STATE OF ILLINOIS

ILLINOIS COMMERCE COMMISSION

Illinois Commerce Commission On Its Own Motion -vs- The Peoples Gas Light and Coke Company Investigation of the cost, scope, schedule and other issues related to the Peoples Gas Light and Coke Company's natural gas system modernization program and the establishment of Program policies and practices pursuant to Sections 8-501.	)))))))))))))	Docket No. 16-0376

PUBLIC

DIRECT TESTIMONY OF JOE VON FISCHER

ON BEHALF OF THE CITIZENS UTILITY BOARD

CUB EXHIBIT 2.0

October 11, 2016

I. BACKGROUND

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

A. My name is Joseph C. von Fischer. My title is Associate Professor and Associate Chair of Biology, Colorado State University. My business address is 100 W. Lake Street, Fort Collins, CO 80523.

Q. On whose behalf are you submitting testimony in this proceeding?

A. I am submitting this testimony on behalf of Citizen's Utility Board.

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

A. My primary research expertise is in greenhouse gases and unraveling the mechanisms that control how much gas is exchanged between the land surface and the atmosphere. I earned my PhD in Ecology and Evolutionary Biology at Cornell University in 2002 and did post-doctoral training at Princeton from 2002 - 2003. I have been on the faculty at Colorado State University ("CSU") for over a decade, having joined in 2003. I have attached a copy of my CV in Exhibit 2.1.

Q. Are you providing any appendices or attachments to your testimony?

A. Yes, I have eight attachments.

Exhibit 2.1: Curriculum Vitae of Joe von Fischer

Exhibit 2.2: Table 1. Leak summary table for areas surveyed

Exhibit 2.3: Figure 1. Map of leaks EDF quantified in the Company's Chicago service territory in 2014

Exhibit 2.4: Table 2. A fictitious set of grids ordered by leak flow rate from high to low

Exhibit 2.5: Figure 2. A fictitious representation of leaks in a grid cell

Exhibit 2.6: Figure 3. Graphical representation of leak attribution methodology

Exhibit 2.7: Picarro Surveyor™ Leak Detection Study: Diablo Side-By-Side Study

Exhibit 2.8: Picarro Surveyor™ Leak Detection Study: Sacramento Side-by-Side Study

Exhibit 2.9: Table 3. Count of leaks EDF found that were within 60 feet (20 meters) of the Company's infrastructure, by material of infrastructure and leak flow rate [CONF]

II. SUMMARY, PURPOSE AND SCOPE OF TESTIMONY

Q. What is the purpose and scope of your testimony?

A. The purpose of my testimony is to share my scientific knowledge of quantification of natural gas leakage from natural gas distribution systems using methane sensors mounted on mobile platforms, and to comment on the benefits of using leak size data to prioritize pipeline replacement and leak repairs in the context of Peoples Gas' ("The Company's") System Modernization Program ("SMP"). Below, I discuss work that I have completed in Peoples Gas' service territory in Chicago, and the implications of this data for the Company in managing the Company's Accelerated Main Replacement Program ("AMRP").

Q. Please provide a summary of your testimony.

A. The Company's AMRP does not currently consider leak flow rate (i.e. volume of methane released over time), and so there is an opportunity for the Company to incorporate this data into its prioritization scheme to optimize the AMRP. Advanced leak detection technology and leak quantification methodologies have already been adopted by utilities across the nation to enhance the prioritization of leak repairs and pipeline replacements.

Advanced leak detection technology, due to its higher sensitivity, can help utilities find more leaks. Leak quantification methodologies use data derived from advanced leak detection technology to estimate leak flow rates from pipelines. Leak flow rates can then be used as an additional layer, after safety factors has been taken into account, to prioritize leak repairs and pipeline replacements, by allowing for the biggest leaks or leakiest segments of pipeline to be identified and addressed first.

EDF has demonstrated the viability of this technology in 10 cities in the U.S., including Peoples Gas' system in Chicago. My testimony details the results of these 10 surveys, controlled release experiments that were used to develop the leak quantification algorithm, field tests that were conducted to validate leak magnitude estimates, criteria used to locate a leak or elevated methane reading, how leaks are binned into size categories, mechanisms for screening out false negatives and positives, protocols for data collection and analysis, the stochastic nature of leak observations, and the procedures that have been used for attributing leaks to infrastructure under a pilot project with Public Service Electric and Gas ("PSE&G").

Advanced leak detection technology and leak quantification methodologies are ready and available for use by utilities, and can serve a useful purpose in prioritizing leak repairs and pipeline replacements.

III. PGL'S CURRENT AMRP AND OTHER LEAK ABATEMENT INITIATIVES

Q. Please summarize your understanding of the Company's Accelerated Main Replacement Program, and efforts to minimize leaks and methane emissions from its pipes.

