost gas rate	1.50%		Carbon impact avoided over five years	-->	**$10,065,739**
Picarro leakage reduction	40%				
Five year ratepayer gas savings:	-->	**$3,832,500**			

† In the year 2020 for 3.0 percent discount rate in 2007 dollars. Source: nap.edu/read/24651
‡ Source: epa.gov/energy/ghg-equivalencies-calculator-calculations-and-references

- Helpful if companies have a target for emissions reduction
  – Can be calculated as tons of CO2 avoided as well

Community Outreach

		Total SOFT cost savings		
Public events per year	1	Goodwill from showcasing advanced utility technology	$10,000	
		Five year goodwill value:	-->	**$50,000**

  – Community outreach is worth spending money on

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Cost Schedule

In the detail that follows, costs of acquisition and operation of the Picarro system are listed per mile of distribution main and are calculated for PGL's planned 2,000 mile infrastructure. Costs are also compared to industry averages for leak management.

Item	Itemized cost	Multiplier	Subtotal
Cost of leasing the system	$105 per mile of distribution main	2,000 miles* of distribution main per year	$210,000
Vehicle operation and maintenance	$0.65 per mile of distribution main	2,000 miles of distribution main per year	$1,300
Fuel costs (SUV, Ford Escape or similar)	$1.72 per mile of distribution main	2,000 miles of distribution main per year	$3,440
Annual cost of Driver and Analyst	$49.10 per mile of distribution main	2,000 miles of distribution main per year	$98,200
		Grand Total	**$312,940**

*2000 miles of distribution main is used in this example to match PGL's total replacement project mileage.

The average cost per mile, including all expenses listed above is approximately $156.22/mile. This compares to industry ranges of $180 to over $2600 per mile[1] of main for leak survey.

Rate per mile calculations are based on the Picarro multi-pass driving protocol and current driving productivity rates of Picarro customers, one car driven 7 hours per day and 250 days per year can survey up to 3055 miles of main per year, on average, providing over >90% coverage of mains and services. Productivity for mains-only survey could be as high as 9165 miles of main annually, at a cost of $52.07 per mile of main. This compares to the industry standard[2] of 9.9 services per hour and 2.5 miles of main per hour, the productivity of which depends on mains/services density.

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[1] Pacific Gas and Electric Company 2017 General Rate Case, Exhibit (PG&E-3), Chapter 6c, Leak Management Expenses by Major Work Category. Leak survey cost per service in 2017 is projected to be $33 per service. PG&E has approximately 79 services per mile of main, yielding a leak survey cost of $2607 per mile of main including associated services and other inspection requirements. Contract leak survey can range between $180-$350 per mile of main according to estimates obtained by Picarro.

[2] *Picarro Surveyor™ Leak Detection Study Diablo Side-By-Side Study*, Timothy Clark, et al., November 2012, Pipeline Research Council International & Pacific Gas & Electric Co.

CERTIFICATE OF SERVICE

I hereby certify that a true copy of the foregoing Testimony submitted on behalf of the Environmental Law & Policy Center was served by electronic mail, upon all Parties of Record, on November 7, 2018.

/s/ Madeline Fleisher
____
Madeline Fleisher