The AMRP is a 20-year program aimed at accelerating the removal of all cast iron and ductile iron in the Company's system –about 2,000 miles of pipeline mains- in addition to other infrastructure upgrades. (Liberty Consulting. May 2015. Final Report on Phase One of an Investigation of Peoples Gas Light and Coke Company's AMRP. ("Liberty Consulting, May 2015.") p. B-2). The pace and cost of the program has been called into question, and now there is opportunity for the Company to consider alternative methods of prioritizing pipeline mains for replacement. An independent auditor, Liberty Consulting, has reviewed the Company's prioritization methods and has recommended that Peoples Gas "conduct a structured study of alternative criteria and weightings for the Main Ranking Index and for the neighborhood approach," or that Peoples Gas "should develop additional measures to reduce leak rates further" (Liberty Consulting, May 2015. Recommendations F.3 and F.4). Additionally, Liberty Consulting recommended that "Peoples Gas should develop, staff, and implement a data quality control program" (Liberty Consulting, May 2015. at F.1).

Although the AMRP has focused on reducing cast iron and ductile iron, partially for the benefit of reducing greenhouse gas emissions, the Company has not quantified the flow rates of individual leaks on those cast iron and ductile iron pipelines and come up with a way to prioritize the leakiest segments. This is especially important because numerous studies have observed that a relatively small number of leaks are often responsible for a large percentage of the overall methane emissions (A. R. Brandt et al., "Methane Leaks from North American Natural Gas Systems", Science, Vol. 343, 14 February 2011, available at http://www.novim.org/images/pdf/ScienceMethane.02.14.14.pdf.). Therefore, it may be possible for the Company to reduce a large portion of its greenhouse gas emissions with relatively low cost to ratepayers.

It is clear that the Commission views greenhouse gas reductions as a benefit to ratepayers. Since the Company is not using the latest technologies and methods available to demonstrate that they are reducing the most greenhouse gas emissions per mile of pipeline replaced or per leak repaired, the Commission should consider requiring the Company to do so.

Q. Please summarize the benefits of utilities using leak size data to prioritize leak repair and pipeline replacement programs.

A. Our data show that natural gas leakage from distribution pipelines is widespread in U.S. cities. This leakage is costly from the perspective of ratepayers and the environment. Methane, the principal component of natural gas, is a potent greenhouse gas that, pound for pound, traps 84 times more heat than carbon dioxide over the first 20 years after it is released, and is therefore a significant contributor to climate change.

We have found that leaks vary widely in magnitude such that the larger leaks are 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 therefore 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.

IV. <u>EDF AND CSU'S COLLABORATIVE PROJECT TO SURVEY DISTRIBUTION SYSTEM METHANE LEAKS AND ENGAGEMENT WITH GAS UTILITIES ON THE USE OF LEAK QUANTIFICATION TO PRIORITIZE PIPE REPLACEMENT AND LEAK REPAIR EFFORTS.</u>

Q. Please provide a brief overview of EDF and CSU's collaborative project to survey methane leaks from distribution systems, and engagement with gas utilities on the use of leak quantification to prioritize pipe replacement and leak repair efforts (the "Project").

A. I collaborate with EDF and Google Earth Outreach to work with 3 Google Street View ("GSV") cars that were specially equipped with methane sensors to detect methane leaks from natural gas distribution systems in several U.S. cities. The goals of our project include: 1) documenting patterns in the location and magnitude of natural gas leakage from the distribution systems of different utilities; 2) demonstrating the benefits of using leak quantification technology to prioritize utilities' pipe replacement and leak repair activities; and 3) creating the impetus for, and facilitating the integration of this technology into utilities' regular leak management programs.

The GSV vehicles that collect data as part of this initiative use a Picarro methane concentration analyzer that has a closed-path design with a sampling frequency of one data point every half-second, resulting in samples every 13 feet when driving at 20 miles per hour. These vehicles are also equipped with a Hemispheres Global Positioning System ("GPS") Receiver to document patterns in methane concentration in space.

Drivers are asked to drive every public street in a study area at least twice to ensure accuracy. Re-driving helps confirm the persistence of elevated methane readings, exclude spurious readings and characterize their emission rate accurately.

Data collected in urban systems and during controlled release experiments informed our development of a data analysis algorithm to interpret data collected through the methane mapping project. We conducted a number of "controlled release" studies at CSU by releasing methane at known rates and then drove through the resulting plume with the GSV car. We analyzed this data for patterns in plume size and shape to develop an algorithm that predicts leak size from measured patterns in methane concentration.

Q. In how many cities has EDF mapped methane leaks from natural gas distribution pipelines as part of this project? Please summarize key findings and implications for utilities' pipeline replacement and leak repair programs.

A. To date, EDF has published methane maps for leaks from natural gas distribution systems in 10 cities: Boston, MA; Burlington, VT; Chicago, IL; Dallas, TX; Indianapolis, IN; Jacksonville, FL; Los Angeles, CA; Mesa, AZ; New York City (Staten Island), NY and Syracuse, NY. In general, leaks were encountered more frequently in systems with high levels of older, leak-prone materials on their distribution systems. That is, utilities where we found a low "miles per leak" index had a greater frequency of leaks, and this was correlated with a higher percentage of leak-prone mains in their systems. Table 1 in Exhibit 2.2 demonstrates this correlation between leak frequency and abundance of leak-prone pipe. Cities with more leak prone pipe are also more likely to have leaks of larger magnitude.

Data gathered through the methane mapping project suggests that the majority of methane emissions from natural gas distribution systems are attributable to a relatively small number of large leaks, as opposed to clusters of small leaks. This finding is supported by multiple independent sources. For instance, a 2014 Stanford University study noted, based on many independent experiments, that a small number of large leaks are responsible for a large fraction of the leakage from natural gas systems.[1] Together, these findings underscore the need for utilities to replace leak prone pipeline materials on their distribution systems, and the benefits of using leak quantification technology to prioritize the largest leaks, after addressing those that pose a safety threat.

Q. How does the technology that is being used as part of the methane mapping project compare with current practices used by utilities for leak quantification?

A. It is my understanding that few, if any, utilities are routinely using leak flow rate data as a criterion for pipeline replacement or leak repair, but this is beginning to change. There are two aspects of the methane mapping project that are technologically novel. First, our group deploys instruments using highly-sensitive laser absorption spectroscopy to develop ultra-sensitive and precise measures of methane concentration. This sharply contrasts with the less sensitive instruments in common use by utilities. Less sensitive instruments are not able to detect small changes above background methane levels, and thus require a higher minimum methane concentration to identify a leak. Many standard instruments are also unable to discriminate between methane and other hydrocarbons like gasoline. The use of high-precision laser-based instruments (*e.g.* those methane analyzers manufactured by Picarro, LiCor or Los Gatos Research) allows us to use a faster

[1] A. R. Brandt et al., "Methane Leaks from North American Natural Gas Systems", *Science*, Vol. 343, 14 February 2011, available at http://www.novim.org/images/pdf/ScienceMethane.02.14.14.pdf.

automobile platform to scan cities for natural gas leaks in a relatively short timeframe. Second, we have done research to estimate leak flow rate from the spatial patterns in methane concentration. In contrast, it is my understanding that utilities generally do not calculate such leak magnitude estimates from their measures of gas concentration. Con Edison has noted that using advanced leak detection technology "provided greater capability to detect leaks in the field trial areas," where it has conducted pilot tests thus far.[2] In these tests, the Picarro was able to find 73 out of 79 gradeable leaks, whereas traditional survey technology was only able to find 36 out of 79 gradeable leaks. As Virginia Palacios' Direct Testimony describes, National Grid, Pacific Gas and Electric ("PG&E"), CenterPoint Energy, and other utilities are moving toward developing the capability to conduct advanced leak detection and leak quantification on an ongoing basis.

Q. Please explain the controlled release experiments that were used to develop the algorithm used for the mapping project.

A. We conducted controlled release experiments between June 2013 and May 2014 by releasing methane at a range of rates (2, 10, 20 and 40 liters per minute (L min^{-1})), and repeatedly drove the sampling vehicle through the plume, varying both the distance between source and vehicle (5, 10, 20 and 40 meters), and vehicle identity (we used 2 of the 3 GSV vehicles on this project). The magnitudes of release rates were based on likely leak sizes from urban natural gas distribution systems. Distances were based on the plausible distances for a vehicle driving on a public street to be within range of a natural

[2] Response to EDF Interrogatories – Set EDF-1. 05/04/2016. Responding Witness: Gas Infrastructure and Operations Panel. Question 6

gas pipeline. We replicated the controlled release experiments for each level of methane release rate, in order to collect 10 to 12 observations per level of methane release rate. A methane release system was designed to emulate street level gas leaks between 2 and 40 L min^{-1}. Chemically pure methane from a compressed gas cylinder[3] was routed to a mass flow controller (MFC)[4] which was set to the desired leak flow rate.

The flow rate from the MFC was verified in the field during each experiment using a primary volumetric flow meter.[5] Methane from the MFC was mixed with ambient air in a 45 liter mixing chamber to safe working concentrations that were just below the lower explosive limit ("LEL"). Concentrations in the mixing chamber were measured continuously with an LEL sensor[6] and we regulated the rate of dilution by adjusting the inlet of a small fan that forced ambient air into the chamber. Methane-enriched air from the mixing chamber was then routed to a three-meter section of perforated plastic pipe. This section of pipe was placed on the ground to emulate a short line-source leak as might occur along a crack in the pavement. Output from the MFC and LEL sensors were sampled once per second and logged every minute using a datalogger.[7]

Even though distance is a significant factor in shaping the observed peak, the distance between the vehicle and a real natural gas leak cannot be known *a priori*. Therefore, we aggregated the controlled release data from all distances because estimates of leak magnitude must operate without that information. As a result, the leak flow rate

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3 CY-ME CP200, Airgas USA LLC.
4 MCP-50SLPM-D-30PSIA, Alicat Scientific, Tucson, AZ.
5 Defender 510, Mesa Labs, Butler, NJ.
6 SEC Millennium, Sensor Electronics Corporation, Minneapolis, Minnesota.
7 CR800, Campbell Scientific, Logan, UT.

algorithm was developed using the best fit for data from all controlled releases within 20 meters (m) of the vehicle.

To develop a predictive equation of the rates of unknown leaks *in situ*, we fit a General Linear Model with the peak properties (maximum methane concentration, peak area, and kurtosis, which is characterized as the ratio of maximum methane concentration to peak area) as predictors. This model uses a log-linear relationship between properties of observed methane leaks and predicted leak flow rate of unknown leaks. This log-linear relationship was indicated as a best fit during statistical analysis of the data. The metric used by the algorithm to identify leaks is maximum methane concentration, which is simply the highest concentration recorded for that peak. The total plume area, reported as methane parts per million (ppm) parts of air across meters of distance between measurements (ppm*meters), is calculated from the excess methane concentration (observed methane concentration minus background methane concentration normally present in air) summed over the length of the peak. Of the three predictors, kurtosis had the greatest explanatory power in predicting leak flow rate, but the other predictors were significant as well.

Q. Were any field tests conducted to validate leak magnitude estimates? What were the results?

A. We have conducted two validation studies. The first was conducted at the time of algorithm development. In this validation, we drove a GSV vehicle through controlled release methane plumes of 2, 10, 20 and 40 L min^{-1} at distances of 5, 10 and 20 m from the vehicle. In all, we collected 58 observations.

As with the training data, we merged data from all distances and used the predictive equation from the linear model to estimate the leak flow rate. We had an overall 86% assignment success; 88% of low leaks (14 of 16) and 86% for medium leaks (36 of 42) were correctly assigned. Two of the low leaks were erroneously assigned to medium. Six medium leaks were erroneously assigned to low. None were erroneously assigned to the high category.

In this test, we also varied the driving speed between 16 and 32 kilometers per hour (km h^{-1}), but we found that differences between speeds had no statistically significant effect on the predicted emission rate. However, we anticipate that vehicle speed may ultimately impact the parameters in the model, especially maximum methane concentration, due to the dynamic instrument response and dilution effects of the air sampling system.

The second test occurred in an urban environment in Fort Collins, CO. Data were collected on July 24, 28 and August 7, 2015 on city streets with active traffic flow. These urban conditions were unlike the unobstructed research site where cars were driven at relatively constant speeds with trajectories that were near perpendicular to the plume trajectory. Instead, the streets were tree-lined to varying degrees, and roads varied in width and traffic flow from heavy traffic divided arterial roadway (40° 34' 37.7004" N, 105° 4' 44.4900" W), to medium traffic divided roadway (40° 34' 32.5560" N, 105° 5' 45.0708" W) to relatively quiet three-lane through street (40° 34' 40.5480" N, 105° 5' 1.1760" W). One location was studied per sample date using the same release and dilution equipment described above. The release rates were 0.5, 1, 10, 25, 45 and 50 L min^{-1}, which is somewhat expanded from the range of rates used in the calibration phase.

The release point was established at a single point 50 centimeters off the edge of the roadway, and the resulting plumes were driven past at distances ranging from 5 to 21 m, depending on lane position and driving direction. Vehicle drive speeds varied with traffic condition, but generally ranged from 15 to 40 km h^{-1}. Four to six passes were made for each release rate at each location. We made results of this urban test more comparable to field data by calculating average emission rates from pairs of passes.

Q. What did your analysis demonstrate?

A. Our analysis indicates that leak flow rate estimates from this urban test were accurately assigned to leak categories. We had an overall assignment success of 76%; 83% for low leaks (5 of 6) and 88% for medium leaks (22 of 25). One of the low leak flow rates was erroneously assigned to medium and three medium leak flow rates were erroneously assigned to the low category. There was a tendency to under estimate the category of high leak flow rates; only 29% (2 of 7) were correctly assigned to the high category, while the other 5 leaks were incorrectly assigned to the medium category. However, we have found in cities nationwide that have a high abundance of leak-prone pipe that both medium and high leak flow rates are rare and would be flagged for accelerated repair.

Results from this urban controlled release indicate an overall lack of bias in our quantitative estimates of leakage rate. Regression of true vs. estimated release rates indicate that our estimated rates are unbiased: estimated slope of 0.959±0.09 (1 standard deviation) was not different from 1 and the intercept of 1.28±2.1 was not different from zero.

Q. What are the criteria for finding a leak/elevated methane reading?

A. We characterized methane concentrations as elevated by comparing individual data points with average background concentrations.

We found background methane levels were highly variable within and among cities and in time, and thus found a fixed threshold suboptimal. Instead, we defined local background methane concentrations as a moving average long enough for the baseline itself to be unaffected by large natural gas leaks, yet small enough to reflect local variations. Controlled release experiments described above indicated that a two-minute window optimized this tradeoff; for example, a large (40 L min^{-1}) leak caused methane to be elevated for 40 m or about 5 seconds at a typical 40 km h^{-1} driving speed, and so a large leak would be observed as less than 5% of elevated concentrations in a two-minute period. Leaks are binned into low, medium and high categories, depending on leak flow rate –that is, the magnitude of elevated concentrations observed over time.

We developed a protocol for flagging methane readings as significantly above background based on typical instrument precision and results from controlled release experiments. The threshold for defining elevated methane concentrations was greater than 10% or greater than 4 standard deviations (SD) above background, whichever is greater. In an examination of data collected in urban areas, we found that the 10% threshold was invoked for more than 90% of readings as compared to the 4 SD threshold; the latter only defined the threshold in areas with high background and/or highly variable methane readings.

Q. Please explain how leaks are binned into "small", "medium" and "large" categories. How accurate is the binning?

A. A regression of known vs. predicted leak flow rates reveals a statistically significant ($p<0.0001$) and useful ($r^2 = 0.43$) relationship between the known and estimated leak flow rate. Some of the unexplained variation arises because distance to the source was treated as an unknown; the size of leaks 15-20 m away were underestimated, those 0-5 m were overestimated, and the prediction was most accurate about 10 m away. As a result of this uncertainty, we sought not to predict discrete leak flow rates, but to rather segregate the leaks into classes, low (0-6 L min^{-1}), medium (6-40 L min^{-1}) or high (above our highest release rate or >40 L min^{-1}).

Along with information about leak size, we sought to also convey the analytical uncertainty associated these estimates. Previous studies in science communication have indicated that this uncertainty can cause confusion and therefore limit the usefulness of the leak magnitude information.[8] Following the work of Severtson (2015),[9] we assigned leaks to categorical bins. Based on conversations with utilities, utility experts identified the primary need as discriminating small leak flow rate < 6 L min^{-1} from medium leak flow rates (6-40 L min^{-1}). We also developed a high bin (> 40 L min^{-1}) for leak rates estimated to be larger than our highest controlled release rate. These bins allowed a high degree of accuracy for assigning individual leaks to the correct bins: 97% of low leaks (33 of 34) and 92% of medium leaks (98 of 107) were correctly assigned.

Q. Are there mechanisms for screening out "false negatives" and "false positives"?

A. We screened out false positives using spatial and temporal features that were relatively unique to natural gas leaks. Firstly, controlled release experiments revealed that leaks at or below 40 L min^{-1} typically caused elevated methane to occur on spatial scales within100 m, and so we assumed elevated methane readings extending further than 100 m were not natural gas leaks. This spatial criterion may lead to conservative results

[8] Severtson DJ (2015) Testing Map Features Designed to Convey the Uncertainty of Cancer Risk: Insights Gained From Assessing Judgments of Information Adequacy and Communication Goals. Sci Commun 37(1):59–88.
[9] *Id.*

where multiple leaks in close proximity cause elevated methane to occur along greater distances than 100 m of roadway, causing those leaks to be discarded from the data set. Secondly, because natural gas is under relatively constant pressure in the distribution lines, we set a temporal criterion of persistently elevated methane concentrations. Elevated readings measured only once were assumed not to come from natural gas leaks. This last step required a GIS analysis to identify when the midpoint of observed peaks were within 100 m of each other.

Thus, we defined a “leak” as a set of elevated readings that was found more than once within a 100 m distance.

To further reduce false detections from wetlands or landfills, which also produce methane through biological pathways, we excluded any readings from the analysis where the average baseline concentrations were more than 2.8 ppm. For example, this situation has been consistently observed around landfills like the Freshkills landfill on Staten Island.

We excluded roads where traffic moved faster than 70 km h^{-1} because the magnitude of vehicle-induced wind movement could cause dilution, and increased location uncertainty that would yield low-quality observations.

Q. Please explain the protocols for data collection and analysis as part of the methane mapping study.

A. The analyzer and GPS system continuously delivered quality control metrics to help identify data to be excluded based on degraded instrument performance. Data points were excluded on the basis of poor GPS position lock or poor methane analyzer performance. These errors usually affect less than 1% of the total data. GSV car drivers were instructed to drive every public road in the study area at least two times. Data that pass quality control metrics were then analyzed to find where methane concentrations were significantly above background, excluding roads and driving speeds faster than 70 km h^{-1}. For each city in which we have conducted methane mapping, the final data set includes only those leaks that passed the above filters and are reported as the average leak location, the estimated leak flow rate and the associated leak flow rate category.

Q. Please explain the stochastic nature of leak observation as part of this study. What are the implications?

A. The probability of observing a leak from low-pressure natural gas pipes appears to be influenced by leak magnitude, with larger leaks observed more frequently. As a consequence, the data that we have collected reflects a sample of the natural gas leaks in any given city, not a comprehensive inventory, because even when leaks are persistent, they are not observed all the time. Atmospheric stability, wind speed and direction, traffic effects and other factors can prevent a sampling vehicle from detecting a natural gas plume. Observation of the plume is thus an unpredictable event to some degree, but this stochasticity can be greatly reduced with increased observations.

There are several important implications of the stochastic nature of methane plume detection. First, our survey of natural gas leaks is a sample and not a complete census. The probability of observing all of the leaks in a city rises with sampling effort, with 8 or 9 drives of a stretch of road required to measure at least 90% of the true population of leaks. In comparison, routine utility leak surveys are intended to be a complete census, though it seems likely that those efforts also miss some leaks. When we compared our leak maps with utilities', we consistently identified leaks that the utilities were unaware of, and vice versa. Yet, without simultaneous mapping we cannot come to any conclusions about the cause of these differences and whether they are the result of temporal heterogeneity of leaks or the stochasticity of detecting leaks. Second, these stochastic effects and our requirement of two or more observations suggest that our estimates of total leak frequency and magnitude should be considered underestimates of the true rates.

Q. With regard to the findings of the Project, how do cities with older, more leak prone distribution systems compare with those that have newer, less leak prone distribution systems?

A. My work shows that cities differed sharply in the number of leaks observed, depending, in part, on whether, and the extent to which, they had conducted accelerated pipeline replacement programs ("APRPs"). In general, cities that are known to have relatively newer, less leak prone distribution systems were found to have fewer leaks than cities with older, more leak prone systems. For instance, Burlington, VT and Indianapolis, IN registered 11 and 5 leaks, respectively, while we found hundreds or thousands of leaks in cities known to have older, more leak prone gas infrastructure such as Boston, MA, Staten Island, NY and Syracuse, NY.

For a more direct comparison, these leak counts should be normalized to the length of distribution lines or to the gas flow rate beneath the survey area, but appropriate data and/or infrastructure were not in place to make this estimate. As a surrogate for this analysis, I calculated the frequency of leaks per unique km of roadway surveyed. This normalization did not alter our broad conclusions from an analysis of the raw data; there only were 6 leaks per 100 km in Burlington and 0.4 per 100 km in Indianapolis, while Boston had 56 per 100 km, Staten Island had 63 per 100 km and Syracuse had 28 per 100 km. In all cities, low leak rates were far more common (83% to 100% of cities' leaks) than medium (0% to 17%) or high (0% to 2%).

We estimated the average leak rates for each city as the sum of estimated leak rates per 100 km of roadway surveyed. When multiplied by the length of roadways in each city, we conservatively estimate that these leaks from Boston amount to at least 1300 tons methane yr^{-1}, 1000 tons methane yr^{-1} in Staten Island and 300 tons methane yr^{-1} in Syracuse.

Many sectors of the natural gas supply system have a "fat tail problem" where large, infrequent leaks cause a significant fraction of the total system leakage. Our data suggest that APRPs generally achieve their goals of significantly reducing the frequency of these larger leaks. The magnitude of the potential for leak reduction using spatially-attributed leak flow rate data is stark: cities that were known to have relatively newer, less leak prone systems due to the implementation of APRP programs show an average 95% reduction in the normalized system leakage rate as compared to other cities.

Q. Have the results of this study been published in a peer reviewed scientific journal?

A. My colleagues and I have submitted this study to Environmental Science and Technology. It is undergoing the review and revision process at this time. We hope it will be published before the end of 2016.

Q. How does the success of this survey method compare to those deployed by typical utilities?

A. We worked with an un-named utility ("UNU") to compare the findings of our leak survey with their own standard field tools and technicians. After mapping sections of the UNU service area, we relayed to them the location and magnitude of the X leaks (actual number not reported here to protect the identity of the UNU). The UNU dispatched field technicians to the X locations, but using standard survey equipment (Heath RMLD), they were only able to find 16% of the leaks that our survey had indicated. About 8 months later, I visited the UNU service area and worked with the UNU staff to study a subset of 32 leaks that were in a contiguous part of the service area, but were part of the 84% of leaks identified by our survey but not found by UNU service technicians.

Over the course of 5 days, I used a Los Gatos Ultraportable Greenhouse Gas Analyzer to search for leaks at the 32 study locations. To confirm that the elevated methane readings were of a natural gas origin, we also analyzed samples for concentrations of methane and ethane. I found 17 of the leaks (53%) to be active natural gas leaks. Two of these were determined to be grade 1 leaks, which are immediately hazardous. In addition, we found evidence that 5 leaks (16%) had been repaired prior to our arrival. About one third of the locations appeared not to have natural gas leaks on the utility side of the meter; 6 leaks (19%) appeared to be biological sources, 1 site (3%) was a restaurant with a source on the customer side of the meter, and at 3 sites (9%) we found no sign of elevated methane after 30 minutes of searching.

Cumulatively, I estimate that 77% of leaks found by our approach in the UNU service area are derived from natural gas leaks. At this time, I am working up the results from this type of effort in the domain of a second UNU, which I conducted during the summer of 2016. Preliminary results support the generality of findings from the first UNU.

My work is not the first to show that the use of new, more sensitive leak detection technologies can detect leaks that may not be found with traditional hand-held utility leak detection devices. Previous work by the utility Pacific Gas & Electric ("PG&E") in

Sacramento and Diablo indicated that use of a Picarro Surveyor system found more leaks in survey areas than did the traditional system (Exhibit 2.7 and Exhibit 2.8). Notably, the Picarro system found multiple type 1 leaks that were not discovered with the traditional equipment. This was also observed in Chicago, where six of the leaks EDF found in the Peoples Gas' service territory were classified as "grade 1" leaks (PGL CUB 3 01), which were not previously found by the utility despite its regular leak survey efforts. This suggests that traditional equipment is not detecting the full universe of leaks. The PG&E studies also documented a pattern where traditional survey techniques found a different set of leaks than were found with the Picarro Surveyor. In Chicago, for example, Peoples Gas was only able to find 10 leaks at the 349 leak locations EDF provided (PGL CUB 3 01 (b)). The Company used a Heath Remote Methane Leak Detector (RMLD) to perform the leak surveys (PGL CUB 3 01 (d)). The Company's data shows that ***[redacted]***

I conclude that incorporating new high-sensitivity leak detection technologies can significantly increase the overall effectiveness of leak survey programs when used in conjunction with traditional survey techniques. And as technologies like the Picarro Surveyor become more tested and widespread, perhaps by other companies in addition to Picarro, the capabilities of these technologies will continue to make them more useful to utilities.

V. LEAK QUANTIFICATION ASSESSMENTS OF UTILITY SYSTEMS

Q. Please summarize the leak quantification assessment that was undertaken by EDF in the Company's service territory.

A. EDF dispatched a Google Street View car specially-equipped with methane concentration analyzers to Peoples Gas's service territory between September and December 2014. These surveys resulted in finding 349 leaks, at a rate of one leak every three miles. 314 of the leaks had a low flow rate (less than 6 liters per minute (l/min)), 35 leaks had a medium flow rate (6 – 40 l/min), and none of the leaks had a high flow rate (greater than 40 l/min). A map of these leaks, as presented on EDF's website, is shown in Figure 1 of Exhibit 2.3.

However, in this survey, EDF was not able to definitively attribute the leaks to the Company's infrastructure, because we did not have the locations of the Company's pipelines. Additionally, EDF did not have data on the locations of known leaks in the Company's system. With this data, EDF would be able to verify whether the leaks we found were new leaks or if they were already known and recorded in the Company's leak backlog. This comparison will also demonstrate to what extent the use of advanced leak detection technology results in the discovery of new leaks that were previously not identified by the Company, as well as the size of such leaks (e.g. whether they fit into the small, medium or high categories).

CUB filed a motion to compel the Company to provide geographic information system ("GIS") shapefiles of the Company's segments that are to be replaced, so that EDF could conduct such an analysis ("Motion"). The Company's response to the Motion claimed that "only 10 were confirmed as leaks that rose to the level of being regulated by the federal United States Department of Transportation's Pipeline [sic] Hazardous Materials

Safety Administration ("PHMSA") regulations." This is not unusual, and does not negate the benefits that can be achieved through prioritizing leaks based on leak flow rate, all else being equal. As Virginia Palacios describes in her Direct Testimony, PHMSA guidance on leak grading does not depend on leak flow rate, but depends primarily on proximity to building envelopes.

Typically, EDF finds more leaks using advanced leak detection technology than utilities find using traditional methods. Many of the leaks EDF finds are considered "non-hazardous" and are not regulated by PHMSA. EDF is not suggesting that advanced leak detection technology and leak quantification methodologies should be used for the purposes of grading hazardous leaks. On the contrary, EDF is suggesting that these technologies and methods be used to allow for a prioritization approach that not only considers safety, but also benefits ratepayers and the environment.

Additionally, it is important to note that EDF is not suggesting that the utility abandon its current method of finding leaks. The leaks that are discovered using advanced leak detection technology are often a different subset of leaks than utilities would find using traditional leak detection technology. In other words, advanced leak detection technology is able to find far more leaks than traditional methods, but traditional methods still find some leaks that advanced methods are not able to find.

Q. Please describe the nature and scope of the leak quantification pilot project undertaken by EDF in collaboration with PSE&G in New Jersey. Can a similar analysis be undertaken in the context of the Company's AMRP?

A. Last year, EDF engaged with New Jersey's oldest and largest utility, Public Service Electric & Gas ("PSE&G") on a collaborative pilot project in the context of that utility's proposed accelerated pipe replacement program. As part of this project, EDF gathered data on methane emissions from leaking pipes in PSE&G's service territory through a mobile leak survey using Google Street View cars that were specially outfitted with methane sensors. PSE&G shared information with EDF on the location and type of its pipelines, enabling the creation of actionable, customized maps attributing leaks to specific pipes targeted for replacement.

Using leak data collected by Environmental Defense Fund (EDF) from May through November 2013, Public Service Gas & Electric (PSE&G), New Jersey's largest utility, is applying a grid method to prioritize pipe segments for replacement.[10]

First, PSE&G's distribution system was mapped and divided into equally sized grids, each measuring approximately 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 in each grid.[11]

Next, using a GSV cars equipped with mobile mounted methane detection equipment, EDF surveyed 30 grids targeted for pipe replacement in order to detect individual leaks in each grid, and to quantify the methane emission flow rate for each leak.

Leak flow rates for all leaks detected in a given grid were then summed and divided by the total number of miles of pipe in each grid to arrive at the estimated leak flow rate per

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[10] PSE&G. (2015, November 16). PSE&G Receives Approval of $905 Million Program to Accelerate Replacement of Aging Gas Infrastructure. PSE&G Newsroom. Newark, NJ. Retrieved from https://www.pseg.com/info/media/newsreleases/2015/2015-11-16.jsp#.VuoR_XoXdS1

[11] 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 map grid is ranked by adding the hazard indexes for individual pipe segments within the grid and dividing them by the total miles of utilization pressure cast iron in the grid, arriving at a hazard index per mile for each map 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 grids categories.

mile of pipe in each grid. This metric allowed for the ranking of grids by overall leak flow rate per mile of pipe (Exhibit 2.4). This data was used to develop maps of each grid cell (Figure 2 of Exhibit 2.5), 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 was used by PSE&G in conjunction with results derived using its Hazard Risk Index Model and other operational factors to prioritize grids for 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. Large individual leaks were also targeted for urgent repair.

As mentioned in the Direct Testimony of Virginia E. Palacios, this prioritization method resulted in PSE&G reducing 84% of the quantified leak flow rate by replacing only 41% of the pipeline miles (112.18 miles) scheduled for replacement. In a business-as-usual scenario, PSE&G would have needed to replace 62% of the pipeline mileage (168.58 miles) to be able to reduce 84% of the quantified leak flow rate.

A similar analysis and customized maps can be developed using data gathered by EDF in PGL service territory by overlaying leak data on infrastructure data, allowing for the relative leakiness of various sections of the utility's infrastructure to be assessed and considered in prioritization of pipe replacement activities.

Q. Please describe the procedure used for attribution of leaks to PSE&G infrastructure under this leak quantification pilot project.

A. To attribute an elevated reading to a location, a series of buffering and consolidation procedures are used, which are graphically represented in sequential order in Figure 3

(Exhibit 2.6). First, the series of points representing an elevated methane reading is buffered using a 20 meter buffer (Steps 1 and 2). This buffer distance represents the average width of a plume of gas at the distances from curbside likely to be encountered while driving a city street, as identified by the controlled release testing described above. Each 20 meter buffer is then consolidated into a single point, that is, the centroid (Step 3), each of which is again buffered using a 20 meter buffer (Step 4). Overlapping buffers (hereafter an "Observed Reading Cluster" or ORC) are then merged into a single buffer, the centroid of which is the location assigned to a "verified leak" (Steps 5, 6 and 7). A verified leak is constituted of at least two overlapping buffers; in other words, a leak must have been detected on at least two separate sampling drives for it to constitute a verified leak.

Any verified leak with an associated ORC intersecting the utility's pipe is attributed to that pipe. In instances where an ORC intersects multiple pipes, such as pipeline intersections, a leak cannot be attributed to a specific utility pipe segment, but can still generally be attributed to the utility's infrastructure. The size of the mapped ORCs represents the relative uncertainty of verified leak locations. The larger the plume of leaked gas, and the resulting ORC, the greater the uncertainty of the actual leak location. Only ORCs and verified leaks attributable to the utility's infrastructure are included on the leak maps. As such, these maps represent only a subset of the total number of leaks identified for each drive area comprising a particular "grid" or parcel of a utility's pipelines.

Q. What purpose do the maps serve in the analysis?

A. For each of the grids driven, two maps were developed. I am presenting two fictitious, side-by-side sample maps in my testimony (Figure 2 of Exhibit 2.5) to reflect the underlying methodological approach employed in collaboration with PSE&G in New Jersey in the context of that utility's pipe replacement program. The map on the left represents ORCs that intersect the utility's pipe and are therefore attributable to the utility's infrastructure. The map on the right reflects the corresponding verified leaks. The map on the left is important in that it reflects the relative locational uncertainty of each leak (locational uncertainty of each leak is reflected in the size of the corresponding ORC, as discussed above). By way of clarification, while legends for the map on the left relate to the relative size of each ORC, i.e. each cluster of observed readings, the legends for the map on the right relate to the size of each individual verified leak.

VI. Conclusion

Q. Please summarize your recommendations and conclusions.

A. Peoples Gas is in a position to make significant improvements in how it prioritizes pipelines for replacement. I argue that this new prioritization framework should include leak flow rate data. Advanced leak detection technology and leak quantification methodologies are ready for use by utilities to optimize leak abatement reduction strategies as demonstrated, for instance, by the pilot project conducted by EDF in collaboration with PSE&G, and can provide a useful metric by which to maximize benefits to ratepayers throughout the course of pipeline replacement programs. This can be accomplished by focusing repair and replacement efforts first on safety needs and then on the largest leaks or leakiest pipeline segments, as appropriate. Leak quantification provides a useful tool through which utilities may verify and validate the need for leak repair and pipeline replacement efforts, ensuring that ratepayer dollars are spent efficiently.

Q. **Does this conclude your testimony?**

A. Yes.